Development of Administrative Processes Ontology: A Case Study of Postgraduate Education Domain

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ABSTRACT
Administration is an important aspect of almost all organisations and directly impacts productivity and efficiency. Hence, applying ontology to administrative domain's processes is essential. This research is focused on creating an administrative ontology and testing the correctness of its processes by using the Postgraduate College of the University of Ibadan as a case study. The domain knowledge was collected using data gathering techniques such as unstructured interview, direct observation, data from trusted sources, existing information system and literature review as a source of data. Relevant knowledge was extracted, refined, and eventually formalized using Description logics. The formalized knowledge was encoded into Web Ontology Language (OWL) format using Protege 5.5.0. The ontology was then tested with 50 competency questions for correctness with SPARQL and DL queries supported by ELK reasoner. Domain knowledge gathered consists of 207 facts, 70 constraints, 84 definitions and 305 initial concepts. 400 formalized expressions were produced from the formalization stage. An OWL file of 8047 lines was generated for the administrative ontology consisting of 1868 axioms (1203 logical axioms, 661 declaration axioms and 4 annotation axioms). The ontology output also consists of 347 classes, 182 Object properties, 28 data properties and 106 individuals. Finally, the competency questions and the answers exhibited 98% similarities when compared with the raw knowledge. This research provides a standardized and reusable knowledge structure for the administrative domain. It also sets the pace for extending the ontology to another peculiar administrative domain other than the Postgraduate College. Finally, the ontology developed can serve as knowledge base to be plugged into administrative applications.

General Terms
Knowledge representation, Ontology.

Keywords
Digital administration, Ontology, Protégé, Web ontology language (owl).

1. INTRODUCTION
The management and implementation of processes within an organisation are crucial aspects of its administration. The key role of administration is to guarantee the efficient performance of all departments within the organisation. This implies that there is a direct link between the administration of an organisation and its productivity. Undoubtedly, technology has brought about significant changes in the way processes occur within establishments (Wayne and Ramiro, 2016). In fact, technology serves as a relevant factor in assisting organisations to adopt new methods that contribute to organisational growth (Mgunda, 2019).

To effectively and consistently utilize the required knowledge to solve problems within an organisation, implicit representations of knowledge play a crucial role (Ayorinde and Akinkunmi, 2019). Artificial intelligence utilizes ontology as a method of knowledge representation to structurally formalize domain knowledge and eliminate ambiguity (Nicola et al., 2009). Specifically, ontology refers to the explicit formal specifications of terms within a domain and the relationships between them (Noy and McGuiness, 2001). Ontology facilitates the semantic web, where web-based information possesses meaningful constructs (Hector and Ugarte, 2017). Thus, the utilization of ontology to represent administrative knowledge is essential for achieving efficiency.

Effective knowledge representation can also be linked to the emergence of the semantic web. A semantic web is a web of meaning, a structured web where meta tags describe data, information, relationships, and connections. Tim Bernes Lee hoped that the semantic web will elevate from web of document to web of data such that standards are defined for data exchange (Hector and Ugarte, 2017). Semantic web is truly a dream and even though the realisation is not yet near, the idea that the internet can become a place where machines solely talk to each other without interference of human is something that cannot be deemed impossible. With the advent of ontology, we can represent knowledge about a domain and represent it in such a way that machines can understand, thereby resulting in the explicit definition of domain terms, activities, knowledge sharing and reuse. Kumar and Dwivedi, 2015 attempted a knowledge base for the University, however the ontology was not in-depth, competency questions were not used for validation and there were very few actual administrative concepts explored.

At present, there is a lack of a comprehensive ontology that accurately captures and explicitly represents the operations within the administrative channel of structured establishments. The purpose of this research is to address this gap by developing a comprehensive ontology for the Administration Domain, with a specific focus on the Postgraduate Education Setting as a case study. The objective is to create an ontology that ensures a high level of clarity and eliminates misconceptions as well as testing the ontology for correctness. This research holds significant importance as it establishes a standardized and reusable knowledge blueprint for administrative systems. By developing this ontology, it provides a solid foundation for understanding and structuring the administrative processes within the Postgraduate College and can serve as a valuable resource for other similar educational institutions.

