IKON-OWL: Using Ontologies for Knowledge Representation of Local Indigenous Knowledge on Drought

Completed Research

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Abstract

Semantic modeling and integration of local indigenous knowledge have become fundamental to improving the degree of accuracy of drought forecasting systems due to the variability of currently used environmental parameters. This research aims to acquire, organize and model natural indicators, behavior and ecological interactions of local indigenous knowledge with a focus on drought forecasting. The data are gathered using qualitative interpretative methodology from the interviews with local farmers and indigenous knowledge expert focus groups. The knowledge is formalised into semantic structure using an ontology for machine readability, reusability, integration, and interoperability with heterogeneous intelligent systems. In this paper, we present the design and development of a domain ontology for the indigenous knowledge on drought. The ontological model is an integral component of the research framework towards the development of semantics-based data integration middleware for local indigenous knowledge and modern knowledge on drought. This research contributes to modeling South African indigenous knowledge on drought into ontological models for use in drought forecasting systems, decision support systems, and expert systems.

Keywords

Domain ontology, ontology development, knowledge representation, semantic integration, local indigenous knowledge, drought forecasting systems.

Introduction

The integration of indigenous and scientific knowledge has become a widely discussed topic by scientists in the field of ethnoecology, biodiversity conservation, agriculture and recently in weather forecasting applications (Ludwig, 2016). While many researchers have often focused on unbridgeable differences between heterogeneous systems, recent debates about how knowledge integration will benefit critical research field such as the climate/weather forecasting cannot be overemphasized (Ludwig, 2016; Guarino, 1998; Fogwill, Alberts & Keet, 2012). Indigenous knowledge (IK) has been in existence since the dawn of civilization, but seems to be forgotten and currently on the way to its extinction, although development of new scientific knowledge is rapid, beneficial and well-documented. IK, on the other hand, is in oral, scattered and unstructured knowledge and has been used by local indigenous people in certain geographic locations from generations to generations (Masinde & Bagula, 2012). The possible integration of this ancient method with modern methods will not be possible until full knowledge representation of the domain is fully achieved.

In the weather forecasting domain, for example, there are complex environmental phenomena, such as drought. Forecasting such a complex event accurately is hampered by the variability of scientific weather data (observation/simulation data) and the difficulty in achieving the desired level of scalability. This has made the integration of indigenous and scientific knowledge a necessity. Indigenous knowledge reflects distinctive expertise in the indigenous environment. A typical example of the indigenous knowledge is the local indigenous knowledge on drought, which comprises the use of a variety of natural indicators associated with the environment for drought forecasting and prediction as against modern scientific methods (Masinde & Bagula, 2012). The local farmers relied almost fully on their experience and indigenous knowledge on drought for their farming decision making. The indicators for the indigenous knowledge are from expert observations and years of use by farmers.

Many local communities and tribal farmers in Africa (and indeed, elsewhere in the world) have developed their intricate native systems of natural indicators for prediction. The Indigenous Knowledge System (IKS) is also used for the local-level environment-related decision-making process in many rural communities as opposed to the scientific knowledge. A study in Burkina Faso showed that farmers' forecasting knowledge encompasses shared and selective experiences (Masinde & Bagula, 2012). For example, the local farmers who have in-depth domain knowledge formulate hypotheses about environmental changes/occurrences by observing natural phenomena such as ecological interactions between species in their natural habitat (Masinde, 2014; Manyanhaire, 2015). The forecasting indicators include the sighting of migratory birds, blooming of certain floras, the water level in streams, astronomical events, meteorological events and in very rare cases, predictions from divinations or dreams.

Although modern scientific knowledge and methods are mostly in use in drought forecasting, Fogwill et al. (2012) argue that modern science and technology with the help of indigenous knowledge will increase the level of accuracy. Therefore, the environmental monitoring community is tasked with the curation of quality vocabularies that will facilitate the detailed understanding of the natural indicators associated with drought forecasting in the local indigenous domain. Studies of the natural behavior and ecological interactions, between different species of insects and animals, can be used to infer drought forecast accurately and importantly in developing an accurate drought early-warning system for the region. The most important method of collecting data on behavior and ecological interaction is through detailed observation (Krebs & Davies, 2009). These observations, known by the IK experts, are shared orally. The data include the names of the animal and plant species, relationships, and their behavioral tendencies due to weather changes.

