Several Required OWL Features for Indigenous Knowledge Management Systems

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Abstract. This paper describes the features required of OWL to realise and enhance Indigenous Knowledge (IK) digital repositories. Several needs for Indigenous Knowledge management systems (IKMSs) are articulated, based on extensive stakeholder input, and analysed on the suitability of semantic web technologies in addressing them. Based on their potential for impact and maturity, several possible applications are recommended for further investigation and inclusion into current or new IKMSs, including: ontology based querying and browsing; a natural language independent ontology for multilingual data access; support for collaborative knowledge generation; and the formalisation of IK for scientific discovery. For each of these possible applications, the required OWL features are discussed, which include representation of vagueness, mereotopology, modularisation, and extended support for internationalisation and annotation.

1 Introduction

Indigenous Knowledge (IK) is the local, traditional knowledge held by people of a particular area. It is central to their cultural heritage and holds significant value. The collection and management of IK is increasingly important for the purposes of preservation, protection, conservation and promotion [1]. IK in rural areas is available in oral format and is held by IK holders in communities. Therefore, IK is mostly collected in free-text format, voice recordings and video, which makes the management and useful dissemination of IK challenging. In South Africa, the national Department of Science & Technology's large-scale National Recordal System project to collect and preserve IK was started in 2010. It requires a comprehensive application infrastructure to manage the data that has been, and is being collected. Existing recorded data in various formats requires integration as well as adaptation to make it accessible to a wider public and the scientific community, and new incoming information should be managed efficiently and effectively. Hence, it provides a substantial practical use case for IK management systems.

While the Semantic Web is still a work in progress, innovative tools and technologies have been developed that can be utilised in software development today.

In particular, there are opportunities for utilising ontologies and semantic web technologies in the area of Indigenous Knowledge management systems (IKMSs) in order to address some of the challenges in management and dissemination of IK. For example, collected IK is often unstructured, transferred in different local languages and described using local vernacular terms. This creates unique challenges that may be effectively addressed through the use of semantic web technologies.

The aim of this paper is to summarise the outcome of our exploration of existing semantic web technologies and the opportunities they create when applied in the domain of IK management. This semantic web technologies-based requirements analysis is subsequently used to formulate the specific OWL features required for them to be effective in IKMSs. We focus on four of the high-level specified needs and link them to eight areas of semantic web technologies. The four needs are ontology-based data access, automated reasoning for scientific knowledge discovery, multilingual ontologies, and collaborative ontology development. The former two result in requirements for extensions to the standard OWL with respect to the expressiveness of the underlying logic, whereas the latter two concern other OWL features that would help realising development and use in real systems.

The paper is structured as follows. The IKMS needs are summarised in Section 2. The survey of applicable semantic web technologies is presented in Section 3. Selected opportunities for application in the domain of IKMSs are described in Section 4 with a focus on the OWL features required for them to be effective. The paper is concluded in Section 5.

2 IK management system needs

IK can be defined as the traditional knowledge that is unique within a community or society, transferred by sharing experiences and skills and by storytelling from generation to generation. IK is a very wide field and spans a multitude of themes such as story telling; food technology; healing and nutrition; arts and crafts; cosmology; and traditional medicines.

Since IK is primarily implicit, it is in danger of being lost unless it is captured and preserved. IKMSs are formalised systems, often supported through technology, with the primary purpose of collecting, managing, preserving and disseminating IK. Collected IK is often unstructured, transferred in different local languages and described using local vernacular terms. This creates unique challenges that may be effectively addressed through the use of semantic web technologies.

The needs for IKMSs were explored through workshops conducted by the authors with potential users of IKMSs in South Africa. The participants included representatives from government departments, higher education institutions, science councils, scientists, traditional authorities and community based organisations. The aspects explored during these workshops included the questions to be answered on IK, the information on IK to be preserved and the functionality required for effective IK management, preservation and dissemination. The results from the workshops were prioritised based on input from the participants and filtered to yield the following list of needs that could potentially be addressed by semantic web technologies:

1. **Effective interrogation of IK:** The unstructured nature of IK and the fact that it often contains vernacular concepts makes interrogation and dissemination extremely challenging. In particular, the ability to query IK, browse IK based on inherent structures and relationships and find answers to complex questions were identified as specific needs.
2. **Access to multi-lingual information:** IK is often collected in the native language of the IK holder. Automatic translation services are not yet readily available for all African languages and manual translation is expensive and time consuming. The ability to access and query over information in different languages will be very beneficial in the context of IK management.
3. **Collaborative knowledge generation:** IK is a shared resource over individuals in traditional communities, geographical areas or communities of practice. A facility to capture and annotate the knowledge in a collaborative fashion will increase the effectiveness of IK collection and management initiatives.
4. **Information classification:** Due to the unstructured nature of IK it is difficult to classify the collected knowledge correctly. Classification is required to effectively structure IK repositories.
5. **Formalisation of information:** IK is a valuable resource for responsible scientific discovery. The formalisation of applicable IK will enhance the effectiveness of scientific exploration.

