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SAAONT: Ontological knowledge-based development to support intelligent decision-making systems for Saudi Arabian agriculture

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ABSTRACT

Ontologies have become an essential tool for domain knowledge representation and a core element of many intelligent systems. It considered an appropriate solution to represent complex concepts and relationships within the agricultural domain. Over the last years, there has been an increasing number of undertaken efforts to develop ontology-based agricultural systems. These existing agricultural ontologies may not be sufficient to provide the desired level of information to individual farmers in Arabic regions, i.e. Saudi Arabia. Additional work is therefore needed to focus on building Arabic ontologies to provide the relevant, contextual and scientifically correct information in Arabia. Furthermore, the current practices within the Saudi Arabian agriculture sector are traditional and lack the technological foundations necessary to build and support intelligent, and sustainable technical solutions. Besides the contribution to the body of knowledge, this paper outlines a state-of-art ontological knowledge-based development for the agriculture sector in Saudi Arabia. It proposes an ontology-driven information retrieval system for agriculture in Saudi Arabia (SAAONT). It aims to firstly, structure and standardize agricultural terminology in Arabic and secondly, provide accurate information to decision-makers, to establish a smarter agriculture environment.

1. Introduction

Ontology is a complex concept, particularly concerning its applications and implementation. It has thus been subject to considerable debate, primarily concerning its implementation (Ukpe, 2013). Ontologies have been reported as beneficial for many domains, including (1) healthcare; (2) smart cities; (3) financial markets; and (4) agriculture (Meenachi and Baba, 2012). This has prompted a global tend focusing on the establishment and development of ontologies for the agricultural sector (Roussey et al., 2010). The Food and Agriculture Organization (FAO) has established the need to incorporate ontology within current agricultural research and development, to improve the current situation in both the agricultural and food sectors and increase smart sustainable development for all its members. Despite the existence of global trends in building an ontology-based knowledge system using English as the core language (i.e., AGROVOC (AIMS, 2019), FoodOn (FoodOn, 2019), and ONTAgri (Aqeel-ur-Rehman and Shaikh, 2011)) there have also been a number of efforts to develop agricultural ontology-based knowledge systems to specifically underpin smart sustainable agriculture domain in countries such as Nigeria (Ukpe, 2013), Sri Lanka (Walisadeera et al., 2015), China (Xie et al., 2007) and India (Prachi et al., 2016).

As one of the largest and wealthy Arab countries, Saudi Arabia has, at various times, commenced a considerable number of agricultural programs to guarantee its food security and develop rural areas, including (a) establishing effective agricultural practices; (b) drawing up responsive plans for farmers and feasible credit schemes; (c) free land distribution; and (d) extension programs to improve the yields of cereals, fruits, vegetables, and animal products. The benefits of such programs have enabled Saudi Arabia to fulfill its domestic requirements and export any surplus to other countries. In considering the limitations of vital resources (i.e., water), the Saudi Government is now moving towards the implementation of smarter technological solutions. To comply with Saudi Vision

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2030, there is currently an urgent impulse to include advanced computing technologies (i.e. Artificial Intelligence (AI) and the Internet of Things (IoT)) in current research and development plans (Alreshidi and Alyami, 2019). A smarter knowledge-base (in the form of an ontology) would facilitate the integration of smarter systems and tackle interoperability issues among heterogeneous smart systems (Alreshidi, 2019). Nonetheless, there remains only a limited number of studies addressing the development of an ontology to underpin the smart solution infrastructure for the agricultural environment of Saudi Arabia.

This paper, therefore, focuses on the establishment process of an ontology-driven information retrieval system for agriculture in Saudi Arabian (SAAONT). This would enable key players in Saudi Arabia, and in particular, farmers, to adopt and contribute to organizing information within the system, to enhance agricultural productivity. Ontology is a method of disseminating information employing appropriate channels to the right individuals when they need to take corrective actions and make the best decisions. Accurate information forms a vital component for enhancing the decision-making process. However, the development of specific domain ontologies faces many challenges, including (a) the process of information retrieval and (b) the amount of information to be organized within the agricultural domain. Furthermore, agricultural machines and technologies do not currently accommodate legacy systems, which will thus require further re-engineering and development.

2. Background

This study conducted a review of the related literature to formulate the terms of the investigation, including ontology, agriculture ontologies and the agricultural context of Saudi Arabia.

2.1. Ontology

Ontologies are developed to facilitate the reuse and sharing of knowledge (Fensel, 2001). Ontology can be viewed as a structured directory creating a medium of hard storage. It is a formal representation of concepts, which are interlinked to form an area of knowledge within a specific domain, to support a reasoning mechanism (Papajorgji, 2012). The most widely quoted definition of ontology was given by Gruber (1995), i.e., “An explicit specification of a conceptualization”. The use of ontologies has demonstrated beneficial practicality in many different AI applications, including: (1) Natural Language Processing (NLP); (2) the semantic web; and (3) integration of intelligent information systems and knowledge-based systems. Ontologies are primarily developed to separate domain knowledge from operational knowledge, thus enabling the reuse of domain and operational knowledge. Most ontologies, regardless of the language of expression, share several structural similarities and tend to describe individuals, classes, attributes and relationships (Horridge et al., 2009).

