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Towards Use of OntoClean for Ontology Contextualization

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Abstract

Ontologies are formal systems of concepts used to describe numerous domains of interest. Ontologies are usually very expressive, but it comes at a price of computationally expensive reasoning over them. In our previous work we discussed the possible performance benefits that can be obtained by decomposing an ontology into contexts. While the benefits are appealing, we discovered that, in our case, the main obstacle against using contextual versions of ontologies was the necessity of performing the costly process of their decomposition with the participation of human experts. In this paper we discuss the possibility of using OntoClean method for streamlining and at least partial automation of suggesting a decomposition of an ontology into contexts. We present a hypothesis about how to build a structure of contexts, and verify this hypothesis against several ontologies used in state-of-the-art research. The ontologies have been obtained by us in the process that uses elements of Systematic Literature Review. The final assessment of the method has been performed by human experts, during interviews, and we present the details of their evaluation in the paper.

Keywords: knowledge bases; contexts; reasoning; systematic literature review; interviews

1. Introduction

Ontologies are formal systems of concepts used to describe numerous domains of interest [1]. They gained popularity as a tool for creating common shared conceptualizations for complicated problems (like, for instance, medicine and health care [2][3]). Ontologies usually use very expressive logical languages (like OWL [4]). This

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allows for specifying complicated interrelationships between concepts, but comes at a price of computationally expensive reasoning [5].

In our previous work [6] we discussed the possible performance benefits that can be obtained by decomposing an ontology into contexts. Humans in their communications profoundly use contexts to simplify the exchange of information [7]. Contextual approaches to ontology management rely on the same observation: grouping together similar pieces of information (like information about a single university) allows them to be expressed in a more concise way and facilitates reasoning.

The results obtained by us in [6] were very encouraging (some of the queries were executed several orders of magnitudes faster for the contextual ontology). However, during our work we encounter a major obstacle in applying the contextual approach more broadly. The obstacle was the high cost (in the terms of time and work) of decomposing an ontology into contexts, which was mainly caused by the necessity on employing the work of human experts in this step.

Retrospective analysis of the results of our contextualization experiment described in [6] allowed us to formulate a hypothesis, which could noticeably facilitate the process of decomposing ontologies into contexts. For this analysis we used OntoClean approach [8] by Nicola Guarino and Chris Welty. OntoClean is founded upon analyzing certain metaproperties of ontology classes and is a very useful and appreciated method of verifying design decisions made during ontology authoring [8].

The hypothesis was based on our observation that objects of the specific classes were chosen to become contextual parameters. Name they were the objects of *rigid* (a metaproperty in OntoClean) classes with the longest predicted lifespan within the ontology.

Therefore, in this paper we present our work on formulating and verifying the hypothesis that the context structure reflecting the objects of rigid classes with the longest predicted lifespan can facilitate experts' work on decomposing currently used ontologies into contexts. Our approach to verifying the hypothesis was as follows. After formulating the hypothesis, we proceeded to obtaining a set of representative ontologies for the current studies in the area. This task was facilitated by the fact that there exists a prominent repository of ontologies LOV [9]. To retrieve the ontologies from the repository in a well organized manner and to make the whole process repeatable, we decided to base the retrieval and selection process on the principles of SLR (*Systematic Literature Review*, described in [10]).

After identifying the set of ontologies, we proceeded to creating a preliminary contextualization for each of them. These preliminary contextualizations were further submitted to experts for their evaluation. The evaluation was performed in the form of an interview with two predefined questions and augmented by a free discussion; the latter allowed us to obtain experts' remarks on the results.

The subsequent Sections are organized as follows. In Section 2 we describe our preliminary study that led us to formulation of the hypothesis, in Section 3 we present the procedure of ontology selection and the process of literature review, Section 4 contains the description of creating preliminary contextualizations, Section 5 describes the results of evaluation, and Section 6 discusses the related work.

2. Retrospective study

In this Section we briefly review the results of [6], which was our motivation and the starting point. In the next part of the Section we present the results of our retrospective analysis, which resulted in formulation of the hypothesis (**H1**). For the purposes of the paper we will assume a very simple model of an ontology: an ontology consists of objects (or individuals), binary relations between objects (also called properties or roles), and classes (or concepts); objects can be instances of classes.