We envisage such a huge unstructured knowledge base that captures how the weather influences the natural indicators; the ecological interactions between different species of animals/plants with the environment are unusually rich in data for generating inference. However, due to lack of vocabulary standardization which is caused by the use of local language and terminology heterogeneity; analysts face significant challenges when attempting to analyze and integrate the indigenous knowledge data with the modern knowledge base. However, this can be solved by attributing semantic annotation and representation of the IK using an ontology. Analyzing the ecological interaction using ontology will provide descriptive and explanatory knowledge that will be useful in weather forecasts and climate predictions. The formal representation of local IK, therefore, promises "*access to a large amount of information and experience that has been previously ignored, or treated as mysticism*" (Ludwig, 2016). The knowledge, with its empirically derived emphasis on the natural world, can provide scientifically testable insights in drought forecasting (Manyanhaire, 2015).

With these promises, the work presented in this paper is part of a research project towards the development of semantics-based data integration middleware for drought forecasting systems. The overall objective was to formalize the local indigenous knowledge on drought, generate interference from the raw data and integrate it with data from computational models using complex event processing (*CEP*)[1] engine. This paper, therefore, presents the design of an **I**ndigenous **K**nowledge on Drought Domain **ON**tology (**IKON**) for the formalization of local indigenous knowledge on drought in the tribal areas of KwaZulu-Natal, South Africa. Using an ontology to represent semantically the individual organisms (i.e. plants, insects and animals), the vocabularies with the relationship in a natural setting will eliminate ambiguities caused by the difference in language barriers. It will also improve the semantic

[1] Complex event processing is an event processing engine where streams of data and events from multiple sources are analyzed to infer patterns and extract useful insights [28].

interoperability between data-stores, to more easily and meaningfully knowledge bases that can be mined for useful information. A complete ontological knowledge model offers a way to assign a possibility to an event in future. Therefore, representation of this wealth of local indigenous knowledge has become a key research issue.

Although there is no specific way to preserve knowledge appropriately, a structured representation such as an ontological model is important and necessary for local indigenous knowledge in drought forecasting, which is the main contribution of this paper. The scope of the indigenous knowledge in this research is on the ontological representation of the local indigenous knowledge on drought forecasting. The ontology helps exploit the synergy of the existing efforts in representing all categories of indigenous knowledge and provides supports for crucial tasks such as semantic metadata representation and improved interoperability between heterogeneous knowledge bases. The ontology is compatible with widely used semantic models and is designed to be lightweight to facilitate reuse and support deductive inference.

The rest of the paper is organized as follows: in section 2 we introduce the background to the problem of lack of formalization of local indigenous knowledge on drought and the challenges of integrating it with other knowledge-based systems. Section 3 describes the research methodology. Section 4 lays out the result and research contribution to the discourse, and section 5 we review some of the ontology modeling efforts in similar domains. In section 6 we conclude this work and outline future work.

Background

The effect of drought on people and the environment is disastrous (Burton, 1993). The ability to forecast drought currently depends on various environmental parameters of climate change such as changes in annual rainfall, average temperature, oceanic circulations and others. These measured properties are used as input data for different environmental modeling. Results from the computational analysis are often not as accurate as expected due to lack of scalability in the raw data. However, studies (Masinde & Bagula, 2012; Masinde, 2014; Manyanhaire, 2015) have demonstrated that some local communities have developed IKS used for prediction and forecasting weather, making them more resilient to environmental change in their localised area. Incorporating indigenous knowledge with modern knowledge tends to create a more accurate knowledge system in predicting climate change and drought. However, the main challenges are documentation of the IK from the IK experts, data analysis, and representation in a form that is interoperable with other knowledge-based systems.