The use of ontologies has been successfully adopted on a large scale, to create specific domain knowledge bases, i.e., medical information for healthcare that is internationally consistent. Many studies (Roussey et al., 2010; Goumopoulos et al., 2009) have identified ontologies as a solution to standardizing specific concepts, thus being capable of addressing issues of interoperability within existing systems (Lauser et al., 2006). However, there is now an urgent need to standardize concepts of ‘agriculture’ about the use of advanced technologies, (Lauser et al., 2006; Joo et al., 2016). This has led several organizations and institutions to develop both global and local ontologies for the agriculture domain, i.e. FAO, AGROVOC (AIMS, 2019), FoodOn (FoodOn, 2019) and ONTAgri (Aqeel-ur-Rehman and Shaikh, 2011). Besides, ontologies are considered an effective solution for assisting key agricultural stakeholders to exploit existing knowledge to enhance decision-making for agricultural processes, including crop selection, time of harvesting and cattle monitoring. The integration of these concepts can assist in the preservation and retrieval of information within the agricultural sector. The key factor demonstrating the benefits of ontologies relates to the development of intelligent machines, due to their ability to create accurate responses to important queries, i.e. monitoring performance, recommending controls and checking statues (Tedman and Tedman, 2007). A further advantage of ontologies is their ability to search information within full texts or data by category, to produce meaningful results through the categorizing and organization of all agricultural knowledge and subsequently publishing it globally, i.e. over the Internet.

2.2. Existing ontological efforts in the agriculture sectors

Agriculture is an important sector for the creation of raw food and materials, as well as playing a vital role in the economic growth of a country, particularly with the emergence of advanced computing and intelligent technologies. However, information tends to be subject to rapid change in response to environmental conditions and geographic locations. This results in a need for all data regarding agriculture to be properly arranged and organized, to enable the key players (i.e. farmers) to easily retrieve information. Researchers and developers have therefore been encouraged to develop ontologies as knowledge bases for the agriculture sector, along with extraction techniques for obtaining useful information. Sicilia and Lytras (2008) identified three main methods through which ontologies can be applied in the agricultural sector: (a) the building of taxonomies (i.e., enabling automatic classification through each taxon); (b) the creation of a common language processing (in which concepts can be matched and queries processed); and (c) aiding the storage and retrieval of information.

There are several well-known methods of conducting the research and development of ontology within the agricultural sector, including FAO, AGROVOC (AIMS, 2019), FoodOn (FoodOn, 2019), ONTAgri (Aqeel-ur-Rehman and Shaikh, 2011), WAICENT (WAICENT, 2019). However, few studies have previously reviewed ontological efforts in the agricultural sector itself, i.e. the work of (Alfred et al., 2014; Prachi et al., 2016; Ngo et al., 2018). This highlights those existing agricultural ontologies maybe not be sufficient to provide the desired level of information to individual farmers in Arabic regions, i.e. Saudi Arabia. Additional work is therefore needed to focus on building Arabic ontologies to provide the relevant, contextual and scientifically correct information in Arabic. The most significant information regarding each ontology, based on existing research and official websites are as follows:

FoodON (Griffiths et al., 2016; FoodOn, 2019): This is an ontology built to represent: (1) food; (2) natural ecosystems; (3) food webs; (4) human-centric categorization; and (5) the handling of food. Also, FoodON's ambitious scope demands input from multiple domains. This ontology focusses on developing semantics for food safety and security, as well as agricultural and animal husbandry practices, linking these to food production, culinary, nutritional and chemical ingredients and processes. Due to being a robust food ontology, it requires a wide consensus to enable further development. It has been used by many platforms, such as the Canadian Healthy Infant Longitudinal Development (CHILD) and the Integrated Rapid Infectious Disease Analysis (IRIDA).

Integrated Agriculture Information Framework (IAIF) (Alfred et al., 2014): This forms a solution for ontology extraction, facilitating the identification of knowledge from related repositories of different domains. It can combine, merge and aggregate data found in existing knowledge repositories. Three sub-ontologies are included in IAIF agriculture: (1) Domain Ontology; (2) Resource Ontology; and (3) Linking Ontology. Furthermore, it enables the reusability of existing agriculture domains through a cross-domain relationship, using RDF-OWL for Knowledge Representation. It also uses files as a storage mechanism.

Scalable Service-Oriented Agriculture Ontology for Precision Farming (ONTAgri) (Aqeel-ur-Rehman and Shaikh, 2011): This ontology describes the core concepts of agriculture, covering several farming practices, i.e., irrigation, the spraying of pesticides, and fertilization. Besides, it provides sensor technology support to obtain real-time values. It is composed of two sub-ontologies (i.e. System Ontology and Domain Ontology), with the later also divided into two parts (i.e. Core and Services). It focusses on supporting agricultural requirements and linking related domain ontologies. Furthermore, it allows for the utilization of the same components to reduce redundancy. The initiation of new agricultural services can be undertaken easily and flexibly, without any need for structural change.

AGROVAC (Sini et al., 2008): This is an ontological structured thesaurus created by European Community and FAO. AGROVAC covers the core agricultural concepts, i.e., food, forestry, and fisheries. It provides a multilingual thesaurus, with English as the main referencing language, which is also translated into some further languages. It allows the reusability of concepts and is capable of indexing, retrieving and organizing agricultural information to enable the efficient search. Due to being an open-access ontology, it does not allow users to add or edit concepts relating to Intellectual Property Rights (IPR) and data custody issues.

Agricultural Ontology Service (AOS) (Sini et al., 2008): This is a web-based application designed to utilize AGROVOC ontology by serving as a common platform for core terms and their relationships, to be shared among cloud-based knowledge systems. Its main aim is to achieve interoperability between different agricultural ontological-based systems. Being based on the core AGROVOC ontological structures ensures it can support standardized agriculture terminology in multiple languages. However, the incorporation of knowledge and the support of other languages remains cumbersome and slow, demonstrating difficulties in accessing similar systems, as well as issues with content creation and updating when it comes to the synchronization process. Like AGROVOC, it faces a number of issues with IPR and data ownership.