2.1. Previous experiments

The work which was our starting point consisted in decomposing an existing ontology into contexts in order to learn whether for the contextualized version of the ontology it is possible to execute queries faster. Our hope for the performance gain was based on the observation that within a contextualized knowledge base, which is divided into smaller pieces called *contexts* or *modules*, some types of knowledge can be expressed much more easily.

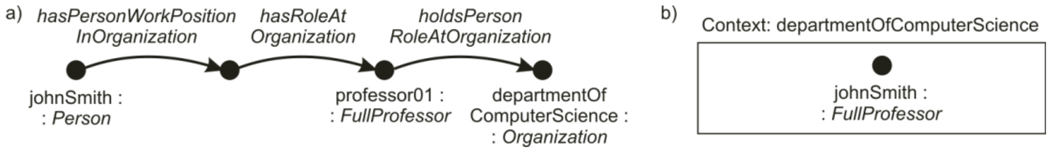

Fig. 1. Information that *johnSmith* is a professor at an organization expressed in (a) flat ontology; (b) contextualized ontology.

The idea behind contextualization is relatively simple. Some of the concepts (or classes) in the universe of discourse are selected as *contexts*. In this way, we can say that *John Smith* is a professor, within the context of *a department of computer science* and avoid formulating more complex assertions about his work, which can usually be expressed only with use of additional objects.

The example of this is shown in Figure 1. This figure presents the excerpts from both the flat (non-contextualized) and contextual ontology used in the experiment. Both express the same knowledge (that *johnSmith* is a full professor), however in different manners. For the contextual ontology it can be seen that the form of expressing the aforementioned fact is much simpler. It, however, comes at the cost of establishing a proper hierarchy of contexts. This, in turn, consists in selecting classes (like *Organization* in the case of Fig 1b.) whose instances become contexts, instead of regular individual objects within the ontology.

In our original experiment the two versions of the ontologies were obtained by contextualizing an existing flat ontology (SYNAT ontology described in [11]). The process of contextualizing had been performed by human experts in the way of analyzing the ontology and its accompanying set of competency questions. The classes picked for the experts into the resulting hierarchy of contexts were *Organization*, *University*, and *Editor*.

This way, unfortunately, proved to be very time-consuming and work-intensive. The experiments showed that it is indeed possible to achieve a significant performance gain (observed speed-up was of a ratio up to 162, indicating that the contextual query has been executed 162 times faster, moreover the ratio grew with the size of the ontology). However, the cost of the process of contextualization turned out to be prohibitive for broadening the range of test ontologies (which in turn is necessary for establishing the potential scope of using contextualization for improving performance).

2.2. Retrospective analysis

In hope of finding a solution to this problem, we performed a retrospective analysis of both the versions of SYNAT ontology. For the analysis, we decided to use the OntoClean method [8]. This method, created by Nicola Guarino and Chris Welty, is known for being helpful in verifying design decisions made during ontology authoring.

OntoClean method bases on the notion of *metaproperties*. These metaproperties are properties of classes within the ontology. One of the most important is *rigidity*, which is related to the question whether it is necessary for an object to be an instance of this class throughout its lifespan. A classic, though a bit ominous, example here is *Human*, which is a *rigid* class (denoted **R+**) as an individual cannot stop being a human without ending its life. A counterexample here is the class *Lawyer*, because for no individual it is necessary to be a lawyer during their whole lifespan (such a class is called *antirigid*, which is denoted as **R-**).

Our analysis of the contextualized ontology created during the experiment allowed us to state that for the hierarchy of contexts, the experts had chosen *only the rigid classes*. Moreover, they are the classes whose instances have the longest expected lifespan within the SYNAT ontology.

The results of this analysis are briefly presented in Table 2. The data about lifespan has been picked for the Roman Catholic Church (the oldest and largest continuously functioning international institution [12]), Cambridge University Press, and University of Bologna.

Consequently, this led us to formulating the following research hypothesis (**H1**): “a preliminary contextualization of an ontology, consisting in building the context structure reflecting objects of rigid classes with the longest predicted lifespan, can be a valuable tool for facilitating expert work on decomposing currently used ontologies into contexts”.

