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Compliance Management and Business Processes in Cloud Environments through Ontology utilization

[1]Agbaegbu JohnBosco, [2]Arogundade Oluwasefunmi Tale, [2]Olaniyi Aborisade Dada & [2]Akinwale Adio Taofeek
[1]Department of Mathematical Sciences, Augustine University Ilara, Epe, Lagos state, Nigeria;
[2]Department of Computer Science, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria;
E-mails: johnbosco.agbaegbu@augustineuniversity.edu.ng; arogundadeot@funaab.edu.ng; aborisadeda@funaab.edu.ng: akinwaleat@funaab.edu.ng

ABSTRACT

The integration of the Internet of Things (IoT) and cloud computing has revolutionized various industries, offering unprecedented opportunities for businesses. However, this convergence has also brought forth challenges in managing compliance and optimizing business processes effectively. In this paper, we propose a methodology to address the issues of cloud compliance to regulatory standards, by leveraging the power of ontology in cloud-based IoT environments. BPMN Model of Cloud compliance requirements is developed with an integrated ontological repository integrating business, regulatory and domain information on various levels of perception that offers a shared abstraction of the associated compliance and business essentials.

Keywords: IoT, Compliance, Management, Business Processes, Cloud Environments, Ontology

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1. INTRODUCTION

In the context of cloud-based services for business operations, compliance business processes involve ensuring adherence to regulatory requirements and security standards (Mustapha et al, 2020). Typically, businesses must prioritize cloud compliance as a fundamental aspect to guarantee adherence to regulatory mandates and safeguard the integrity of their data and systems. Adhering to compliance standards is of utmost importance for businesses to ensure they meet the necessary regulatory prerequisites (Seddon et al, 2013). Some of the popular compliance standards for cloud-based services include the General Data Protection Regulation (GDPR), Payment Card Industry Data Security Standard (PCI-DSS), and Health Insurance Portability and Accountability Act (HIPAA).

1.1 Ontology

The word ontology was first used in philosophy and later implemented by the Artificial Intelligence society to formally define knowledge domains. Over the years there has been multitude of definitions (Bravo et al, 2019). Even then, Gruber had defined ontology as an explicit specification of a shared conceptualization (Gruber, 1995). Ontology is an influential tool for improved compliance management and business process in cloud settings. Ontology is a formal representation of knowledge that defines the concepts and relationships in a specific domain. In the framework of compliance management and business processes, ontology can support establishments to describe and appreciate the rules, regulations, and processes that oversee their operations.

Cloud computing enables the delivery of computing services and resources as utility-like services through a network (Elgammal & Turetken, 2015). In cloud computing environments, ontology-based approaches can be particularly useful for managing compliance requirements and business processes across multiple domains and applications. The rules described as compliance requirements are the objectives organizations strive to achieve in their determinations to confirm they are mindful and prepared to observe relevant laws and regulations (Arogundade et al, 2014). Overall, this paper provides insights into how ontology can be used to enhance compliance management and business process in cloud environments, offering a promising solution to the complex challenges of regulatory compliance in the cloud.

According to (Mell & Grance,2011), the cloud computing settings have five significant features that differentiates it from the other technologies and makes it useful to clients, these are as follows:

i) On-demand self-service: This refers to the ability of users to provision computing resources (e.g., virtual machines, storage, etc.) as needed, without requiring human intervention from the service provider.

ii) Broadband access: This is a high-speed internet connection that enables users to access cloud services and resources from various locations.

iii) Resource pooling: It involves the provider's computing resources being pooled together and dynamically allocated to multiple users based on demand. Users share these resources while remaining isolated from each other.

iv) Rapid elasticity: Cloud services can quickly and automatically scale up or down in response to changing workload demands, allowing users to easily adjust resources as needed.

v) Metering capabilities: Providers can measure and monitor resource usage, allowing users to be billed based on their actual consumption of resources, similar to utility billing models.

2. LITERATURE REVIEW

Cloud computing (CC) has gained significant popularity due to its benefits in terms of scalability, cost-effectiveness, and flexibility. However, the adoption of cloud computing also introduces new challenges related to compliance management and business process management (BPM) in cloud environments. It is affected by heterogeneity challenges. As such, cloud services have many challenges to resolve, such as conflicts arising from limited knowledge about cloud resources and service description, security, interoperability, service discovery, and selection (Agbaegbu et al, 2021).

According to Amini and Jahanbakhsh (2023), cloud computing is a state-of-the-art computing platform acting as a leverage for all its stakeholders. It is a clear departure from previous editions in so many ways. It grants admission to and use of the greatest tool without initial payment.

Di Martino et al, (2023), developed a methodology that uses the semantic notation of business process management which relies on domain ontologies with an implementation approach known as SemPreAnn, it also analyzes compliance to purposes and other regulatory apprehensions.
The study by Zhou et al. (2021), used their ontology model for both resource transportation and activity information, they also proposed a medical transportation resource discovery approach together with resource matching and guidelines.

In their publication titled "FIPA-based Reference Architecture for Efficient Discovery and Selection of Appropriate Cloud Service Using Cloud Ontology," Abbas et al. (2020) introduced a designed IEEE multi-agent foundation known as Intelligent Physical Agent (FIPA). This compliance model serves as a referencing cloud discovery and selection technique based on cloud ontology.

Lassila and McGuinness (2001) sees ontology as an asset, it is an explicit requirement of a conceptualization: determined and logical terminology, it does not include ambiguous clarification of classes and relations between terms. According to Corea and Delfmann (2017), their study has the capability to investigate business processes for compliance to business rules while relying on an ontology-based framework.