World Agriculture Information Center (WAICENT) (WAICENT, 2019): This is an agricultural multilingual knowledge management system supported by FAO and available through the Internet to support end-users decisions on a global basis. It also organizes and links information to facilitate user access and perform searches using keywords, as well as offering a visualization system.

OntoSim-Sugarcane (Beck et al., 2010; Meenachi and Baba, 2012): This is an ontology-based application representing southern Florida organic sugarcane production, in terms of (1) soil moisture; (2) nutrient cycling; (3) plant growth; (4) hydrology; and (5) crop growth nutrient uptake. It facilitates the adaption of similar models to differing landscape environments and offers user-defined relationships between modifiable objects. Furthermore, it enhances its ability to be shared by enabling the modification and reuse of objects. However, it also contains a number of debugging errors and does not include all agricultural concepts.

Food Safety Semantic Retrieval System (FSSRS) (Yang et al., 2011; Cao and He, 2008): This is an experimental ontology-based semantic retrieval system, including the majority of essential food safety aspects to be followed in the event of emergencies, as well as providing end-users with access to all available knowledge concerning food safety.

OntoCrop Ontology (Maliappis, 2009): This has been primarily created for the gardening aspect of agriculture and to examine ontology usage within a particular domain. In addition, as a domain model for a knowledge base, it is used as a refining and classification tool to facilitate the indexing and searching processes within agricultural knowledge domains.

2.3. Rational for Saudi Arabia agricultural ontology (SAAONT)

Saudi Arabia covers approximately an area of approximately 2,149,690 square kilometers, containing nearly 30.77 million inhabitants. It is the largest country of the Gulf region covering the majority (i.e. 80%) of the Arabian region (Al-Hamzi, 1997), with its western shoreline bordering the Red Sea for a distance of 1750 km. Due to its high and extreme temperatures, Saudi Arabia's environmental conditions are not generally conducive to agriculture (Fiaz et al., 2018), although a number of agricultural programs have been initiated at various times in an attempt to ensure sustainable development and food security (Bailey and Willoughby, 2013). Over recent years, Saudi Arabia has experienced a rapid level of development. However, it has also faced the issue of limited natural resources, in particular, water, resulting in a reduction of its agricultural production (Al-Subaiee et al., 2005), with a negative impact on the agricultural sector and limiting the available food supply from local farms. However, a sustainable increase in agricultural production could be achieved by improving the productivity of the land and the use of water resources. One barrier to such initiatives is the lack of technical background among farmers in Saudi Arabia, leading to challenges for creating a native language agriculture-based ontology. If this trend continues, the country is expected to suffer from serious difficulties, thus highlighting the need to formulate a national policy integrated with all possible solutions concerning improved food supply and nutritional status.

Saudi Arabia has recently achieved unprecedented economic and housing growth, but most development projects have been based on unsustainable practices. However, the launch of the kingdom's Vision 2030 has inspired optimism that this will lead to unprecedented global projects, i.e. NEOM, which includes building a capital city applying the principles of sustainable development. Articles published by the Saudi News Agency (SPA) have confirmed that the region will focus on nine specific investment sectors: (1) the future of mobility; (2) the future of biotechnology; (3) the future of food production (4); the future of technical and digital sciences; (5) the future of advanced industrialization; (6) the future of media production; (7) the future of entertainment; (8); the future of living; and (9) the future of water and energy use. The adoption of smart sustainable technologies has the potential to assist in the monitoring, control, and management of natural resources in the agricultural sector (Ingram and Gaskell, 2019). Therefore, by acknowledging the limited availability of vital resources (i.e. water) the Saudi Government is now considering moving towards smarter technological solutions, i.e. new projects such as NEOM. In compliance with Saudi Vision 2030, there is now a powerful push to involve advanced computing technologies (i.e., AI and IoT) in current research and development planning.

The development of ontological knowledge-bases is a method of disseminating information by means of the correct channels to ensure the most appropriate actions and decisions. Accurate information is a vital component in enhancing the decision-making process. However, the development of specific domain ontologies is faced with a number of challenges, inducing: (a) the process of information retrieval and (b) the amount of agricultural information required. Furthermore, agricultural machines and technologies do not easily accommodate legacy systems, due to their need for re-engineering and further development. The creation of a smarter knowledge-base, in the form of an ontology, would facilitate the closer integration of smarter systems and address issues of interoperability among heterogeneous smart systems. Nonetheless, there are only a limited number of studies concerning the development of an ontology underpinning the smart solution infrastructure for Saudi Arabian agriculture. Furthermore, it is vital to establish an ontology-driven agricultural information retrieval system for Saudi Arabia (SAAONT) for adoption by key players (and in particular farmers) to facilitate the organization of information within the system in order to enhance productivity. The need for food security in Saudi Arabia cannot be overstated, as the continued growth in its population demands that its population avoids any danger of starvation (Fiaz et al., 2018). It is therefore recommended that an intelligent transformation is initiated, commencing with Saudi Arabia agriculture ontology, to reduce the existing challenges and achieve food security and sustainability.

3. Methodology

This section describes the methodologies employed to develop an ontology focused on the relevant structural and behavioral aspects, i.e. the selection of a foundational ontology; ontology reuse; conceptual modeling; and architecture design characteristics.

3.1. SAAONT ontology development methodology and conceptual modeling

This work aimed to develop a specific domain ontology for the Saudi Arabian agricultural sector. After selecting a methodology to guide the development of the SAAONT ontology, it was vital to select an appropriate language to describe the behavioral aspects of the tasks, following the main steps of building an ontology proposed by Noy and McGuinness (2001). There are several methodologies recommended for use in developing domain ontologies, as described by Bontas et al. (2005), de Almeida Falbo (2004), Kim et al. (1995) and Uschold and King (1995). In general, the creation of an ontology is subjected to four milestones: (a) the requirement and analysis of the ontology domain; (b) the design and implementation of an analyzed ontology; (c) testing and validation; and (d) developing new concepts and maintenance.

