Dealing with Vagueness in Semantic Business Process Management through Fuzzy Ontologies

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Abstract. One of the primary focuses of Semantic Business Process Management is the application of ontology-based semantics for the machine processable representation of business processes and the automation of their management lifecycle. Towards that direction, various ontologies have been proposed, each covering one or more aspects of the knowledge required to describe a business process. Yet, one major limitation of these ontologies is their inability to express knowledge that is vague as they are based on bivalent ontological formalisms. In this context we argue in this paper, through concrete examples and use cases, in favor of using fuzzy ontologies for the effective capture, representation and exploitation of the vagueness that may characterize business processes and we provide initial directions of how this may be practically achieved.

1 Introduction

The use of ontology-based semantics for the modeling of business processes is an emerging research area that aims at creating process descriptions with explicit and shareable meaning, thus achieving better management of organizational knowledge and higher level of process automation [5] [9]. In this context, a number of approaches and ontological schemas have been proposed, covering not only the strict notion of business process [5] [8] but also wider related aspects like organizational structures or business functions [7] [12].

Yet, a dimension of business process knowledge that has so far been inadequately considered within the relevant community is that of vagueness. Vagueness, typically manifested by terms and concepts like Tall, Strong, Expert etc., is a quite common phenomenon in human knowledge and it is related to our inability to precisely determine the extensions of such concepts in certain domains and contexts. That is because vague concepts have typically fuzzy boundaries which do not allow for a sharp distinction between the entities that fall within the extension of these concepts and those which do not. This is not usually a problem in individual human reasoning but it can become one when multiple people need to agree on the exact meaning of such terms and when machines need to reason with them. For example, a system could never use the statement *"This process requires many people to execute"* in order to determine the number of people actually needed for the process.

In this paper we argue over the need for a systematic way of capturing, representing and ultimately using vague knowledge in business process management and we propose for that the utilization of techniques and methods from the area of fuzzy ontologies [2]. The latter are extensions of classical ontologies that based on principles of Fuzzy Set Theory [11] allow the assignment of truth degrees to vague ontological elements in an effort to quantify their vagueness. As such, and given that the prevailing approaches for semantic business process management are ontology-based, fuzzy ontologies are a natural candidate for dealing with vagueness in this area. Of course, the idea of applying fuzzy representation techniques in business process modeling has been the subject of some works so far [6] [14], the most recent being that of [13] where the authors focus on the vagueness that may characterize decision situations in event-driven business processes and propose for that the utilization of fuzzy linguistic variables and fuzzy rules. However, the primary limitation of the above approaches in terms of vagueness treatment is the lack of ontology-based semantics for describing vague business process knowledge in an explicit, formal and shareable way.

A basic argument for this is that the modeling inconsistencies that may arise due to the freedom that business analysts have to name and describe process knowledge can also occur (and in fact even more severely) when the analysts need to describe vague concepts and terms. As argued in [2] vagueness is a phenomenon with a high level of subjectivity and context-dependence and therefore it is very important that the various interpretations a piece of vague knowledge may have are explicitly defined and shared among those who are intended to use this knowledge. A second argument has to do with the semantic querying and reasoning capabilities that fuzzy ontological formalisms can provide. The ability to automatically infer, when querying a business process model, implicit facts, is equally important in the presence of vagueness as it is in the classical case.

The focus of this paper is on the illustration of the need and applicability of fuzzy ontologies in vague business process management so that the foundations for future research on this area may be set. Therefore in section 2 we draw and analyze examples from state of the art business process ontologies and related application scenarios in order to highlight the forms in which vagueness may be present in semantic business process information and the need for a formal treatment of it. In section 3 we describe the notion of fuzzy ontologies and we show how these may be developed and used for business process modeling by means of relevant state of the art methods and techniques. Finally, in the last section conclusions and directions for future work are provided.

2 Vagueness in Business Processes

2.1 Vagueness in Semantic Modelling

Vagueness as a semantic phenomenon is typically manifested through predicates that admit borderline cases [10], i.e. cases where it is unclear whether or not the predicate applies. For example, some people are borderline tall: not clearly tall and not clearly not tall. In the relevant literature two basic kinds of vagueness

are identified: *degree-vagueness* and *combinatory vagueness* [10]. A predicate has degree-vagueness if the existence of borderline cases stems from the apparent lack of crisp boundaries between application and non-application of the predicate along some dimension. For example, *Bald* fails to draw any sharp boundaries along the dimension of hair quantity while *Red* can be vague along the dimensions of brightness and saturation. On the other hand, a predicate has combinatory vagueness if there is a variety of conditions all of which have something to do with the application of the predicate, yet it is not possible to make any sharp discrimination between those combinations which are sufficient and/or necessary for application and those which are not. An example of this type is *Religion* as there are certain features that all religions share (e.g. beliefs in supernatural beings, ritual acts etc.), yet it is not clear which of these features are able to classify something as a religion.