2. REVIEW OF RELATED WORKS
Knowledge representation is essential for clarifying structural definition to achieve next generation information systems.

According to Tim Berners-Lee, the Semantic Web is not a distinct entity but rather an extension of the existing web. It aims to provide information with clear and precise meaning, facilitating effective collaboration between computers and people (Berners-Lee, Hendler et al., 2001). The future generation of the web will merge current web technologies with formal methods of knowledge representation (Grau, 2004). This integration will enable more intelligent and efficient web-based interactions, allowing for enhanced sharing, organisation, and utilization of information on a broader scale.

The problem of knowledge representation is a fundamental challenge in the field of artificial intelligence (Mahalakshmi & TV Geetha, 2009). It involves finding ways to represent information about the world in a format that computer systems can utilize to perform complex tasks, such as diagnosing medical conditions or engaging in natural language conversations. Knowledge representation and reasoning are crucial for enabling computers to understand and process information effectively. The representation of knowledge determines how it can be utilized, and the methods of reasoning allow computers to derive new knowledge or make logical inferences based on the available information.

Addressing the issue of knowledge representation is essential in achieving the goals of artificial intelligence. How information is communicated and represented significantly impacts how it is understood and used by computer systems. Therefore, careful attention must be given to the models or languages employed for representing knowledge to facilitate accurate and effective processing and reasoning. Over the years, the concept of knowledge engineering has undergone significant changes. Initially, knowledge engineering focused on constructing knowledge systems for problem-solving tasks. However, in recent times, knowledge engineering has expanded to incorporate knowledge from multiple sources (Schreiber and Aroyo, 2008). This expansion has transformed knowledge engineering into a more complex and challenging task, contributing to the development of the semantic web as we know it today.

Knowledge reasoning is a crucial aspect that comes into play once an intelligent system has been built. It involves establishing and verifying the primary objective of an artificial intelligent system, which is to emulate human thinking abilities. Therefore, it is essential for any intelligent system to possess reasoning capabilities. Reasoning is an abstract concept, and its effectiveness is reflected in the system's ability to make decisions, draw inferences, and reach conclusions. These decisions, inferences, and conclusions must be based on the knowledge used to construct the system; otherwise, the system's reasoning would be flawed. Any logical deduction that relies on a formal ontology is considered reasoning (Oberle, 2014).

Some specific research in recent times that have attempted and contributed to the field of ontology as it pertains to governance and other related domain includes:

2.1 Conceptual linked data model for South African municipalities public services domain (Gerald and Moyo, 2023)

In recent times, governance has evolved into electronic government (eGov) which makes information communication and sharing a lot easier. The establishment of standards is necessary for this electronic governance if various parts of the government will work seamlessly together in this eGov. Research was carried out on South African municipalities and their public services (Gerald and Moyo, 2023). Unified Modelling Language was used to model the services while ontology development approaches were used to create an ontology in form of a web ontology file (owl) and Protégé tool.

2.2 Ontology construction of city hotline service for urban grassroots governance (Chen et al, 2022)

This research investigates the hotline service for governance in urban grassroots. An ontology was built to provide a structure framework for the domain using TOVE methodology (Chen et al, 2022). All necessary and detailed concepts were defined and Protégé tool was used to create city hotline service ontology. Ontology was tested in various hotline scenarios in relation to urban grassroots governance. The testing findings show that the ontology is beneficial and practical for satisfying the needs of hotline services in urban grassroots government. The efficiency and effectiveness of city hotline services can be increased by employing this ontology, eventually benefiting the urban community.

2.3 An ontology for Chinese government archives knowledge representation and reasoning (Wang et al, 2021)

This research emphasizes the importance of government archives as valuable resources for economic development, social operations, and strategy. Poor knowledge management technology inhibits the sharing and re-use of these valuable resources that are locked within the archive. To solve the problem, this paper proposed the creation of Chinese Government Archive Ontology (GAO) which made use of the theories and methods of the semantic web (Wang et al, 2021). The research also demonstrated the practical applicability of GAO through examples such as SPARQL queries and event logical representation based on the 5W1H (Who, What, When, Where, Why, How) framework.