3 Semantic Web technologies

Based on the selected needs as described in the previous section, a number of existing semantic web technologies that may be applicable in IKMSs were identified. They were analysed based on their maturity and application readiness in IKMSs and four were selected as appropriate for implementation [2]. In addition to the four technologies selected in [2], “formalisation of scientific knowledge and discovery” is also considered appropriate for IKMSs. Even though the technology is relatively immature, the impact of its successful implementation to support the scientific exploration of IK will be high.

The technologies considered most relevant for application in IKMSs are described below, together with a short explanation of their relevance:

Semantically enhanced querying uses semantics in search, resulting in more precise results. Reasoning services over ontologies also allow the system to compensate for incomplete information. Ontology-based search is an emerging field, with several prototypes but few scalable solutions. It can be of particular value in IKMSs, as it can allow sophisticated and accurate querying over complex knowledge structures within IK repositories.

Semantic browsing of information allows browsing of information in a system based on the concepts and relationships defined in an ontology. Tools for ontology-driven navigation are mature; however, further work is needed for robust and scalable linkages to underlying data sources. Semantic browsing of collected IK can be particularly powerful as it will facilitate guided navigation through the complex knowledge structures within IK repositories.

Formalisation of scientific knowledge and discovery using an ontology can enable scientific verification and exploration of captured IK. The technology is still immature but the impact of success will be high.

Multi-lingual access to information using ontologies enables browsing and searching of knowledge in different languages and of accessing related information stored in different languages. This field is mature with a number of successful applications and can be particularly powerful in promoting navigation of recorded IK by indigenous communities in their own languages.

Collaborative knowledge generation using ontologies can enable communities to create precise representations of their IK in their area of interest in a collaborative manner, using tagging and metadata. This technology is mature with a number of robust applications.

In order to promote the adoption of these technologies, they were studied further, with a focus on the OWL features required to effectively apply them in IKMSs. The selected technologies are discussed in the following section.

4 Goals and required features

We first discuss two main areas that impact on OWL expressiveness directly, namely semantically enhanced querying and browsing of information, and scientific knowledge discovery, and then on two that focus on usability extensions with a potential for logic-based extensions, namely multilingualism, and collaborative ontology development. Each topic has a brief description and is followed by the OWL requirements.

4.1 Semantically enhanced querying and browsing of information

Description Semantic web technologies can enable enhanced querying of IK, by going beyond the simple string matching used in keyword-based search and using the semantics of the metadata stored with the IK. Keyword searches use string and linguistic matching of the search phrase and the information to be searched, but cannot exploit subject domain semantics and knowledge about the structure of information to find better results. Using ontologies allows the use of semantics in search, resulting in more precise and relevant results, even across institutional/software system boundaries.

Example 1. Plant A is used to treat lung conditions and plant B to treat shortness of breath. Searching for treatments for lung conditions in an ontology-driven system uses the relationship between breathing and lungs to return both A and B, while a standard keyword query will return only A. ♢

Using reasoning services over ontologies also allows the system to compensate for missing (incomplete) information during the execution of a query. Thus, even if not all the information was explicitly captured in the system, it can, through inference, deduce the correct answer to a query. This is not possible in standard queries only over relational databases.

Example 2. The tuber of the protected plant *Disa polygonoides* (i.e., orchid or *Uklamkleshe*) is used to treat voice loss after illness. It is captured in the system that *Disa polygonoides* occurs in the KwaZulu-Natal province, but it is not captured explicitly where the tuber occurs. A query can, through reasoning, find the habitat of the tuber, even though it was not explicitly stated, by inferring knowledge from parthood (of the plant), and mereotopological and spatial theories (to deduce the location).

The fruits of *Eugenia albanensis* (i.e, *Vlakappel* or *Umnanjwa*) are eaten to treat diarrhoea. As above, the location of the fruits can be deduced from that of the plant. ♢

We note that an ontology is a formal representation of the knowledge from domain expert's point of view. It is thus a logical theory that contains knowledge represented according to the domain experts' understanding. This creates the opportunity to have a facility to browse the information in the system based on the concepts defined in a domain and the relationships between them. Ontology-guided navigation will enable users to discover information based on the meaning of the topic and its relationship with other topics in the domain.