To solve these challenges, there a need for the formalization of the IK domain in the form of a domain ontology to create semantic annotations of the natural indicators, the behaviors, and relationship in the ecosystem. Ontologies have been used successfully to standardize a domain through the use of metadata terminology for the discovery, representation, integration, reuse, and generation of inference (Gerber, Kotzé and Van der Merwe, 2010). Taxonomies often build on the controlled vocabularies using parent-child relationships to describe the conceptual inter-relationship between entities in a specific domain and capable of supporting richer operations with more advanced levels of reasoning. In semantic environmental modeling, ontologies build on metadata to provide a representation of knowledge about the domain and to provide a resource for reasoning and generating inference.

Methodology

Research Methodology Overview

This research adopts an interpretive qualitative methodology which is oriented towards procedural breakthrough and more focused on the understanding of the research problem as stated in section 2. There are few stages involved in the proposed research as depicted in Figure. 1 below. This paper presents the ontological modeling and development stage in the semantic annotation section of the research project.

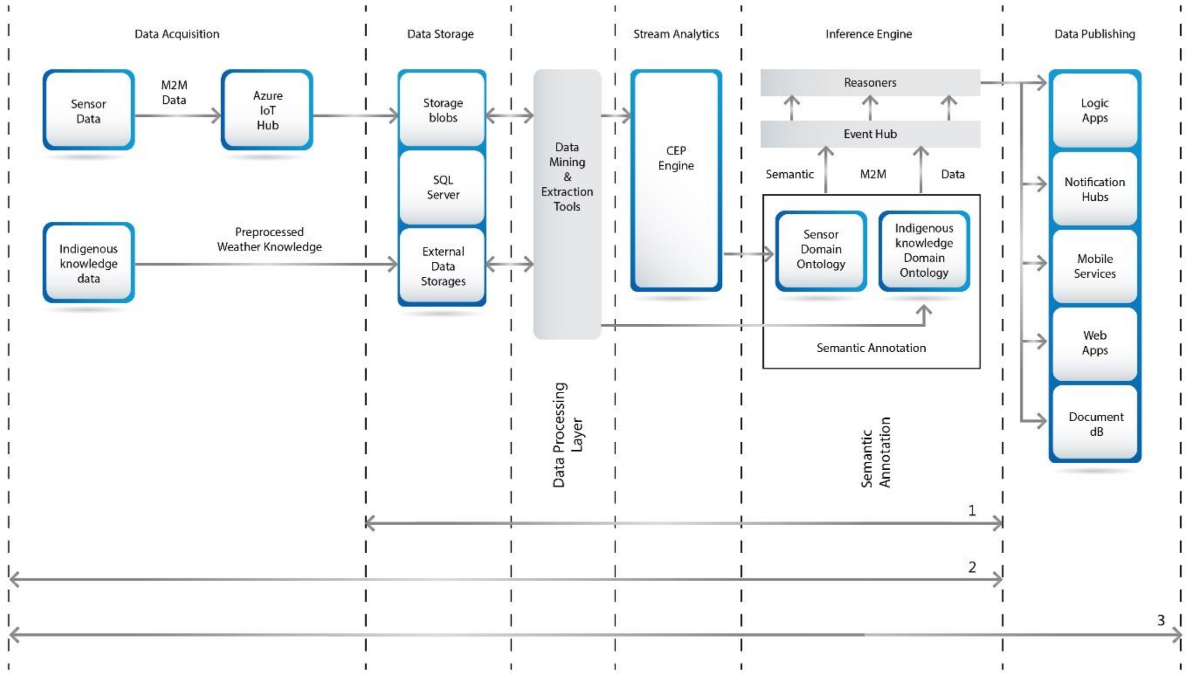

Figure 1. A semantics-based data integration middleware framework for drought early-warning expert systems.