2.4 Building Alumni ontology to bridge industry- institute gap using protégé 5.5 (Kakad and Dhage, 2021)

This research focuses on the enhancement of the education system through alumni involvement. The alumni is non-academic stakeholders, but they also contribute to the education system through expert lectures, workshops, and conferences based on their experiences. This knowledge was used to create an alumni ontology which also serve as a bridge to narrow the gap between the industry and academic institutions. The ontology development approach made use of DL (Description Logic) query as well as Protégé tool.

2.5 Semantic-based e-government framework based on domain ontologies: a case of Kuwait region (Alazemi et al, 2018)

E-government faces challenges in integrating information systems and representing data across different organisations. Semantic Web technologies based on ontologies offer promising solutions to these problems. This research proposes a semantic-based framework for e-government and introduces the Protégé platform for ontology development (Alazemi et al, 2018). Author presented ontological models for the Kuwait Education Ministry and Medicine Ministry domains using the Web Ontology Language (OWL). The framework and ontologies contribute to the semantic integration of e-government and facilitate the development of semantic web applications.

3. METHODOLOGY

Figure 1 shows the overall system architecture of the administrative processes ontology development. It illustrates the knowledge gathering stage through data gathering techniques which produces administrative domain knowledge. The useful knowledge is extracted from the data gathered and formalized using description logic approach and symbols. The formalized knowledge is then used for editing the ontology using Protégé tool. The ontology is generated in the form of Web Ontology Language (OWL) and in the presence of an inference engine, it is tested for correctness using competency questions.

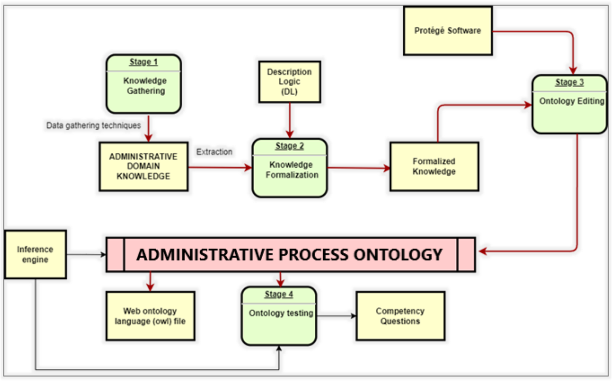

Figure 1: Overall methodology for the administrative processes' ontology development

To achieve the purpose of this research, it is important to understand the end goal, which is the creation of a knowledge-based system that is compatible with the administrative domain of a typical organisation. An intelligent system is a system that mimics human behavior. Since the inherent property that makes a human intelligent is the possession of knowledge, it is therefore pertinent that knowledge be formatted in such a way that would be understood by computer systems. In this case, the knowledge is in the form of an ontology, and it is based on the postgraduate administration domain specifically.

The idea is to standardize terms and procedures in the domain explicitly, all other knowledge can then be reasoned, and implicit knowledge can be inferred. This process can simply be likened to creating a robot, except in this case, multiple entities and tasks are considered, whereas a lot of robots are created to perform specific tasks, this ontology covers a range of activities within the domain.

3.1 KNOWLEDGE GATHERING, EXTRACTION AND REFINING

The various knowledge gathering involved in this research was targeted at non-numerical data and achieved through various techniques such as:

Unstructured interview: Unstructured interviews gathered flexible data from organisation's stakeholders for the ontology, aiming for broader applicability. Interviews were conducted at different times to understand organisational operations, excluding specific details for ethics and security reasons.

Direct observation of domain: During the research, direct observation was applied to collect domain knowledge. Participants and organisational operations were observed for interactions, processes, and behaviors as they occur to gather knowledge. Coincidentally, one of the researchers was under official assignment within some units of the environment of the case study at the beginning of the research work. This gave ample opportunity for effective observation and recording of data.