It should be noticed that vagueness is different from inexactness or uncertainty. For example, stating that someone is between 170 and 180 cm is an inexact statement but it is not vague as its limits of application are precise. Similarly, the truth of an uncertain statement, such as *"Today it might rain"*, cannot be determined due to lack of adequate information about it and not because the phenomenon of rain lacks sharp boundaries.

In an ontology the elements that can be vague are typically concepts, relations, attributes and datatypes [2]. A concept is vague if, in the given domain, context or application scenario, it admits borderline cases, namely if there are (or could be) individuals for which it is indeterminate whether they instantiate the concept. Primary candidates for being vague are concepts that denote some phase or state (e.g Adult, Child) as well as attributions, namely concepts that reflect qualitative states of entities (e.g. Red, Big, Broken etc.). Similarly, a relation is vague if there are (or could be) pairs of individuals for which it is indeterminate whether they stand in the relation. The same applies for attributes and pairs of individuals and literal values. Finally, a vague datatype consists of a set of vague terms which may be used within the ontology as attribute values. For example, the attribute *performance*, which normally takes as values integer numbers, may also take as values terms like *very poor, poor, mediocre, good* and *excellent*. Thus vague datatypes are identified by considering the ontology's attributes and assessing whether their potential values can be expressed through vague terms.

2.2 Vagueness in Business Process Knowledge

The term "process knowledge" refers to the information describing the control flow of a process as well as its content, namely all artifacts that its definition may refer to. These artifacts are typically derived from and express the business environment and the organizational context of the process. Vague pieces of information and knowledge may appear in all three dimensions of process knowledge, namely structure, domain and organizational context.

To illustrate this point, we have considered and analyzed, with the help of our company's consultants, two different cases of business process knowledge. The

first case involved a set of generic business process related ontologies, developed in project SUPER [1], which may serve as reusable knowledge schemas in practical semantic business process modeling scenarios. The analysis of these ontologies, which included among others the Business Process Modeling Ontology (BPMO), the Business Goals Ontology (BGO), the Business Roles Ontology (BROnt) and the Business Motivation Ontology (BGO), involved the identification within them of elements that can be interpreted as vague, according to the definitions of the previous paragraph. Our criterion for classifying an element as vague or not was merely the potential existence of borderline cases, not the number of them. That meant that even if an element could potentially have only one borderline case, it was considered vague.

The outcome of this analysis is summarized in table 1 where a sample of the elements we managed to identify as vague, along with a brief explanation of their vagueness, is presented. As one can easily see, the identified as vague elements are quite central to their respective ontologies (e.g. the hasBusinessGoal relation) and as such they are expected to be found in many relevant application scenarios. Furthermore, the use of vague terms like "desired" in the definition of elements (e.g "Desired Result") indicates that in practice there could be an almost infinite number of vague ontological elements in these ontologies that would be the result of the combination of such terms with non-fuzzy elements (e.g. "Loyal Customer", "Expert Analyst" etc.).

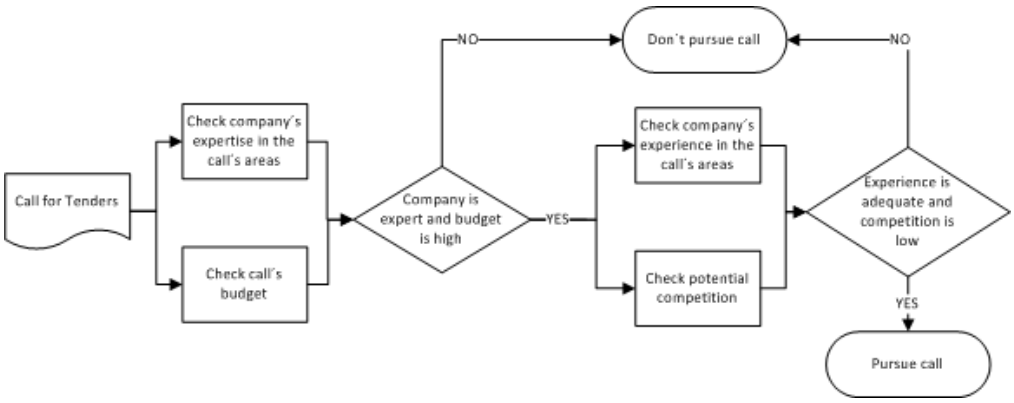
Table 1. Exemplary vague elements from business process ontologies