Our work on verifying this hypothesis is presented in the following sections.

Table 1. Rigid classes and lifespan of their instances in SYNAT ontology.

Classes that form the hierarchy	Lifespan	Rigidity	Remarks
Organization	~2000 years	R+	
University	~1000 years	R+	
Editor	~500 years	R+	
Examples of other classes	Lifespan	Rigidity	
InformationResource	~350 years	R+	
Person	~100 years	R+	
SubjectArea	~50 years	R-	Governmental classification
Project	~20 years	R+	
Event	~5 years	R+	Events associated with academia (like courses)

3. Selecting the ontologies for the verification

The first step towards verifying the hypothesis (H1) was to select a set of ontologies for which such preliminary contextualization could be performed. For this task we used the Linked Open Vocabularies (LOV) repository [9], an established and widely used catalogue for semantic vocabularies. To make our choice more impartial, we decided to use a procedure which is based on the principles of SLR (*Systematic Literature Review*) presented in [10].

3.1. Linked Open Vocabularies and SLR

The Linked Open Vocabularies date back to 2011 when they were established, as a part of DataLift research project [9]. LOV aims at facilitating sharing and reusing ontologies within Semantic Web and Linked Open Data initiatives.

LOV web service offers the functions of browsing the ontologies (vocabularies) as a catalogue, divided in areas of interest, and as a graph of interlinked entities. A very important function of LOV is its SPARQL end-point [13], which enables its users to query the repository only about a selected portion of data. We used this function in the further part of our experiments.

Systematic literature reviews (SLRs) in the domain of software engineering have been popularized primarily by Barbara Kitchenham and Charles Sanders [14], who analyzed the guides and principles of SLR in medicine and adopted them to the specifics of IT domain. Each SLR consists of three phases: planning the review, conducting the review and reporting the review. Its characteristic features embrace using pre-specified eligibility criteria, systematic search strategy, and assessment of the validity of findings. Studies performed like that can be repeated by other researchers and their results can be reproduced. In our selection of ontologies we tried to employ a subset of these rules, to reduce the possible bias and to make our choice clear and well justified.

3.2. Selecting ontologies – protocol

Within our procedure of selecting ontologies, we decided to adapt the following elements of SLR: (1) formulating inclusion criteria and exclusion criteria for the ontologies, (2) formulating a search strategy, (3) performing the assessment of the obtained results. The important steps of justifying our research questions and summarizing the results were omitted, however they are included in our study as a whole (see Sections 2 and 5).

Our inclusion criteria embraced (IC1) and (IC2) are shown in Table 2. The rationale behind the first criterion is the fact that we wanted to include in our study the currently used ontologies. We also assumed the minimal size of an ontology to avoid selecting those very narrowly focused (without the need to be contextualized).

Our exclusion criteria focused on eliminating these ontologies which could not be reasonably processed by us. Therefore, in order to be included, the ontologies had to satisfy both the inclusion criteria, and were excluded if they did satisfy at least one of the exclusion criteria.

Table 2. Inclusion and exclusion criteria for ontology selection

Symbol	Criterion
IC1	Ontology uploaded to repository in 2019 or later
IC2	Ontology contains at least 25 concepts (classes) and at least 10 properties (roles)
EC1	Ontology does not have a downloadable version
EC2	Ontology is not in English
EC3	Ontology does not have any documentation associated

In our search strategy we decided to use LOV as our data source, and a SPARQL query as a way to target specific ontologies. The query used in our search is presented in Figure 3a. It automatically ensures the satisfaction of IC1 criterion.

The query provided us with 56 results for which the other criteria were checked. After applying the rest of the criteria, we were left with 13 ontologies (see Fig. 2b).

At this point, following the SLR rules, we applied quality criteria to the remaining ontologies. We had formulated two such criteria: (QC1) lack of errors during ontology loading, and (QC2) the quality of the documentation associated with the ontology. For the first criterion we used 0-2 scale with (0) meaning that there were errors during loading the core ontology, (1) errors while loading imported ontologies, and (2) indicating no errors. For the second criterion we used 0-3 scale with (0) meaning unreadable documentation (e.g. only in a language other than English), (1) short documentation containing only the list of entities (possibly with their annotations), (2) documentation which contains at least short explanation of basic concepts and relationships, and (3) documentation with detailed description of concepts and relationships.