Data from trusted source: Another helpful data collection point for this research is the data gotten from trusted sources. In this case, the website of the case organisation provided certain knowledge about the domain. Although, majority of the data available on the website were specific to the organisation, however, data was filtered to extract only generalized information and to avoid violating individual privacy. In other words, personal information was exempted from the collected data. Focus was given to the organisational structure in this regard.

Existing information system: There is an existing information system that handles certain processes within the case study, which is in the form of a centralized portal. In as much as this work is not directly interested in developing or improving the current information system, the current information system however was able to provide an insight into some of the activities that take place within the organisation. The information system is not a complete representation of the entire domain, but it does provide some data that were valuable to the building of the knowledge repository which is vital to the success of this work in the long run.

Literature review as a data source: Literature review has been a huge data source to point this research in the right direction when necessary. Knowledge of current and previous works that have been done in ontology were accessed. Literature review has also helped to access data about attempts that has been made towards the realization of the semantic web. Basically, comparison was done on existing research to discover research gaps. Another area where data gotten from literature review has been helpful to this research work is that it has helped to mitigate errors that were made in previous research. Useful knowledge was further extracted from the complete data gathered for further structuring. This is a fusion of the various data collection approaches that has been mentioned.

Once the knowledge extraction phase was done, the extracted knowledge was refined for further structuring. This was the commencement of the knowledge modelling stage, and the acquired knowledge was still in its raw form. This can be easily understood by humans but is of little or no understanding to intelligent systems until the facts were transformed into classes or what is known as hierarchy so that there can be some form of structure. The properties which connect the concepts were also defined while individual concepts were separated. Some samples of refined knowledge are represented in Table 1.

Table 1: Fragmented Samples of refined knowledge

S/N	Knowledge concept type	Fragment Sample(s)
1	Class/Hierarchy	Person (employee (head of department, department worker), student (applicant student, registered student)) etc.
2	Properties/Relationship	responsibility of, maintains payment, maintains records, has employee etc.

S/N	Knowledge concept type	Fragment Sample(s)
3	Individuals	University of Ibadan, Mr. X, Professor John Doe etc.

3.2 KNOWLEDGE FORMALIZATION

Although the data has moved a little higher from the raw form, it is still in a form that cannot be clearly differentiated contextually from each other. The only difference is that they have been broken down and placed into different categories of classes, properties, and individuals. Now, with the help of description logics, mathematical notations were used to represent them and convey their meanings. These mathematical notations are simply logical symbols. Samples of formalized knowledge can be seen below:

- ✓ $University \equiv CentralUniversity$
- ✓ $ContractStaff \sqsubseteq Staff$
- ✓ $RecordOffice \equiv Office \sqcap isPlaceOf.RecordOperation$
- ✓ $Form \equiv PaperForm \sqcup DigitalForm$
- ✓ $OngoingActivity \equiv Activity \sqcap \neg(reaches.EndGoal)$

3.3 ONTOLOGY EDITING

It is no news that the computer system only understands low level language. The more an expression tends towards the low-level language, the more probable it is that the computer understands it. As much as the description logic contains mathematical notations, it is still required to encode those notations into an Extensible Markup Language (XML) format that will make it suitable for parsing when accessed by machines. The web ontology language is the extension of resource description framework (RDF) which makes it represent data in a linked format. Therefore, the web ontology language is used for this purpose. Some of the representations in web ontology language (OWL) are illustrated below:

Class hierarchy e.g.:

```
<SubClassOf>
    <Class IRI="#PaymentRecord"/>
    <Class IRI="#OfficialRecord">
</SubClassOf>
```

Relationship declaration e.g.:

```
<SubObjectPropertyOf>
    <ObjectProperty
IRI="#maintainsPaymentRecord"/>
    <ObjectProperty
abbreviatedIRI="owl:topObjectProperty"/>
</SubObjectPropertyOf>
```

Data property declaration e.g.:

```
<Declaration>
    <DataProperty IRI="#employeeID"/>
</Declaration>
```