Data Collection

The data collection starts with the creation of the focus groups (10-15 farmers) which are IK experts from the area under study in Swayimane, KZN, South Africa. Subsequently, using the interview method and questionnaire sampling technique, IK data were obtained from the focus group, through a series of oral consultation and meeting sessions. The indigenous knowledge is essentially in oral, undocumented and unstructured format. According to Kumar and Phrommathed (2005), the first step in research data collection is to ensure the data collection aims is clear of ambiguities. Therefore, there were 29 standardized open and closed-ended interview questions in the questionnaire. The focus group meeting consists of informal standard conversation. Each of the farmers, ranging from 35-65 years old, has a minimum of 20 years' experience as a local farmer. Each and every interview and focus group meeting session conducted were recorded using a digital voice-recording device. Also, to increase the sincere participation of the IK experts, smart mobile phones were procured for selected literate farmers. This is done with the sole aim of using the Android application developed for the project to capture the type (pictorially), description and spatial coordinates of identified natural indicators. This allows building a comprehensive knowledge base of IK indicators with description attributes remotely on our indigenous knowledge database server.

Ontological Modeling for Indigenous Knowledge on Drought

Conceptualizing a domain using ontology has long been recognized as a prerequisite for understanding the domain and processing information about it. Application of ontology has modernized the inference systems capability by permitting interoperability between heterogeneous knowledge systems and semantic web applications (Fahad & Qadir, 2008). Developed ontologies can also furnish the necessary semantics for inference generating capability required in intelligent systems (Fahad, Qadir & Shah, 2008). Moreover, due to their formal representation and explicit specification of a domain, they are being used in a wide range of applications and knowledge-based systems (Antoniou & Harmelen, 2004). Ontology is a logic-based, formal, machine-readable description of a specific domain (M.C. Gerber, A.J.

Gerber & van der Merwe, 2015; Guarino, 1998; Guarino, Oberle & Staab, 2009). The domain is described in such a way that the meaning is understandable by both humans and machines. Ontological modeling of the Indigenous Knowledge domain-controlled vocabularies, taxonomies, properties, and relationship ensures adding of semantic (meaning) annotation to the data for an accurate inference generation from the knowledge base (KB) and to make them available in a structured form that can be processed by computers (Guarino, 1998).

Currently, domain ontology that captures the context of local indigenous knowledge on drought explicitly using standardized languages, which will ensure data exchange and semantic integration across software boundaries is missing (Akanbi, Agunbiade & Dehinbo, 2014). Huang and Chen (2007) stated that development of a domain ontology is an essential part of building intelligent knowledge-based system. Domain ontology describes the properties, attributes and interrelationships of concepts, pertaining to a specific domain. It must be developed for reuse and compatibility with an upper ontology. Designing ontologies is the first step towards the integration and interoperability vision (Gerber et al., 2015; Akanbi & Masinde, 2015). There are several ontology development methods for specific needs. The method employed in our development, suggested by Noy and McGuinness (2001), is used for developing a domain ontology from the beginning. This method comprises seven phases of research task for the development of the ontology.

Understanding the domain and determining the scope of the ontology

According to Noy and McGuinness (2001) in their ontology design methodology, it is important to clarify the objectives of the ontology and limits its scope. This is necessary due to the several types of ontology ranging from task ontology, application ontology, domain ontology to upper ontology. The ontology to be developed for the indigenous knowledge on drought is a domain ontology. A domain ontology defines a common vocabulary about the objects, concepts within a domain, their relationships, the activities or behaviors that take place in that domain, theories and elementary principles governing the domain (Gómez-Pérez & Benjamins, 1999; Dombeu & Huisman, 2011; M.C. Gerber & A.J, Gerber, 2011.). The ontology design or modeling approach is an iterative process that repeats continuously to improve the developed ontology, there are several stages involved which can be revisited if there are flaws detected during the ontology design life cycle process. The first step towards the development of our domain ontology is the determination of the ontology scope. So our domain ontology is focused on local indigenous knowledge on drought, and it is proposed for conservation and knowledge standardization. It helps researchers and academicians to share information of the domain and utilize this vast knowledge base. This will also facilitate semantic representation of the knowledge and its use with other heterogeneous information systems.