As shown in Fig. 1, the methodology selected in this current study followed that proposed by Noy and McGuinness (2001). Firstly, it determines the domain and scope of the ontology and deep analysis; secondly, it defines the classes and relationships (i.e. class hierarchies and properties) forming part of the ontology structure considering the reusability of other domain ontologies; finally, the creation of SAAONT is followed by regular updates and maintenance.

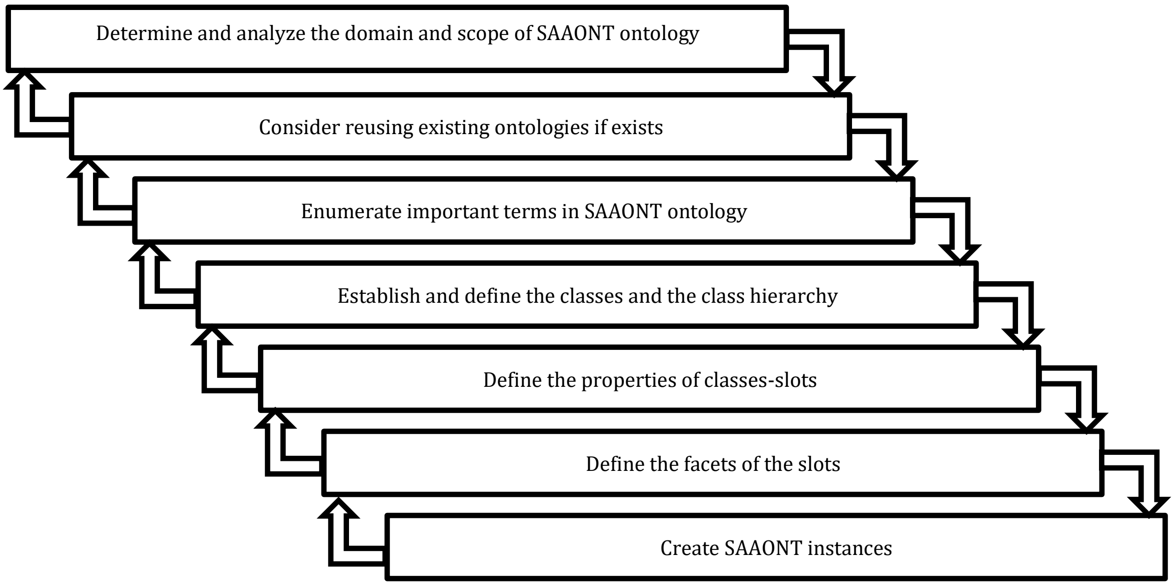


Fig. 1: Methodology adopted to underpin the SAAONT ontology development process

3.2. Software tools used in the SAAONT development process

There are many available ontological tools to create, modify and retrieve information, in order to demonstrate an agriculture-based ontology system that allows farmers to obtain the most recent information about crops, markets, seed quality, and diseases. In addition, information can be retrieved with the assistance of query retrieval systems such as DL-Query and SPARQL. Furthermore, a large number of tools are available to visualize the developed ontology, i.e., OntoGraph.

Protégé: This is an ontology development tool created by Stanford University during the 1980s. It allows developers to build knowledge-based systems and construct reusable ontologies, focusing on aiding the knowledge acquisition process for expert systems. It is oriented towards the development of an ontology and knowledge base. Protégé currently exists in a variety of frameworks supporting a large number of advanced enabling the construction and management of Web Ontology Language (OWL) ontologies. Furthermore, it enables the construction of domain ontologies without any syntactic information, thus providing improved flexibility for meta-modeling (Musen, 2015).

HermiT OWL Reasoner: This is an open-source reasoner for ontologies written using OWL under the GNU Lesser General Public License (LGPL). It can determine whether an ontology is consistent, as well as identifying sub relationships between classes, based on a novel 'hyper tableau' calculus, which provides far more efficient reasoning than any previously-known algorithm. It can classify complex ontologies within seconds for any available system to handle. HermiT uses direct semantics and passes all OWL to conformance tests for direct semantics reasoners and is compatible with Java. It uses the OWL API, which is backward compatible with the OWL API. In addition, it can handle DL Safe rules, which can then be directly added to the input ontology in a functional style or other OWL syntaxes supported by the OWL API.

Onto Graf: This is an integrated tool within the Protégé development environment providing easy navigation of a developed ontology and is used to support the interactive navigation of relationships within OWL ontologies. It provides several layouts for the automatic organization of the structure of a created ontology. Moreover, it supports visualization of various relationships: (1) subclass; (2) individual, domain/range object properties; and (3) equivalence. It also filters visual views based on relationships and node types, in order to create the desired view.

DL-Query: This is a tool providing a powerful and easy-to-use feature for searching a classified ontology, offering additional features to OWL applications by providing support for data and object properties, through Query Box, equivalent class, subclass and Query result frame. The query language (class expression) supported by the plugin is based on the Manchester OWL syntax, i.e. a user-friendly syntax for OWL DL, based on collecting all information relating to a particular class, property, or individual into a single construct, known as a frame. A class definition can be tested by assuming membership of arbitrary descriptions, without creating details of a named class (Protégé, 2019).