The results of the quality assessment are shown in Fig. 2c. As the result of the assessment we decided to include in our further study the 4 ontologies with the highest quality rank, and the one additional ontology which achieved 4 points out of 5 (the other one was excluded from the study due to its similarity to one of the highest ranked ontologies). The ontologies are described in the next section, which also explains their contextualization.

a)
```
PREFIX vann:<http://purl.org/vocab/vann/>
PREFIX voaf:<http://purl.org/vocommons/voaf#>
PREFIX xsd:  <http://www.w3.org/2001/XMLSchema#>

SELECT DISTINCT ?vocabPrefix ?vocabURI {
 GRAPH <https://lov.linkeddata.es/dataset/lov>{
  ?vocabURI a voaf:Vocabulary.
  ?vocabURI vann:preferredNamespacePrefix ?vocabPrefix.
  ?vocabURI <http://purl.org/dc/terms/issued> ?issueDate.
  FILTER ( ?issueDate >= "2018-01-01"^^xsd:date )
}} ORDER BY ?vocabPrefix
```

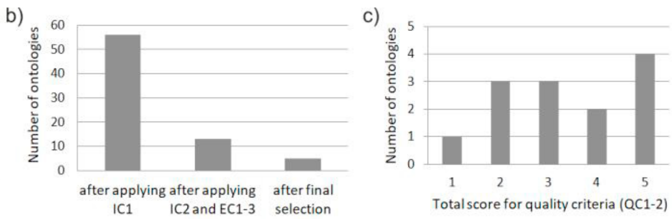

Fig. 2. (a) The query used for primary selection; (b) the number of papers after subsequent phases; (c) breakdown of quality score.

4. Contextualizing the selected ontologies

In this section we shortly describe the selected ontologies and present our work on contextualizing them. For each of the ontologies, we performed a short analysis of its rigid classes and assessed the lifespan of their instances. After that step, we chose the classes that we recommended to include into the hierarchy of contexts.

4.1. Occupancy Profile ontology

Occupancy Profile ontology [15] has been developed in order to represent people's behavior inside buildings. The ontology is focused on actions performed by the people and the energy impact the actions produce. The ontology contains 50 classes and 47 properties.

Table 3 presents the results of our analysis. From among the rigid classes we have chosen those whose instances have the longest predicted lifespan and arranged them in accordance with the relationships between them in the ontology. As the result we propose the hierarchy consisting of *Building*, *Apartment*, and *BuildingSpace* contexts.

Table 3. The results of analysis for Occupancy Profile ontology.

Classes that form the hierarchy	Lifespan	Remarks
Building	~200 years	
Apartment	~200 years	
BuildingSpace	~200 years	
Examples of other classes	Lifespan	
Occupant	~100 years	
Meeting	~20 hours	
Movement	~10 years	
MovementModel	~50 years	
Device	~50 years	

Table 4. The results of analysis for CARESSES ontology.

Classes that form the hierarchy	Lifespan	Remarks
Goal	~100 years	
Norm	~100 years	
Operator	~30 years	
Robot	~30 years	
Examples of other classes	Lifespan	
Location	<=30 years	This concept is a part of personal subontology
HouseObject	<=30 years	This concept is a part of personal subontology
TopicAboutLife	<=30 years	This concept is a part of personal subontology
Event	<=30 years	Includes yearly events (personal subontology)
Action	~3 hours	

Table 5. The results of analysis for Timebank ontology.

Classes that form the hierarchy	Lifespan	Remarks
Limitation	unlimited	
Skill	unlimited	
Examples of other classes	Lifespan	
User	~30 years	
Request	~1 year	
AddressElement	<1 year	dependent on Request
DurationDescription	<30 years	dependent on User

4.2. CARESSES Ontology

CARRESES ontology [16] contains concepts that are of use for socially assistive robots. The robots are expected to use social interaction as the means for enhancing health and psychological well-being of elderly people. The ontology contains 99 classes and 93 properties.

During our analysis of this ontology we had to perform two additional non-standard actions. The first action consisted in contacting a specialist from the domain of assistive robots, to get additional expertise on the possible lifespan of a robot.