Consider reusing existing Ontology

Reusing data or knowledge improves the quality of the development process. Currently, there is no ontology that explicitly captures and represents the local indigenous knowledge on drought in line with our proposed project for integrating this knowledge with other heterogeneous knowledge bases. Therefore, the domain ontology will be developed from scratch and will be made compatible with existing upper ontologies for easy reuse and future integration efforts.

Enumerate terms in the Ontology

This phase involves the development of the terminology about the domain; this is done by reviewing related published and working papers and interviewing the Indigenous Knowledge domain experts through questionnaires and workshops with the focus groups. This allows the analysis of the domain data based on axioms and terms. Enumerating the terms in the domain provides an explicit knowledge of the domain. The outcome of this phase for our proposed ontology helps to conceptualize and have a detailed understanding of the controlled vocabularies used, the class, properties, and relationship.

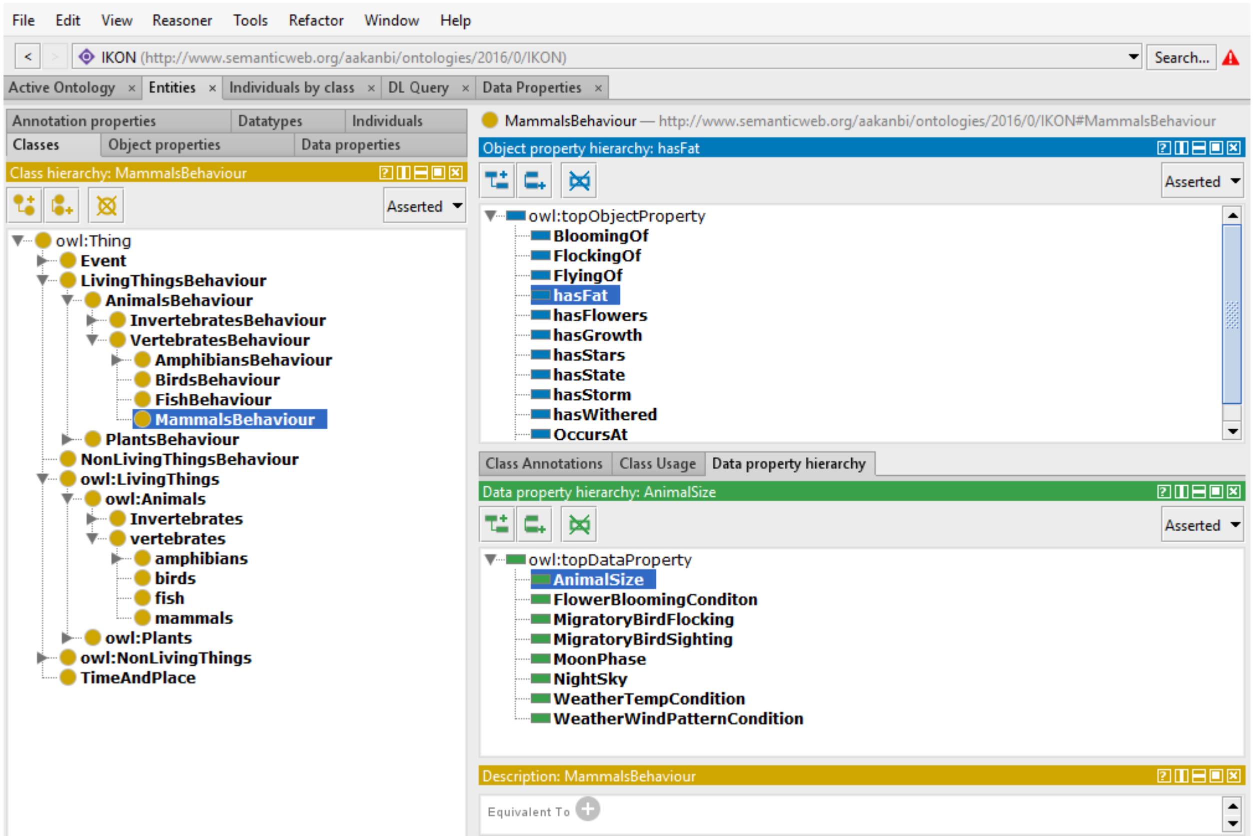

Figure 2. The hierarchical representation of the IKON Ontology with defined object and data properties in Protégé.