WebVOWL: This is a web-based application for interactively visualizing ontologies. It adopts Visual Notation for OWL Ontologies (VOWL) by delivering graphical depictions for elements of OWL. It also allows interaction techniques exploring the ontology and customizing its visualization. The VOWL graphs are automatically generated from JSON files (WebVOWL, 2019).

4. Results and discussion

This section presents the initial outcomes of this study. Firstly, it provides an overview of the SAAONT ontology-based system architecture. Secondly, it outlines the developed SAAONT, identifying the main classes and some of the DL-query results from SAAONT ontology. Finally, it highlights the challenges and opportunities encountered during the lifecycle development of SAAONT.

4.1. SAAONT ontological knowledge-based system architecture encouraged

The SAAONT system architecture was based on a review of several ontological knowledge base architectures (Qin et al., 2019; Khamparia et al., 2014). Fig. 2 shows the system architecture of SAAONT ontology, which consists of several components:

- **Views:** This is mainly responsible for the interaction between end-users and smart applications, allowing them to perform queries and providing information retrieved from knowledge-based SAAONT.
- **Applications and APIs:** This contains applications and APIs responsible for running programming codes and performing quires with the assistance of a query engine.
- **Ontology and Artificial Intelligence:** This is responsible for hosting the SAAONT ontology and knowledge bases in the domain, using the Protégé interface. Moreover, it uses an ontology reasoner (i.e., HermiT) to validate the ontology and check its consistency.
- **Storage and physical hardware:** This is used to host all of the above components on physical mechanisms and provide a permanent location for storing information from SAAONT.

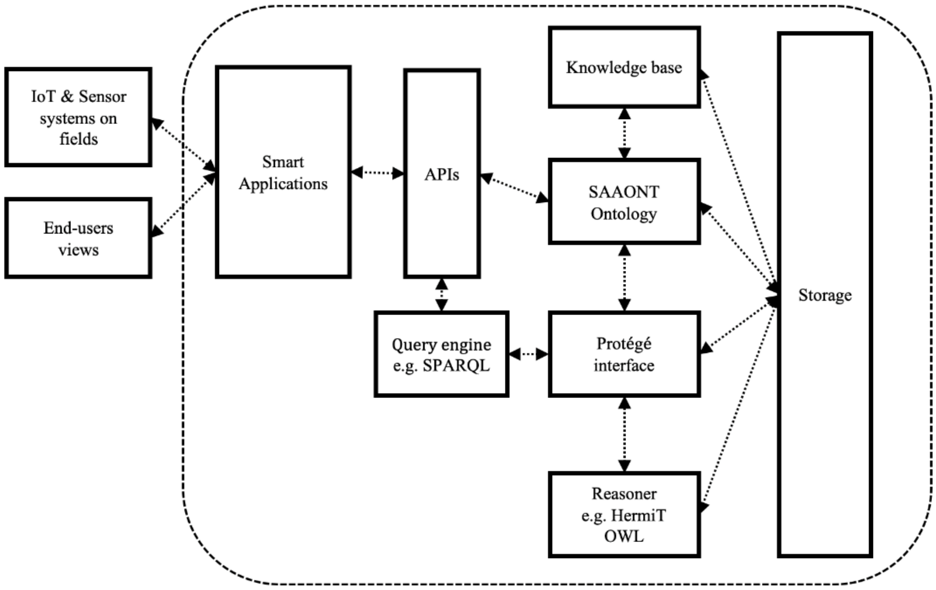


Fig. 2: System architecture of the SAAONT ontology knowledge-base

4.2. Saudi Arabian agricultural ontology (SAAONT)

Despite the presence of guidelines for building an ontology to assist in decision making, there remain various alternatives for correctly modeling a domain using an ontology development approach. In general, the most effective solution relies on the application used to build the ontology, including what to expect. Building a specific domain ontology is an iterative process (Noy and McGuinness, 2001), with a thin line existing between the end of the ontology and the start of the knowledge base. During ontology development, classes (known as taxonomies) describe concepts in the domain, with OWL classes interpreted assets containing individuals. Classes can be organized into hierarchies containing super and subclasses. Thus, subclasses play a specialized role in relation to the super classes.

The protégé ontology editor tool was used to create and develop SAAONT ontology, assisting in the creation of SAAONT classes to describe specific subjects and instances, as well as details of the knowledge base. These classes describe agricultural concepts in Arabic. Fig. 3 shows the primary ontology graph created by the Protégé software tool, highlighting the top hierarchy classes of the SAAONT classes, including the following concepts:

1) Agriculture
2) Environment
3) Agricultural Equipment and
4) Pests.

Instances can be defined in relation to an object within a class, to demonstrate its properties, i.e. Horse Ax and Black_Palm_Weevil Relationships between classes are defined by object properties, with each containing several classes of domain and range, i.e., Plant, Human, Seed; PlantedBy, Seeds, Human. The data property of each class gives values for instances of a particular class, while also creating a relationship between that class and a data value, i.e., temperature (weather, Integer). The development of SAAONT ontology is not complete until individuals have been included, with a large number required for each class. SAAONT ontology considered that a small number of individuals were sufficient for a class, due to it being in the early stages of development. When individuals were added, an appropriate association was made between the object and data properties.

The use of the online web-based ontology visualization tool (WebVOWL) enables a view of the overall initial structure of SAAONT ontology. Fig. 4 (below) outlines all classes, relationships, and instances created by the Protégé editor.