The second action was connected with assessing the lifespan of classes describing the personal knowledge of patients (or *Operators*, see Table 4). Concepts like *HouseObject* or *Location* generally describe instances that can last very long. In CARESSES ontology they are, however, included in the part called a personal subontology. This subontology contains topics important for operators, and therefore cannot outlive them within the ontology. We accounted for this fact by describing these classes as "dependent on the class *Operator*" and by appropriately constraining their lifespan. As the result we propose the hierarchy consisting of *Goal*, *Norm*, *Operator* and *Robot* contexts.

4.3. Timebank Ontology

Timebank Ontology [17] was designed for Peer-to-Peer Service Exchange. Users offer their time and work in the form a special currency. At the same time they might also issue requests, in which they ask other users to spend some time doing something for them. The ontology contains 127 classes and 49 properties.

This ontology also had a distinguishing characteristic, which was the presence of classes that describe concepts of unlimited lifespan (see Table 5). The classes are *Limitation* and *Skills* whose sets of instances can evolve during the ontology lifespan (so they are not enumerated classes like, e.g., *DayofTheWeek*), but they can be shared among a large number of users and requests indefinitely. Due to this characteristic we decided to include these two classes in our proposed context hierarchy: *Limitation*, *Skill*.

4.4. Summary of the contextualization phase

The two remaining ontologies were ArCo Ontology [18] (focusing on describing objects of cultural importance) and FIESTA-Priv Ontology [19] (focusing on describing IoT systems). The analysis of these ontologies was quite straightforward (ArCo Ontology was the smallest of the selected ontologies, and FIESTA-Priv had relatively small set of the core classes). As a result we decided to choose only a single class for each of the ontologies to represent contexts (*CulturalProperty* for ArCo, and *System* for FIESTA-Priv) and not present the detailed tables in this paper due to space limitations.

The time spent for proposing the preliminary contextualization for the selected ontologies oscillated around 2-5 working days and was performed by a single person. Comparing it to the time spent on contextualizing SYNAT ontology in our original research (12 working weeks, 2 persons involved), one can see a noticeable improvement.

During our analysis we also refined the method by taking into account dependencies between classes in regard of their lifespan (like shown in Sec 4.2). Moreover, we decided to exclude classes of unlimited lifespan and a fixed number of individuals, and include such classes in the case when they number of individuals may grow (see Sec. 4.3).

Our work on verifying the obtained results is presented in the next Section.

5. Verification of the results

To verify the obtained result we used the help of two human experts, both involved in working with contextual knowledge bases before. With each of the experts we conducted an interview, which consisted of a brief discussion about each ontology and a presentation of our results.

After each discussion and presentation the two following questions have been asked: (Q1) "in your opinion, how likely it is that the proposed contextualization may be practical for the ontology?" and (Q2) "do you think that the presented decomposition may be useful for the futher work upon contextualization?" For both the question we collected the answers on the scale of 0-10, where 0 means very unlikely/not useful at all, 5 means somewhat likely/somewhat useful, and 10 very likely/very useful.

The rest of the interview was unstructured and consisted in gathering opinions expressed by experts during the discussions.

The results of the verification are gathered in Table 6. The table presents experts' answers to questions (Q1) and (Q2) as well as their remarks about specific ontologies. Apart from that during the interview we collected the following general remarks (we present the 10 most important ones):

- analysis of competency questions should be included also in the process of contextualization,

- use of dependencies is a good idea,
- use of OntoClean is a very good idea,
- use of other OntoClean metaproperties could be beneficial,
- the analysis could base on the characteristics of properties as well,
- an exemplary collection of objects could be given with each contextualization,
- classes which represent events should probably be excluded from the analysis,
- classes which represent units and measurements should probably be excluded from the analysis,
- some ontologies already have modular structure, and the method should account for it,
- an alternative contextualization should also be proposed to allow for better assessment.

The contextualizations for ontologies were generally assessed consistently by the experts. The contextualization which sparked the most controversy was the one for Timebank ontology. One of the experts decided that this ontology should not be contextualized, and the other one considered use of *Limitation* and *Skill* as the contexts a very good idea.