Define Class and hierarchy

For our proposed ontology, the local indigenous knowledge classes and their hierarchy are defined using Protégé 5 (Protégé, 2011). Five main classes are identified and are subclasses of Thing. The five main classes were classified under the `owl:Things` into superclasses `owl:LivingThings`, `owl:NonLivingThings`, `owl:LivingThingsBehaviour`, `owl:NonLivingThingsBehaviour` and `owl:Event`, each of them with their own hierarchy of subclasses. Based on the expert knowledge, the domain was classified and the mapping of the domain classes to the ontology was achieved through object-oriented techniques using multiple inheritances. The IK domain ontology does not aim at representing all types of events or scenarios. It provides a set of concepts and relations to model the events or scenario in the domain. After the main superclasses of the local indigenous knowledge, the subclasses of each of the superclasses will be defined.

The superclass `owl:LivingThings` will be classified into two subclasses of `owl:Animals` and `owl:Plants`, each with its own derived subclasses and individuals that are instances of the subclasses e.g. `Mugumo tree`, `wild figs`, `Peulwane birds`, `Lehota frog`, `Sifenefene worms`, etc. The `owl:NonLivingThings` class is used to capture the non-living entities of the IK domain, with individuals such as temperature, rain, humidity, etc. Behaviours (or observations) are represented as subclasses of `owl:LivingThingsBehaviour` and `owl:NonLivingThingsBehaviour`. An `owl:LivingThings` and `owl:NonLivingThings` provides a view on a set of entities which is consistent with a description. The `owl:LivingThingsBehaviour` and `owl:NonLivingThingsBehaviour` is used to model the corresponding behavioral activities of the `owl:LivingThings` and `owl:NonLivingThings` respectively, e.g. sighting of migratory birds, blooming of flower, withering of plant, etc. The mapping of the semantically annotated behaviors (observations) to the entities is a formalization of domain knowledge and allows deductive inference.

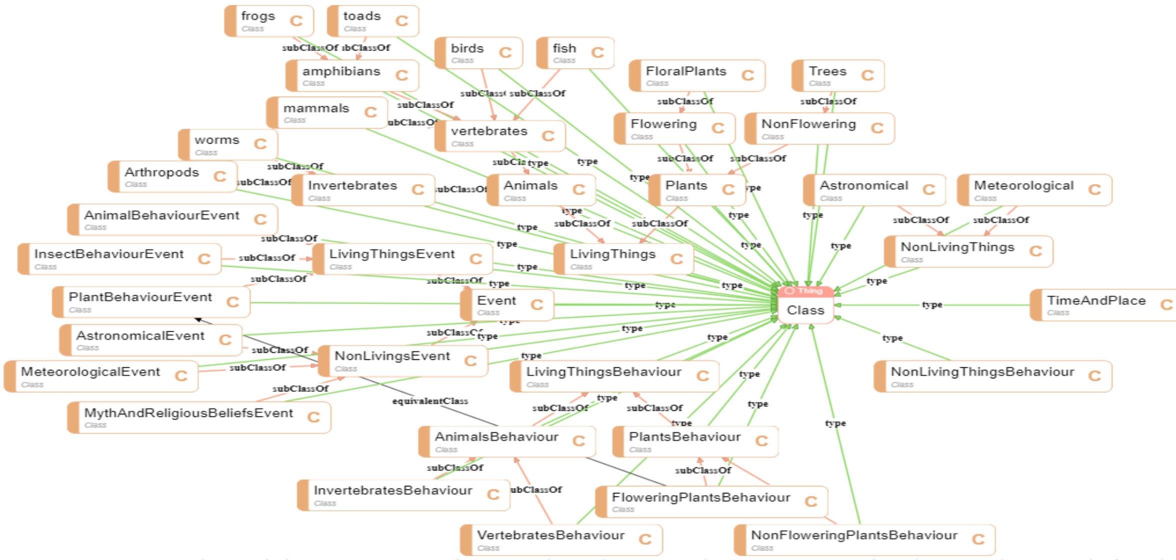

Figure 3. A screenshot of the IKON Ontology within the Ontodia[2] program, displaying the graph for the purposes of data representation and navigation