Element	**Ontology**	**Vagueness**
Managerial Role	BROnt	Combinatory vagueness due to the lack of sharp discrimination between those conditions that are necessary for someone to be considered as having a managerial role
CompetitorRole	BROnt	Degree-vagueness along the dimensions of the number of competitor's business areas and target markets that constitute someone as a competitor
hasBusinessDomain	BPMO	Combinatory vagueness due to the lack of sharp discrimination between those conditions that are necessary for something to belong to a given domain
Strategic Goal	BGO	Combinatory vagueness due to the lack of sharp discrimination between those conditions that are necessary for a goal to be strategic
Desired Result	BMO	Combinatory vagueness when criteria for desirability have not been set or are vague, degree-vagueness when these criteria are arithmetic

[1] http://www.ip-super.org/

The second case of business process knowledge we considered involved a specific application scenario, derived from [1], where the process of tender call evaluation had to be modelled as part of a decision support system. A tender call is an open request made by some organization for a written offer concerning the procurement of goods or services at a specified cost or rate. The evaluation of a tender call by a company refers to the process of deciding whether it should devote resources for preparing a competitive tender in order to be awarded the bid. A diagram describing this business process is depicted at figure 1.

Fig. 1. Tender Call Evaluation Process



Our analysis of this process involved identifying which aspects of it (structure, domain knowledge etc) had vague characteristics. Our findings can be summarized as follows: First, some of the process's various decision conditions according to which a specific action is decided are vague. For example, in order to take the decision about pursuing the call, two criteria that need to be satisfied are i) the budget of the project to be **high** and ii) the company's experience to be **adequate**. In both cases there could be borderline cases as it is indeterminate what is the exact threshold over which the budget is considered high (degree vagueness) or how many years and how many projects are required exactly for the company to be considered experienced in a given area (degree vagueness in two dimensions). Second, many of the underlying organizational and domain pieces of knowledge that are needed for performing various steps of the overall process are also vague. For example, the assessment of the potential competition for the call requires knowledge about the company's competitors. Yet, the existence of other companies that are borderline competitors is possible, mainly due to the lack of clear criteria about what constitutes a competitor and what not (combinatory vagueness). A similar argument can be made for the knowledge about the company's areas of expertise.

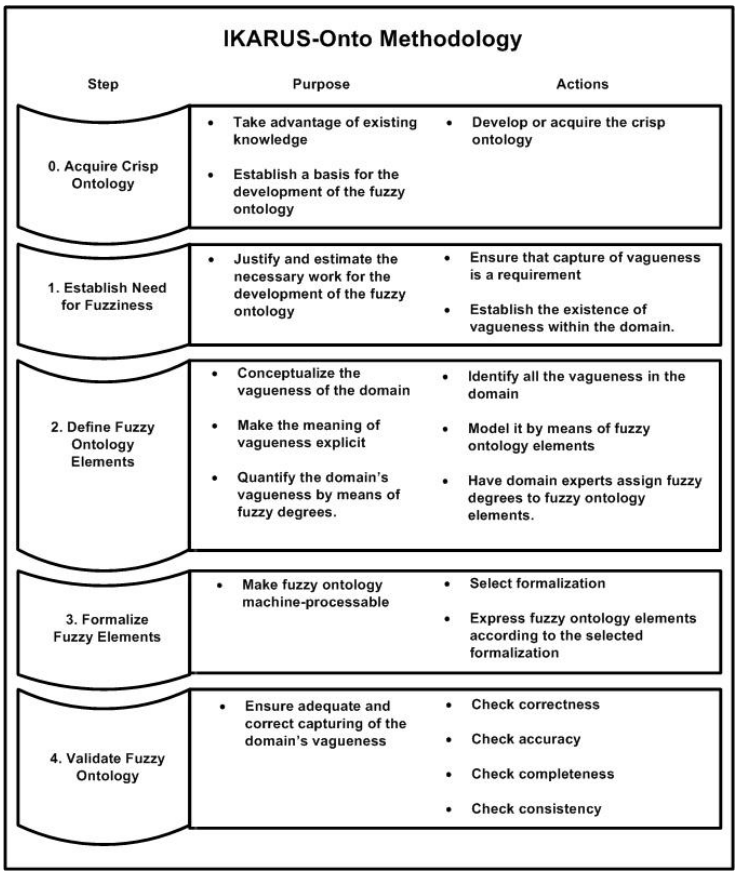
This second case illustrates, apart from the existence of vagueness in a common business process, the potential problems that may be caused during the latter's execution when this vagueness is not formally considered. Different people who will perform the same process will most likely produce different results, exactly because they will interpret various pieces of knowledge in a different manner (e.g. what budget is considered "high" or which companies are competitors). And it should be noted that this is not merely a problem of inadequate measurement or lack of concrete business rules but an inherent problem caused by the vagueness of human knowledge. For example, even if there is a business rule suggesting that competitors are those who have clients in the same industries and services in the same areas the question remains: what is the minimum number of similar clients or services that a given company needs to have in order to be considered a competitor? In the next section we describe how fuzzy ontologies may be practically applied for dealing with questions like that.