Simple statement (Domain-range representation) e.g.:

```
<ObjectPropertyDomain>
    <ObjectProperty
IRI="#isResponsibilityOf"/>
    <Class IRI="#StudentAdmission"/>
</ObjectPropertyDomain>
<ObjectPropertyRange>
    <ObjectProperty
IRI="#isResponsibilityOf"/>
    <Class IRI="#AdministrativeBranch"/>
</ObjectPropertyRange>
```

Complex statements e.g.:

```
<EquivalentClasses>
    <Class IRI="#AdministrativeStaff"/>
        <ObjectIntersectionOf>
            <Class IRI="#Staff"/>
            <ObjectMaxCardinality
cardinality="1">
                <ObjectProperty
IRI="#canBelongTo"/>
                <Class IRI="#Department"/>
            </ObjectMaxCardinality>
        </ObjectIntersectionOf>
</EquivalentClasses>
```

Protégé is an ontology editing tool that provides a graphic user interface (GUI) for creating ontologies. Thus, the OWL file can be generated and modified easily by adding new, updating, and deleting concepts with Protégé tool. It also supports ontology visualization. The version of Protégé used was 5.5.0.

3.4 ONTOLOGY TESTING

One of the ways of testing the administrative ontology is the test for consistency and contradiction. This is done using reasoners. Reasoners are plugins for protégé tool that have reasoning capabilities, automated reasoning algorithms and techniques to perform logical inference and consistency checking on ontologies. The ELK reasoner is used for this purpose in this research. The ELK reasoner helps in detecting logical contradictions and inconsistencies within the administrative ontology's axioms. Thereby helping to identify and resolve conflicts or errors in the ontology design.

Another important way of testing for the correctness of this ontology is the use of competency questions. Competency questions are formulated during the ontology development process. These questions touch the various areas of the administrative domain. Afterwards, on the completion of the ontology, these questions are converted into Description logic (DL) and SPARQL queries and then used to probe the ontology. The answers received from the competency questions are compared to the actual knowledge to check for correctness. The competency questions formulated for testing the administrative processes ontology are seen in below:

i. What are the various sections within the Postgraduate Administrative system?
ii. List out all invoices waiting for payment by Postgraduate students in the Computer Science Department
iii. Show a trail of Document RQ8765541
iv. Who is the Head of the Department of Computer Science?
v. Who is the Postgraduate Coordinator of the Department of Economics?

4. IMPLEMENTATION AND DISCUSSION OF RESULTS

4.1 KNOWLEDGE COMPILATION

The knowledge collected during the knowledge gathering stage is divided into different categories and the output are seen in.

This was compiled into a word editing application in the form of textual data. The compiled knowledge were extended into formalized versions. This was also compiled in textual data but with the inclusion of special logical symbols, this makes the compiled formalized knowledge look very much like mathematical equations.

4.2 ONTOLOGY AUTHORING

The ontology is edited with Protégé 5.5.0, an ontology editing software. The software was run on Windows Operating system, 64 bits, 32GB RAM.

4.2.1 CLASS IMPLEMENTATION

Some of the classes in the domain are Payment, Operation, location, Message, LetterSubject, Goal, Information, Office, Report, Publicinformation, Process, Person, Signature, Stakeholder, Status, Studyime, Task, UniversityBranch and Institution among others.

4.2.2 OBJECT PROPERTY IMPLEMENTATION

Some of the object properties belonging to Administration domain are actionCoordinatedBy, activityManagedBy, addressedTo, affairDirectedBy, assignsTaskTo, assists, assistIn, belongsTo, consistsOf, containsData, coordinates, collaboratesWith and awardsAdvancedDegreeTo among others.

4.2.3 DATA PROPERTY IMPLEMENTATION

The data properties belonging to the Administration domain are activity_status, current_location, ate, date_received, department_name, description, document_id, event_description, event_id, startTime, status, student_issued, terminationTime and title mong others.

4.2.4 AXIOMS IMPLEMENTATION

These are the axiom representations in the Administration domain as seen in Figure 2.