Examples of current research and proofs of concept of this approach include: Ontology-Based Data Access [3, 4]; the Simple Knowledge Organization System (SKOS) [5]; WONDER: a graphical tool to browse and query databases using an ontology [6]; Quelo: an intelligent query interface based on ontology navigation using pseudo-natural language [7]; GoPubMed: a tool to explore biomedical literature using the Gene Ontology [8]; Textpresso: an ontology-based information retrieval and extraction system for biological literature [9]; and; DLMedia: an ontology-mediated multimedia information retrieval system [10].

Required OWL features One can identify multiple desired features beyond the standard OWL species to realise the automated reasoning functionality envisioned in the preceding paragraph. They concern principally: (*i*) spatial and mereotopological KR&R and (*ii*) handling impreciseness and gaps in the knowledge about the subject domain.

Representing and reasoning over spatial knowledge and the objects occupying those regions of space (mereotopology) is known to be difficult with OWL, in particular regarding the properties of the relations (reflexivity, symmetry, etc.), the limitations for the so-called composition tables (arbitrary role composition), and scalability with a large number of instances [11, 12]. The informal example with the tuber amounts to a $\mathsf{TuberX} \sqsubseteq \exists \mathsf{properPartOf.P}$, $\mathsf{Trans(properPartOf)}$, $\mathsf{PlantY} \sqsubseteq \exists \mathsf{locatedIn.HabitatZ}$ where $\mathsf{HabitatZ}$ is a habitat type (say, $\mathsf{Wetlands}$) that is realised in some particular geographical area (say, the eThekwini bay) where the plant grows, then we can assert $\mathsf{properPartOf} \circ \mathsf{locatedIn} \sqsubseteq \mathsf{locatedIn}$ in OWL 2 DL, so that we infer that TuberX is also located in HabitatZ. In a second step of the query, one can retrieve the instances of HabitatZ, but this does not link PlantY to the eThekwini bay in particular and there may be wetlands that do not have PlantY, which we are not interested in and should not be in the answer. Put differently, it seems we have to link type-level knowledge with instance-level data, for which one could use punning features and be not fussy about the ontological status of species. However, with many geographic areas and species, this becomes cumbersome to maintain and is not very scalable when taking into account the object property characteristics and property chains. Perhaps a language with only simple property chains, transitivity, and punning may have nicer computational properties for large ABoxes than OWL 2 DL.

The second requirement is yet to be worked out in more detail. Our first assessment leans strongly toward rough and fuzzy extensions to OWL and its extended automated reasoning services (e.g., [13, 14]). Roughness can be useful to analyse the individuals in the knowledge base so as to refine the classes in the ontology in a bottom-up fashion [15], yet this is still a manual task and the rough subsumption reasoning of [13] is yet to be implemented. Moreover, because one cannot even have both the basic semantics of roughness and scalability of implementations [15], some sort of software-supported, intelligent, dynamic, linking and 'conversion' system between OWL 2 DL and its OWL 2 QL profile is needed. Fuzziness is useful in several scenarios, covering both the knowledge representation and some information retrieval requirements. For instance, it is useful to have fuzzy concrete domains with fuzzy data types, fuzzy concepts, and to use a degree of truth for some axiom [14]. Examples of this include: some plant can be found nearby a pond or nearby another that is nearby a pond; *peri-peri* (chillies) are grouped into four types; and the perceived effectiveness to a degree of using plant X for ailment Y, respectively. Further, for artefact annotation and retrieval, DL-Media [10] may be useful; although it is based on DLR-Lite only (cf. OWL 2 in [14]), it is expected to be implemented in a separate subsystem of the IKMS.

4.2 Formalisation of scientific knowledge and discovery

Description Formalising the knowledge and information captured in the system can enable scientific verification and discovery. The IK captured in the system can be formalised into an ontology and enriched with scientific information. This will allow scientists to use the knowledge for purposes such as hypothesis testing and consistency testing of theories.

In order to utilise the full power of ontologies, new information received by the system must be accurately classified according to the defined concepts in the knowledge base. The accurate classification of information will enhance the comprehensibility of the knowledge and the accessibility and ease of retrieval of the information.