Class Properties

Properties are used to describe attributes of the class, e.g. characteristics of a class of animal. The properties of a class can be classified into data properties and object properties. The data properties can be simple or complex, depending on the type of class, and are special attributes whose values are the object of (other) classes. However, the object properties are defined to relate classes and their objects. Further refinement could be added to the properties to include property constraints which describe or restrict the set of possible property value. Below are some of the object properties of our ontology. All the object properties created are based on the ontology classes interrelationship.

> ***hasFlower*** relates a Flower plant with the `FloweringPlantBehaviour` which is the state of flowering depending on the seasonal changes.
>
> ***OccursAt*** relates the occurrence of an Event with the corresponding class.
>
> ***hasWithered*** relates the Plant with `PlantBehaviourEvent`.
>
> ***BloomingOf*** is an object property that relates Flower with Blooming.
>
> ***hasPhase*** relates Moon with phases of moon such as `FullMoon`, `HalfMoon` and `SmallMoon`.
>
> ***hasTemp*** relates to the daily average Temperature. This can either be High or Low as assumed by the IK expert.
>
> ***hasWindSpeed*** relates to the average `WindSpeed` for the day as determined by the IK expert.

Class Instances

The class instances are the member (individuals) of the class and are the structural component of an ontology. The instances are "Individual" created after defining the classes, sub-classes, object properties and data properties of the domain. The **I**ndigenous **K**nowledge on Drought Domain **ON**tology (**IKON**) can be used to understand the overview of intricate indigenous knowledge on drought. The mapping of the semantic annotated observations or behaviors to the class entities is a formalization of domain knowledge and allows generating inference from weather events automatically. The inference generated from the developed ontology will be integrated with modeled data towards the development of semantics-based data integration middleware for drought early warning information system.

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[2] An OWL and RDF diagramming tool used to visualize RDF files and configure SPARQL-endpoint.

Findings and Research Contribution

This research provides better insights on the local indigenous knowledge on drought for the area under study. Most of the indigenous knowledge on drought is currently in an oral unstructured format and used mostly by local farmers for their farming decision-making process. However, the reliability of this knowledge has been tested and adopted by generation to generation. The integration of these heterogeneous knowledge sources would increase the accuracy of weather forecasting systems, currently plagues by the variability of the environmental parameters. This research, therefore, contributed to the development of indigenous knowledge taxonomy and domain ontology for local indigenous knowledge on drought. The developed ontology will facilitate semantic representation and annotation of the domain using standardized vocabularies.

For example, based on the expert knowledge from the interview with the local farmers in the area under study; the sighting of migratory birds (`phezukomkhono`) is a natural indicator of the onset of a new season. The sighting occurrence event is an instance of the subclass `AnimalBehaviourEvent`. The indicator is captured using the system input values of data properties of sighting event: `MigratoryBirdsSighting` or `MigratoryBirdsFlocking`; both events are equivalent. Another event is the flowering of `MugumoTree;` this signifies there would be a bumper harvest. The information system can use the combination of these events which are a statement of assertions from indigenous knowledge expert and has been captured by the ontology for deductive inference. Also, in our ontology (IKON)[3], all the classes and subclasses are semantically linked using the appropriate object properties, inferences can be generated for accurate weather forecast based on the relationship captured by the domain ontology.

The findings of this research revealed that there is a similarity that can be explored in the way the knowledge is acquired and interpreted. Although the modern methods make use of advanced weather equipment to obtain data used for environmental modeling, indigenous knowledge experts look for signs in nature to predict future weather conditions. The semantic integration of these two heterogeneous knowledge bases will increase the level of accuracy in drought forecasting data. Besides, this research tends to solve the previously unbridgeable gap in the structured and unstructured form of data in the heterogeneous knowledge bases. Currently, lack of structure and formal representation of indigenous knowledge makes integration attempts difficult. What is missing is a domain ontology that captures the context of local indigenous knowledge on drought explicitly using standardized languages, which will enable data exchange and semantic integration across software boundaries. Hence, with the semantic representation of the indigenous knowledge using an ontology, the knowledge will be fully documented in a structured way that facilitates effective information retrieval, representation, and integration across software systems.