4.3 ONTOLOGY METRICS

These are the values of each of the representations mentioned above. It is a summary of the entire ontology of the administrative processes domain as seen in Figure 3.

4.4 COMPETENCY QUESTION

These are the competency questions implemented into DL and SPARQL queries together with respective results.

Competency question 1: What are the various sections within the administrative system?

Query and answer 1: The query and answer to the above is seen in Figure 4.

Competency question 2: What is the Current Location of Document RQ101123?

Query and answer 2: The query and answer to the above is seen in Figure 5.

Competency question 3: Show a trail of Document RQ8765541

Query and answer 3: The query and answer to the above is seen in Figure 6.

Competency question 4: What are the different types of Documents defined within the Administration Ontology?

Query and answer 4: The query and answer to the above is seen in Figure 7.

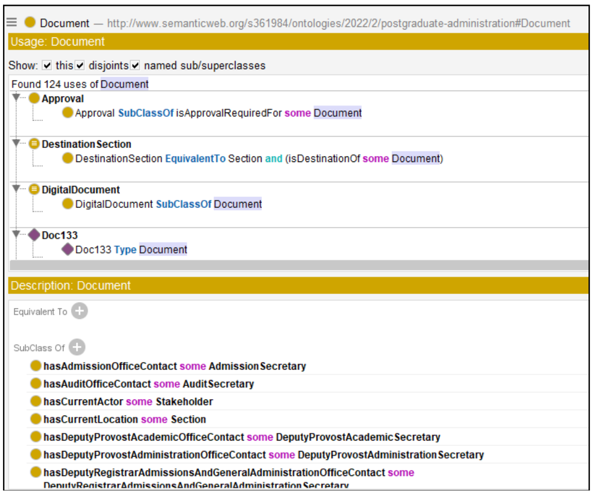

Figure 2: Document description and axiom implementation

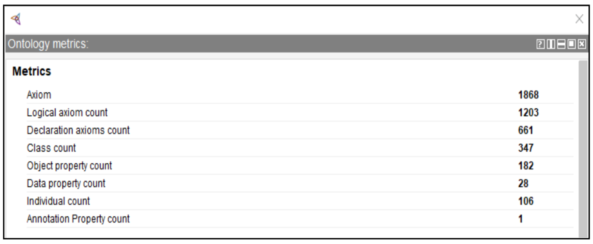

Figure 3: Ontology metrics

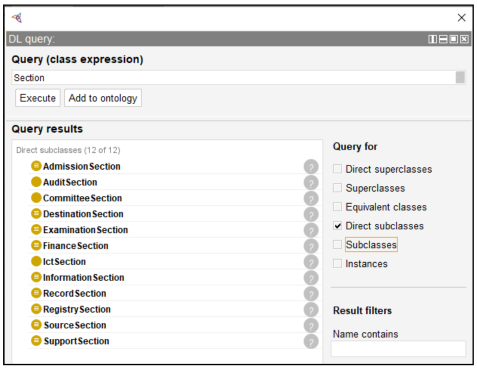

Figure 4: Competency question and answer 1 using DL query

Competency question 5: What is/are the documents involved in Event EV76542637?

Query and answer 5: The query and answer to the above is seen in Figure 8.

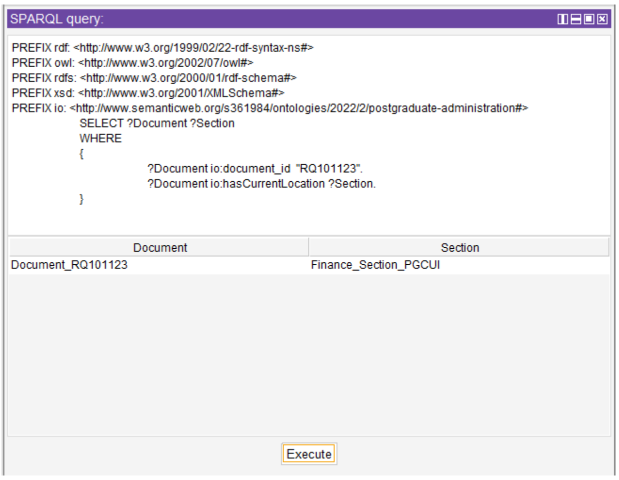

Figure 5: Competency question and answer 2 using SPARQL query.