Examples of current research and technology include: Taxonomic classification: the classification of knowledge on a class level based on the declared properties in the knowledge base; and Formal concept analysis: using a collection of objects and their properties to automatically derive an ontology or extend an existing knowledge base using the knowledge base itself together with information provided by a domain experts [16]. Proofs of concepts and applications available include: an automatic system for addressing the Chemical Compound problem, by interpreting transformations on the compound structures as updates in an ontology [17]; automated reasoning services for bio-informatics [18]; hypothesis testing using rough ontologies [15]; testing the differences of versions of a knowledge base using semantic diff [19]; and automatic classification of protein phosphates using an ontology, resulting in classification that surpassed that of human annotators and identified gaps in the theory that would not have been possible otherwise [20]. A frontrunner in demonstrating that ontologies contribute to knowledge discovery for IK is the Traditional Chinese Medicine e-Science system [21], which let them discover that there are 'hubs' in herb-drug relations—i.e., which herbs are central in TCM and thus pharmacologically of high importance for treatments of comparatively many illnesses—which was not possible by manually going through the many disparate information sources [22].

Required OWL features The requirements for knowledge discovery using OWL can be seen to some extent as a re-casting of item (*ii*) in Section 4.1, for here we also deal with handling 'gaps', but then with the purpose to find truly novel knowledge from the viewpoint of the scientist [18] as opposed to answering user queries. This can be divided into to three different strands: exploit existing infrastructure, standard OWL and reasoning (e.g. [20, 17]), use OWL but with another reasoning paradigm (e.g. abductive reasoning [23]), or link ontologies to data mining and machine learning techniques that assume much data is available (e.g., [22]). The first option requires a very expressive language to represent the knowledge as precisely and accurately as possible and obtain most inferences from it, whereas scalability is of comparatively little concern. For the latter two strands, the requirements we identified are those already described in the literature cited here.

4.3 Multi-lingual access to information

Description Ontologies are logical representations of a domain and can thus be natural language independent. This creates the opportunity to enable browsing and searching of knowledge in different languages and of accessing related information stored in different languages.

Example 3. A query can be formulated in any supported natural language (e.g. any of the 11 official languages in South Africa). Internally, the query is translated into a query over the ontology, which is language-independent, and results can be extracted and presented in any of the available languages. ♢

Examples of current research and technology include: query expansion for queries in different languages [24]; multi-lingual ontologies [25–27]; lexicalised ontologies [28, 29]; annotation of information in different languages [30, 31]; and parsers, morphological analysers and grammar engines. A proof of concept for this approach is MUSIL: a multilingual search facility in a library [32].

Required OWL features The required features do not in any way have to do with expressiveness of OWL, but rather with looking at better meeting the *internationalisation* and multilingualism design goals of the standard and with application features that can layer on top of an ontology (e.g., query expansion and pseudo-natural language verbalisations of the ontology). We focus on the former. As a first step, we aim for a single representation that is independent of natural language, similar to the basic approach of OBO using ID numbers as concept 'names' with any number of labels for the names, which then can be annotated with aspects such as a language tag. Recent enhanced 'OBO imports' options in development tools are a step in that direction, although in, e.g., Protégé it renders only one of the labels and one cannot yet choose between labels of different languages. The well-known limitation with that approach, however, is that it allows for only 1:1 mappings between named classes in different languages, which is regularly not the case. For instance, the isiZulu *ingcula* is a "small bladed hunting spear", which, when represented in the 'English understanding' would have a class Spear, with two properties, e.g. $\mathsf{Spear} \sqsubseteq \exists \mathsf{hasShape.Bladed} \sqcap \exists \mathsf{participatesIn.Hunting}$, and then some fuzziness to represent small, following [14], with, say,

$\mathsf{MesoscopicSmall} : \mathsf{Natural} \rightarrow [0, 1]$ as a fuzzy datatype,

$\mathsf{MesoscopicSmall(x)} = \mathsf{trz}(\mathsf{x}, 1, 5, 13, 20)$ with trz the trapezoidal function,

so that we can have

$\mathsf{SmallSpear} \equiv \mathsf{Spear} \sqcap \exists \mathsf{size.MesoscopicSmall}$

and subsequently declare something alike

$\mathsf{Ingcula} \equiv \mathsf{SmallSpear} \sqcap \exists \mathsf{hasShape.Bladed} \sqcap \exists \mathsf{participatesIn.Hunting}$.