The experts' opinions were generally favorable, and the majority of our decisions (like exclusion of enumeration classes) were accepted by them. The average score for the first question was 5.7 (somewhat possible for immediate use) and for the second question 7.2 (between somewhat useful and very useful for further work on contextualization). This, in addition to the relatively short time needed for the preparation of contextualization, allows for expressing careful optimism about the method. We also can say that the hypothesis (H1) has been at least partially confirmed.

We are aware that the small number or participating experts might be considered a drawback of our research. However, the accessibility of experts in this area is low, and the consistency of the given answers is an additional argument in favor of the confirmation of (H1). In this work we also aimed at collecting useful opinions about the development of our method, and in this area, the experts' answers proved themselves to be very helpful.

Table 6. A summary of interviews.

The ontology discussed	Expert 1 answer to Q1	Expert 1 answer to Q2	Expert 2 answer to Q1	Expert 2 answer to Q2	Remarks
Occupancy Profile Ontology	8	8	6	7	*Occupant* could be added to context hierarchy
CARESSES Ontology	5	8	4	6	*Goal* and *Norm* should be excluded from the hierarchy
Timebank Ontology	3	6	6	8	the ontology describes one context and should not be contextualized
ArCo Ontology	7	8	5	6	ontology modules should be considered
FIESTA-Priv Ontology	7	8	6	6	more elaborate context structure could be used

6. Related work

In our work we rely strongly on the notion of context-as-a-box (a box containing a piece of knowledge) introduced in [20]. This concept has been later elaborated on and mathematically developed in [21]. The reduction of predicate arity (happening because of introduction of contexts), described there, constitutes a foundation for our hope of increasing the performance of reasoning by contextualization.

The second branch of publications, on which we strongly base our research, are the papers presenting various models of contextual ontologies and semantic knowledge bases. These primarily include works on Description Logics of Contexts [22] and Contextualized Knowledge Repositories [23]. While they authors, however, introduce very elegant models for capturing contextual knowledge, they offer little advice concerning contextualization of standard ontologies.

Therefore, we also relate in our work to the positions about principles of contextual modeling in general ([24] and [25]), and good practices in ontology authoring [8]. From the methodological point of view, we used elements of Systematic Literature Reviews [10] and interviews for discussion with experts ([26] and [27]). To the best of our knowledge, our work is the first to use interviews for verifying a hypothesis about principles of constructing a contextual knowledge base, which, perhaps, makes it to some extent unique.

7. Conclusions

In this paper we presented our multi-stage work on formulating and verifying a hypothesis about possible usefulness of elements of OntoClean method for creating contextualized version of ontologies. Our motivation for creating these contextualized versions stemmed from our previous research [6], where we demonstrated that the performance of specific kind of queries can be greatly improved (with the time of execution even two orders of magnitude shorter) over executing the queries against the non-contextualized ontology. At the same time, the research showed that the process of contextualization is very time consuming.

The hypothesis was formulated as follows: "a preliminary contextualization of an ontology, consisting in building the context structure reflecting objects of rigid classes with the longest predicted lifespan, can be a valuable tool for facilitating expert work on decomposing currently used ontologies into contexts", and was based on our retrospective analysis of the results of our previous research.

In order to verify the hypothesis we have carried out a several-step process. The steps embraced (1) collecting the ontologies for contextualization, (2) performing the preliminary contextualization, and (3) verification of the results by human experts. The step (1) has been executed with use of selected elements of SLR (systematic literature review), like inclusion and exclusion criteria, to make it repeatable and accountable. During the step (2) the method proposed in the hypothesis has been applied to the ontologies and slightly refined. The step (3) has been conducted with use of interviews and previously prepared questions.

The gathered opinions allow us for expressing careful optimism. The experts stated that, on average, the preliminary contextualizations were between somewhat useful and very useful (average score of 7.2/10) for further work on decomposing the ontologies into contexts. This allows us to say that the hypothesis (H1) has been at least partially confirmed.

Generally favorable opinions open a way for us to broaden the range of our experiments. In future, the method can be partially automated. Use of knowledge graphs like WikiData [28] can provide information about lifespan of objects instantiating popular concepts like buildings, countries, or devices. The experts' remarks show the way for further refinement of the method, which would involve use of other OntoClean metaproperties and more careful analysis of dependencies, especially for classes included in competency questions.

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