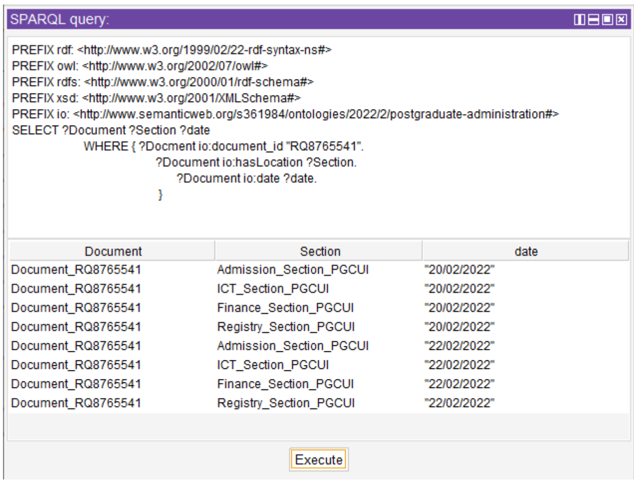

Figure 6: Competency question and answer 3 using SPARQL query.

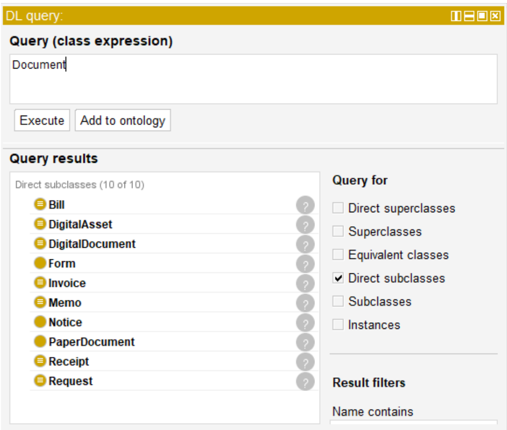

Figure 7: Competency question and answer 4 using DL query.

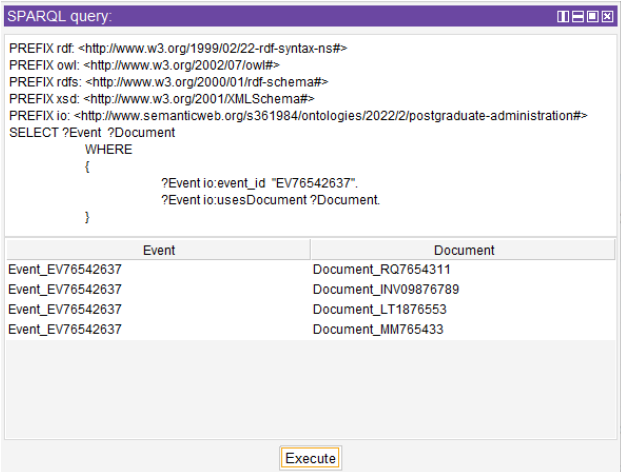

Figure 8: Competency question and answer 5 using SPARQL query

5. DISCUSSION OF RESULTS

This research is focused on formalizing the knowledge in the Administration domain using the Postgraduate College as a reference point for data gathering. Knowledge formalization is conducted after data collection consisting of 207 facts, 70 constraints, 84 definitions and 305 classes. Knowledge formalization, especially the use of description logics formalization is the backbone of many knowledge representation task and has been established by previous research works in areas such as information retrieval (Jiang, 2020), Answer set Programming (Giordano et al, 2021) and knowledge-based augmented reality (Flotynski, 2020). Description logics axioms were created from the Postgraduate administration domain knowledge comprising of facts such as the sectional heads, section names, document types etc, Definitions of concepts and constraints. These axioms show the knowledge about the domain in mathematical forms by using conjunction, disjunction, negation, inclusion, universal restriction, existential restriction etc. The final outputs of this stage are 400 formalized expressions.