This is actually just one of the possibilities of a formalised translation of an English natural language description, not a definition of *ingcula* as it may appear in an ontology about IK of hunting. But let us assume for now we do want to go in this direction, then we require more advanced capabilities than even lexicalised ontologies, which only link dictionaries and grammars to the ontologies (for most South African languages, dictionaries are limited in size and soft copy availability). A possible solution to this impasse is to use ε-connections between natural language-dependent versions either by connecting, e.g., inqina.owl#Ingcula@zu to a *set* of axioms or to a dummy class (say, hunting.owl#SmallBladedHuntingSpear@en) with the above-mentioned definition for Ingcula. The current integration of ε-connections with OWL [33] has a *link property*, which is a binary relation between instances of classes that belong to different ε-connected ontologies and its definition must include a single `owl:foreignOntology` tag in the source ontology (inqina.owl) pointing to the target ontology (hunting.owl), which can be used in axioms—but there is not just one other 'natural language ontology': ideally, there are 10 others. Hence, if OWL-integrated ε-connections were to be used, they would have to be extended. Alternatively, many separate bridge ontologies can be defined and linked with `owl:import` statements in a shell ontology that imports both the natural language dependent ontologies and the bridge ontologies.

One could argue about whether a specification for inter-ontology mappings should be part of the OWL standard, and we are trying various alternatives, but given the recent activities and the various approaches toward multilingual ontologies, some coherent, interoperable, framework for multilingualism and OWL would be a welcome addition.

4.4 Collaborative knowledge generation

Description Semantic web technologies can be utilised to provide a facility to enable a community to create a precise representation of the knowledge in their area of interest in a collaborative manner. Content loaded can be tagged by the community to enrich the meaning and accessibility of the items and inform the definition of their metadata for that area of interest.

Example 4. A community of drum builders can collaborate to define the domain of their interest by collaboratively developing an ontology or conceptual data model of the domain. As content is added to the system, community members can use this shared representation to tag and annotate the content. ♢

Current research and technology include: Modelling tools such as mind maps, graphs, conceptual models that provide an intermediate representation, collaborative ontology development tools with semantic wikis [34]; and Folksonomies: enabling communities to classify digital assets through shared metadata [35].

Required OWL features This main topic, like multilingualism, does not really concern the OWL language features with respect to the underlying logic, but instead concerns additional 'framework' support to enhance OWL's usability in real systems.

Collaborative ontology development tools exist, as well as basic implemented migration paths from intermediate representations such as mind maps or the Semantic Wiki MoKi [34]. Where OWL comes into the picture is the annotations of what has been added by whom and when. Annotation features have improved in OWL 2 compared to its predecessor, in particular the welcome axiom annotations, so it is still possible to incorporate information such as notes, provenance, and other matters like knowledge being 'approved' and 'under review'. However, the annotation properties carry no formal semantics in OWL 2. With the collaborative nature of ontology development for IK, some knowledge carries more weight than others at least temporarily, and it would be nice to assess what the differences in entailments are when, say, the 'under review' axioms are ignored. A more complicated scenario is handling alternative perspectives that are represented in an ontology thanks to the input from contributors with diverse backgrounds—the drum builders, the museum curators, and the music academics—so that one could select to add or remove those ones annotated with

"`<some string>`" and evaluate the inferences. This indicates it may perhaps be addressed by an annotation-driven on-the-fly modularisation of the ontology. Another possibility may be to use a semantic diff [19] in case each stakeholder group had added their knowledge in separate, yet to be integrated, ontologies. The latter may become a necessity when there is unresolvable conflicting knowledge, but the principle of collaboration is adhered to and from that perspective, the modularisation approach is preferred.

5 Conclusions

Several important needs for indigenous knowledge management systems were described and analysed to identify where ontologies are relevant. Four areas were selected for analysis and requirements specification with respect to OWL and its technical infrastructure for automated reasoning, being (1) enhanced, ontology based querying and ontology navigation to browse the knowledge in the IKMS; (2) formalisation of scientific knowledge and discovery; (3) a language independent ontology for multilingual data access; and (4) a facility to support collaborative knowledge generation. While some requirements can be met with the existing OWL standard, improvements will be useful regarding the interaction of more and less expressive OWL species, fuzzy ontologies, better support for a multilingual setting (including enhanced ε-connections and linking classes to very small modules), and annotation-dependent reasoning.

Currently, we are experimenting with isiZulu verbalisations of OWL ontologies and exploring semantic annotations of digitised cartographic maps with mereotopological relations. Ongoing and further research will entail a prioritisation of the possible applications and the development of a demonstration case in the National Recordal System to practically show the value of ontologies in IKMSs.

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