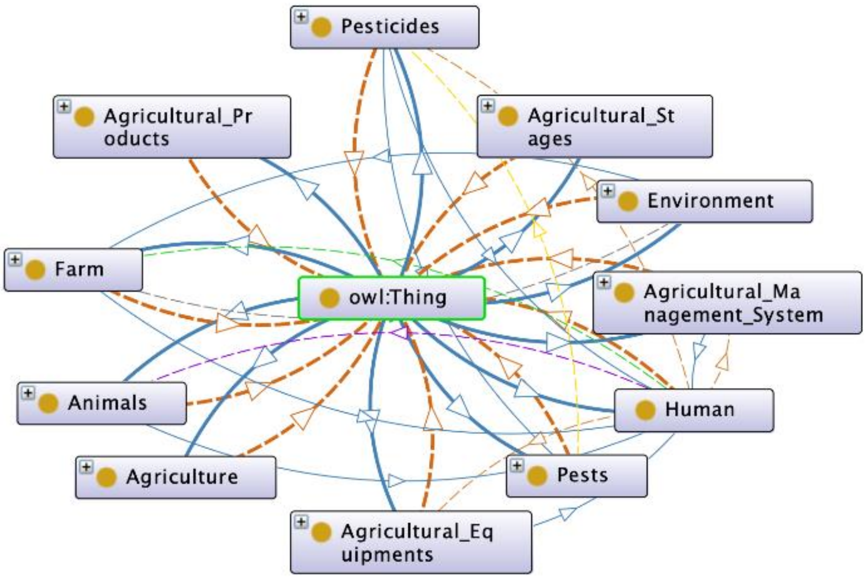


Fig. 3: Top classes hierarchy graph of SAAONT

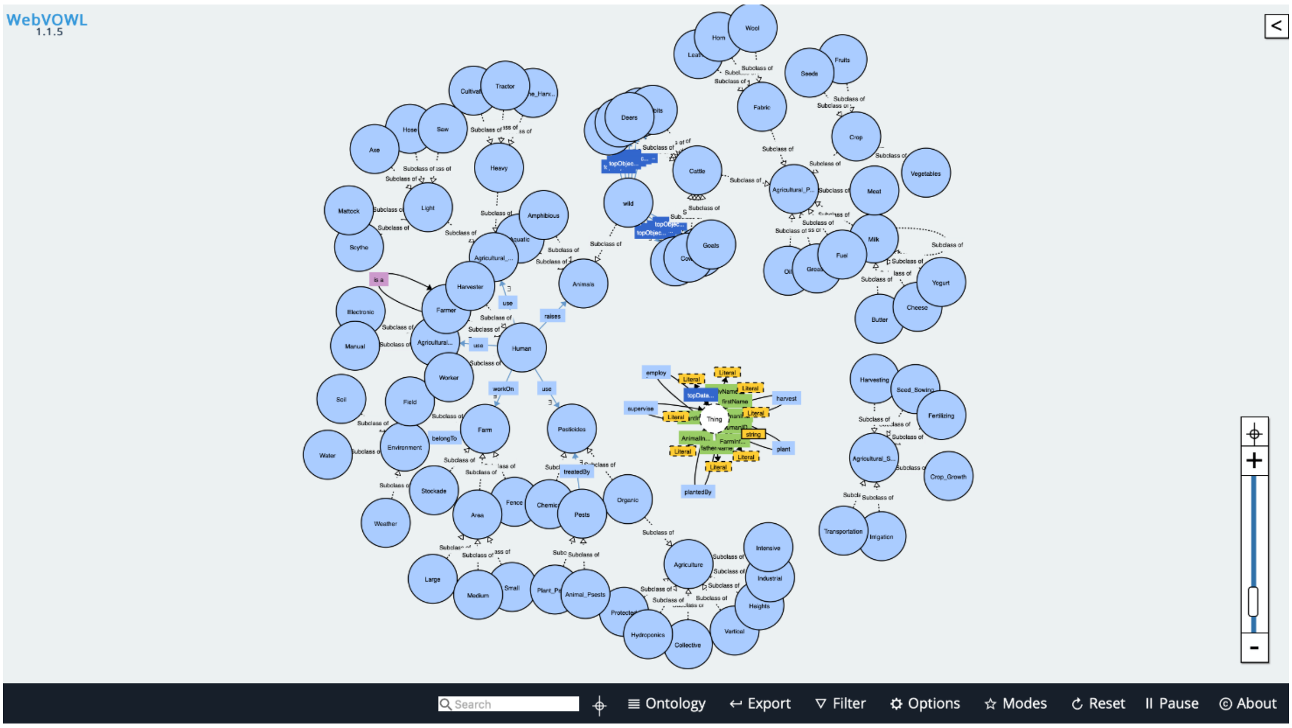
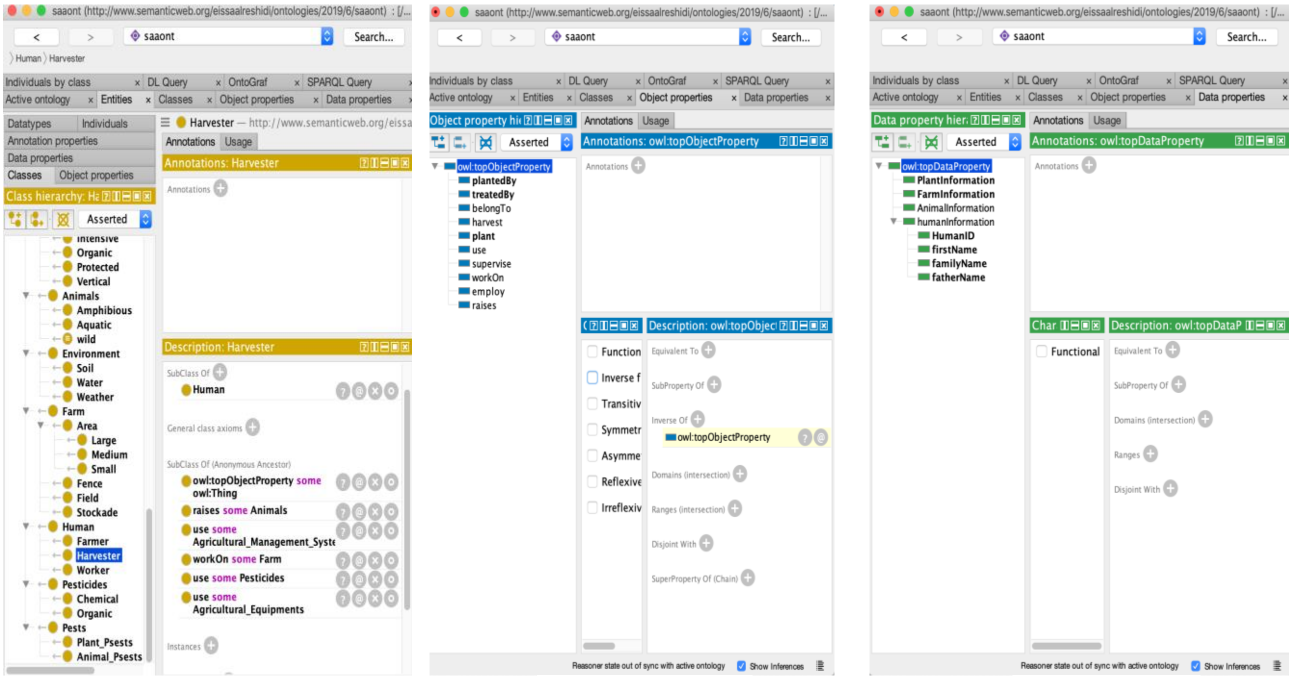