The ontology is a set of triples. Some of the class results from the ontology includes Section, Office, Document, Personnel, Approval etc. The class hierarchy shows the relationship between super classes and subclasses such as Person and Employee, respectively. There are Object properties that connect the classes together such as hasOffice, hasDocument. Data properties connects the classes to instances such as name, designation, document_id. There are also individuals or instances, the employee names are not real names but arbitrarily generated names, likewise the document_id. In addition to the class and properties, other outputs at this stage includes the Ontograf and ontology file. This presents the knowledge in graphical forms. The web ontology (owl) file is a source code that can be reused by related domain to build an extending ontology or plugged into administrative applications. The ontology representation mentioned above were supported by Protégé 5.5.0 software. Some known research works have also made use of Protégé 4.1 Beta (Radhika et al , 2019), Protégé 5.0 (Moudoubah et al, 2021 & Ayorinde and Oyedeji, 2019), Protégé 5.5.0-beta-9 (Nandhinidevi et al, 2021) and Protégé 5.0(Kaur and Aggarwal).

The ELK reasoner helped to verify the correctness and consistency of the Ontology. Other reasoners as identified in previous research include Pellet reasoner (Khamparia and Pandey, 2017) HermiT reasoner (Kakad et al, 2022) (Moudoubah et al, 2021). The use of competency questions is a very good approach to evaluating the scope of an ontology. Much research have used competency questions to evaluate their ontology; Munoz et al (2002) made use of 20 competency questions to validate a data governance ontology, Schulze et al (2021) used 15 competency questions to evaluate a Purchase-To-Pay ontology, France-Mensah and O'Brien (2019) made use of 8 competency questions to validate an Integrated Highway Planning Ontology. For the administrative process ontology, 50 competency questions that spans across the Postgraduate administration domain were chosen to probe the ontology. The competency questions are in 5 broad categories namely general information-based competency question, document-based competency question, stakeholder-based competency question, activity-based competency question and event-based competency question. The questions were in plain English but converted to DL and SPARQL Query. Ontology results in the form of query response are seen in figures 4 - 8. The competency questions exhibit a similarity of around 98% with the initial raw data that was collected. This shows that ontology is quite correct and can draw explicit conclusions i.e., give plain responses based on prior data. In addition, some of the competency questions requires implicit answers, this requires the ontology to make some sort of logical reasoning, the competency answer shows that the answer is accurate.

6. CONCLUSION

This study delves into a comprehensive examination of addressing the issue of non-clarity and misconception within the administrative sphere. The primary objective is to develop an ontology specifically tailored for this purpose. The key goals of the research encompass constructing an ontology for the administrative processes of the postgraduate education domain and assessing its accuracy. Data was collected from the Postgraduate College at the University of Ibadan. The ontology was created employing description logics, web ontology language (OWL), and the Protege tool. Subsequently, a diverse set of competency questions was employed to evaluate the ontology. Moreover, the study recognizes its limitations, being confined to the administrative aspect of the postgraduate domain, thus opening doors for future research and improvement in other domains.

This study concentrates on utilizing ontology for standardizing processes. The formalized knowledge encompasses the everyday activities and existing concepts within the Postgraduate Administration Domain, aiming to address misconceptions surrounding specific processes. Its primary function is to provide clarity to all system stakeholders, particularly those new to the system. The competency questions used to validate the ontology span various aspects of the domain, thereby affirming its robustness in capturing all crucial areas.

The knowledge compiled, processed, and explored in this research plays a significant role in the works of knowledge engineering researchers, particularly those interested in the rapidly advancing field of ontology in computer science. In essence, this research contributes to the broader domain of artificial intelligence, striving to inspire further research, foster discussions, and encourage innovation within the computer science community.

For future endeavors, it is recommended to expand this ontology to achieve greater generality, enabling the solution to be adapted to organisational settings beyond the postgraduate college.

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