Related Work

Modern approaches to the representation of local indigenous knowledge involve the structured documentation of the knowledge in text format and eventually being saved in a database or archive. Very few efforts have been made in the semantic representation of local knowledge using ontology, which will facilitate knowledge integration and interoperability across different domains. In this section, we present a non-exhaustive survey of some research efforts of ontology modeling in similar domain.

A number of studies have been done regarding the modeling of indigenous knowledge, but not for the drought forecasting domain. For example, Coetzer, Moodley, and Gerber (2014) modeled expert knowledge of a flower-visiting behavioral ecology and represented it in an event-centric domain ontology – FV-DO and RBH-DO, which is built on the Population and Community Ontology (Walls et al., 2014). Their modeling approach is of general use in formal representation and conceptualizing knowledge of animal behavior and ecological interaction. Haron and Hamiz (2014) proposed a model for indigenous knowledge of confinement dietary with the aim of understanding the indigenous confinement dietary knowledge. The Food Ontology developed will also provide organized and centralized information retrieval of confinement dietary.

[3] Ontology publicly available at http://github.com/yinchar/Indigenous-Knowledge-on-Drought-Domain-Ontology.git

Coetzer et al. (2017) developed a unique ontology to standardize terminology for the discovery, integration, and reuse of ecological data. The classes of the domain ontology are defined with another ontology defined for the corresponding behavioral ontology and used to model the ecological informatics. The research work by Bally, Boneh, Nicholson, and Korb (2004) on the method of stimulating forecasting information involves the development of a forecast ontology for formulating and presenting weather forecast and their interrelationship. Elicited information for each weather procedure was combined into a comprehensive ontology for improving weather forecasting process.

Along with the above-mentioned efforts is a research project for the development of Indigenous Knowledge System (IKS) by the government of South Africa under the supervision of the Department of Science and Technology. The strategic objective of the IKS supported by the National IK Management System (NIKMAS)[4] is to develop a system that interface Indigenous Knowledge Systems with other Knowledge Systems ("NIKMS," 2017). With the aim to constitute a semantic web digital system, comprising indigenous knowledge networks, documentation centers, and confidential local registers.

Conclusion and Future Work

We present the development of domain ontology for the representation of local indigenous knowledge on drought. This indigenous knowledge domain ontology development is a phase in our ongoing research project towards the semantics-based data integration of local indigenous knowledge and modern knowledge on drought for a more accurate drought early-warning system (Figure 1). The ontology currently covers the core principles of indigenous knowledge on drought, natural indicators (*living and non-living things*), behaviors/signs of the natural indicators and events (*astronomical, meteorological, myth & beliefs*). The ontology organizes and represents the common understanding for unstructured information of the domain, and interpreting semantically the relationship between the classes and the behaviors of natural indicators. The semantic representation and integration were vital to accurate knowledge discovery because it allowed important local knowledge to be modeled and used for reasoning.

The approach can, therefore, be used to develop upper-domain ontology for other kinds of the unstructured knowledge base. In future work, this ontological component work will be integrated into the drought early-warning system framework for the semantic integration of the heterogeneous data sources. Inference generated from the ontology will be integrated with modeled data from the study area. The augmentation of the data sources would increase the accuracy of weather forecasting data.

Lastly, this research describes the contribution of the study which rests mainly on the ontological representation of local indigenous knowledge on drought in Swayimane, KwaZulu-Natal, South Africa. It focuses on modeling the natural indicators, relationship between the natural indicators and their corresponding behaviors, which implies certain environmental conditions. The model can thus be used in drought forecasting systems, decision support systems, expert systems and machine learning applications.

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[4] See http://www.nrs.dst.gov.za/

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