Fig. 4: Overall initial classes and relationships of SAAONT

Fig. 5 shows screenshots of examples of classes, object properties, data properties, and individuals in SAAONT. The SAAONT was implemented with: 217 axioms; eighty-four classes; ninety-one relationships; twelve object properties; nine data properties; and one individual. The intimal tests have been carried out using the HermiT OWL reasoner for the early stages of development. The reasoner can use classes, relationship hierarchies and conditions to check whether each class contains any errors, in which case it will be declared inconsistent with the ontology. It permits integration with external applications to access and retrieve knowledge base concepts from SAAONT. This forms the core level of the SAAONT ontology, as it also employs sub-relevant domains, i.e., IoT classes and business processes classes.



Classes Hierarchy Objects Properties Data Properties

Fig. 5: Examples of classes, object properties, data properties and individuals in SAAONT

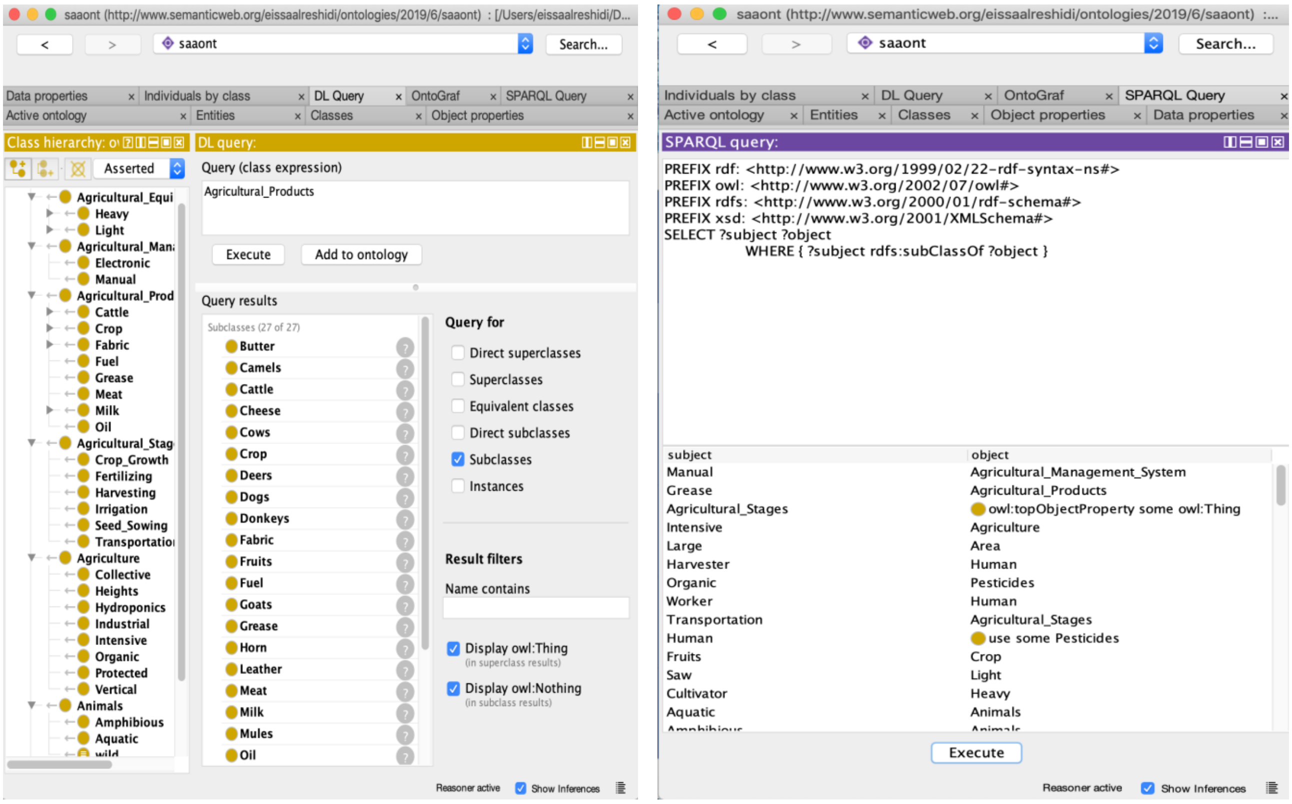
4.3. Obtaining results from SAAONT using DL query