3 Modeling and Using Vague Business Processes Knowledge through Fuzzy Ontologies

A fuzzy ontology utilizes notions from Fuzzy Set Theory in order to formally represent the vague ontological elements described in paragraph 2.1. The basic elements it provides include i) **Fuzzy Concepts**, namely concepts to whose instances may belong to them to certain degrees (e.g. *Goal X is an instance of StrategicGoal at a degree of 0.8*), ii) **Fuzzy Relations/Attributes**, namely relations and attributes that link concept instances to other instances or literal values to certain degrees (e.g. *John is expert at Knowledge Management to a degree of 0.5*) and iii) **Fuzzy Datatypes**, namely sets of vague terms which may be used within the ontology as attribute values (e.g. the attribute *experience* mentioned above). In a fuzzy datatype each term is mapped to a fuzzy set that assigns to each of the datatype's potential exact values a fuzzy degree indicating the extent to which the exact value and the vague term express the same thing (e.g. *a consultant with 5 years of experiences is considered junior to a degree of 0.4*)

As with classical ontologies, using and applying fuzzy ontologies in practical scenarios requires corresponding methods and tools for developing them, formally representing them and performing reasoning and querying over them. Two recent developments that may cover a great part of these requirements is the IKARUS-Onto [2] methodology and the Fuzzy OWL 2 framework [4]. The first, depicted at figure 2, provides concrete steps and guidelines for identifying vague knowledge and conceptually modelling it by means of fuzzy ontology elements, placing particular emphasis into the explicitness and shareability of the vagueness's meaning. The second enables the formalization of fuzzy ontologies through the OWL 2 language and provides querying and reasoning services over them through a corresponding reasoner [3]. The adoption and application of the above frameworks in semantic business process modeling is quite straightforward as they are based on and extend already established methods and tech-

Fig. 2. The IKARUS-Onto Methodology



niques from traditional ontology modeling. Thus, the semantic treatment of a business process whose related knowledge includes vagueness would involve i) the building of a process ontology without considering vagueness ii) the fuzzification of this ontology through IKARUS-Onto and Fuzzy OWL 2 and iii) the querying/reasoning over the fuzzy process ontology through Fuzzy OWL 2.

To assess the feasibility and potential value of our approach we applied it in developing a fuzzy ontology for the aforementioned tender call evaluation process. Due to space limitations we cannot describe this ontology in detail, nevertheless it suffices to say that pieces of knowledge with degree-vagueness were typically modelled as fuzzy datatypes (e.g. budget and experience) while those with combinatory vagueness (e.g. competitors) were modelled as fuzzy relations or concepts. Figure 3 depicts two sample definitions in Fuzzy OWL 2.

Fig. 3. Sample of Fuzzy Tender Process Ontology

```
<owl:Axiom>
    <fuzzyLabel>
        <fuzzyOwl2 fuzzyType="axiom">;
            <Degree value="0.6"/>
        </fuzzyOwl2>
    </fuzzyLabel>
    <owl:annotatedSource rdf:resource="CompanyX"/>
    <owl:annotatedTarget rdf:resource="Competitor"/>
    <owl:annotatedProperty rdf:resource="&rdf;type"/>
</owl:Axiom>

<rdfs:Datatype rdf:about="HighProjectBudget">
    <fuzzyLabel>
        <fuzzyOwl2 fuzzyType="datatype">
            <Datatype type="rightshoulder" a="350000.0" b="500000.0"/>
        </fuzzyOwl2>
    </fuzzyLabel>
</rdfs:Datatype>
```

In any case, the developed fuzzy ontology formed the basis of a simple decision support system which queried the ontology in order to evaluate the tender call evaluation criteria and provide a suggestion to its users on whether they should pursue a given call. We had this system used by some of our consultants and we asked from them to provide some informal feedback. The positive remarks we received regarded the explicitness of the fuzzy elements's meaning (a result of using IKARUS-Onto) as well as the automation achieved in the retrieval of vague knowledge that made easier the evaluation of the fuzzy decision criteria. On the other hand, the task of defining fuzzy degrees and membership functions was deemed as quite difficult and time-consuming, indicating thus the need for more automated methods for vague knowledge acquisition.

4 Conclusions and Future Work

In this paper we utilized concrete examples and use cases from the literature in order to highlight the omnipresence of vagueness in business process knowledge and to argue in favour of using fuzzy ontologies for dealing with it in a semantically rich manner. Furthermore, we provided a small but representative example of how some of the latest fuzzy ontology engineering methods and tools may be practically used for dealing with vagueness in business process modeling. In the future we intend to further substantiate and support the use of fuzzy ontologies in semantic business process modeling by providing dedicated methods and tools for the capture, management and exploitation of vague process knowledge and by applying and evaluating these methods in real application scenarios.

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