Once the SAAONT is created, results can be obtained from its knowledge base. This commences with running the HermiT OWL Reasoner to validate the SAAONT ontology and check the consistency of its classes and relationships. It is then possible to generate queries using DL-Query, obtaining the outcome from SAAONT. Fig. 6 shows the query results when asking SAAONT questions about farming products, demonstrating that it retrieves all relevant agricultural products, i.e. fibers; rabbits; seeds; and cheese. The built-in DL-query tool within Protégé provides several filter options to include or exclude the following: (1) direct super classes; (2) super classes; (3) equivalent classes; (4) subclasses; and (5) instances. Fig. 6 also demonstrates that it is possible to run SPARQL queries and retrieve information from SAAONT. However, it should be noted that SAAONT is currently still in the early stages of performing detailed queries and giving accurate results.

4.4. Opportunities and challenges

This section discusses challenges encountered during the creation of SAAONT and highlights opportunities for ontological development in the Arabian agricultural domain. During the building of SAAONT, a number of challenges suggested reasons for the previous low levels of Arabic research, i.e. the lack of technological support and adequate resources. This current research complements the outcomes of Al-Khalifa and Al-Wabil (2007), Albarghothi et al. (2017) and AlAgha and Abu-Taha (2015) identifying the following main challenges. Firstly, there is inadequate support for the Arabic language in existing semantic web tools, as well as a shortage of Arabic semantic web applications. There are a number of words with similar meanings that can be written with different letters and formats, sometimes originating from the same word root. Arabic letters can be written in different styles. A user query can contain synonyms of a word, but not the exact terms used in the ontology, resulting in differences between a user's terminology and the ontological terminology. This is due to the current limited research and development in the field of Arabic Semantic Web technologies.

Computational processing of Arabic text differs from its English counterpart, leading to the need to develop controlled vocabularies and ontologies to explicitly define machine-process able semantics. Arabic encompasses more complex morphological, grammatical and semantic aspects than those existing in the NLP algorithms used for English and which therefore cannot be directly re-purposed. One of the main challenges faced during the development of SAAONT ontology concerns writing and processing queries made in Arabic. This requires the integration of developed Arabic solutions, such as programming languages API and scripts (i.e., Python and Java) before building a SPARQL query in Arabic. In addition, several issues have been found with the Protégé tool, due to it being insufficiently flexible to update classes or properties, with an impact on data correctness. Furthermore, a considerable amount of time is required to add, edit and delete classes in SAAONT, thus generating the potential for errors.



(a) DL-Query (b) SPARQL

Fig. 6: Running inquiries and obtaining results from SAAONT using DL-Query and SPARQL

However, once the above challenges have been resolved, there are a number of opportunities to further enhance SAAONT, thus enriching the Arabic Ontological Dictionary by expanding existing Arabic Ontologies from an agricultural perspective. This would mitigate the gap between different terminologies resulting from the existence of little previous work on Arabic vocabularies, i.e., Arabic WordNet (Black et al., 2006). In addition, it would establish a lexical database for the agricultural sector in the Arabic language, one that can be re-used and integrated with other Arabic ontologies. SAAONT provides rich opportunities for Arabic language users to contribute to building a knowledge base for the agriculture sector in Arabian regions, as well as linking their contribution to emerging Arabic ontology repositories. The SAAONT project provides end-users (i.e., farmers and developers) with a shared framework with which to integrate and develop new real-world concepts, meanings, and values, alongside improving the existing Arabic repositories. The current rapid improvement in the development and sharing of knowledge bases in many domains (including agriculture, government, and farming) has resulted in organizations gradually switching to knowledge management as an effective method of obtaining improved and high-quality products. It should be noted that, as the Saudi Arabian government enters the age of e-government, e-commerce, e-health, and e-agriculture (along with the creation and sharing of ontologies and knowledge bases), it is vital to ensure that data can be presented in Arabic.

5. Conclusion and future work

This paper has addressed the fact that most current agricultural ontologies are unique and contain various advantages, but also that they have a number of limitations, primarily due to supporting multiple languages but with little recognition of Arabic. It has discussed how SAAONT ontology provides a knowledge base for Arabic concepts of terms related to agriculture and the lifecycle of seeds, grains, transportation, storage, and consumption. It identified that semantics determines that SAAONT is based on terms found in the classified domain, along with definitions based on descriptions in the ontology. Further development of the ontology would, therefore, ensure that Saudi Arabia develops a smart sustainable economy, due to the ability of knowledge-based systems to provide key players with the required information in a way that is convenient and easy to understand. This study recommends Protégé to define complex ontology, due to the interfaces enabling the definition of classes, individuals, properties and relationships, thus saving time when developing an effective ontology.

This study concludes that the current stage of SAAONT requires further development to demonstrate that the proposed system is capable of operating in complex areas and handling large data sets, while also competing with similar systems. Therefore, future work should involve: (a) further enrichment of the knowledge of SAAONT classes, properties, and individuals, as well as the relationship between classes; (b) opening the ontology for contributions from stakeholders when testing and validating the developed SAAONT; (c) establishing a web-based server to host a user-friendly graphical interface to facilitate interaction with SAAONT ontology; and (d) build and test an easy-to-use query system to access and retrieve information from the developed SAAONT knowledge-based system.

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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