In Deng et al (2019), the researchers provided a framework based on two core ontology modules. called the Catalogue Ontology and Business Process Ontology with an extensive ability for understanding explicit domain ontologies. The catalogue ontology uses the Universal Business Language with relevant industrial standards like FunStep ISO 10303-236 for furniture ontology to express event characteristics as it relates to the several domains. The Business Process Ontology encapsulates machine readable vocabularies for the semantic description of business processes which can also be extended by basically incorporating novel ontologies.

Di Martino et al, (2019) proffered a semantic-based decision support system with the capacity to support stakeholders in the adoption of the resolutions in an e-government-based processes.

3. METHODOLOGY

This research work uses the build and process method; since the research will design a system with procedures to guide the events involved in the system. The study uses the approach according to Tseng et al. (2009). Figure 1 demonstrates the steps within the work flow which include

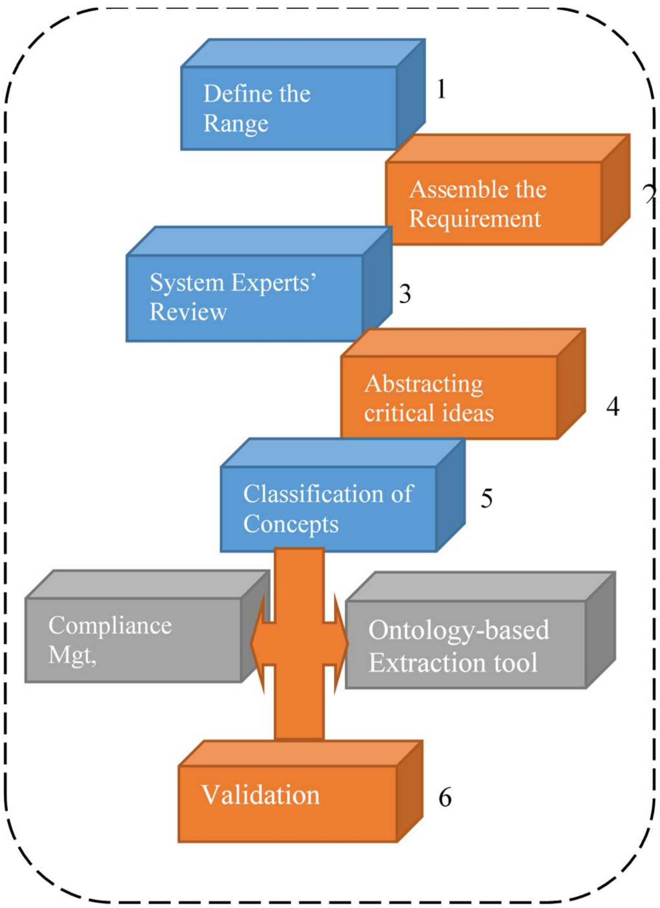


Figure 1: Methodology Process flowchart

3.1 Framework for Computing Research

1. What is our purpose? This enquiry is correlated to step 1 of the process workflows
   a. (How did the study obtain data) – the study acquired needed data for modelling cloud compliant-based business process.
   b. (develop a model) - the study developed a platform that aids stakeholders in managing compliance related issues upsetting cloud business processes while leveraging ontology.

2. Where will data come from? This query is linked to phases 2, 3 and 4 of the process workflow.
   a. (Origin of Data) – this research captured data from regulatory standards with medical bias like the International Classification of Diseases version 11 (ICD-11), HIPAA, GDPR and PCI DSS
   b. (Model and data utilization) – the compliant business process for the cloud was modelled using BPMN2.0, while the ontologically-enabled compliance management model was developed using OWL and protégé 5.5
3. Was the goal achieved? This query is linked to phase 6 in the process workflow
   a. (Draw conclusion) - the researchers having acquired the necessary knowledge, demonstrated a working model. Reference will also be made to comparatively analyze existing methodologies to ascertain strengths and weaknesses.

Proposed Methodology for Ontology Creation

In this section, an all-embracing ontology design is described. The motivation is to assist ontology engineers with enhanced tool to support ontology construction while conforming to evolving standards.

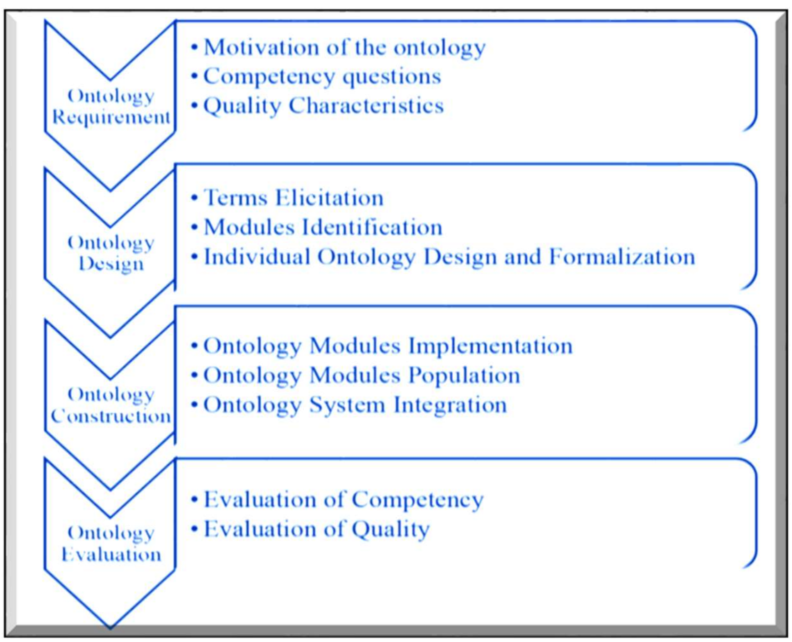


Figure 2: Phases of the proposed ontology (Bravo et al, 2019)

The central attributes of this methodology cover the following headlines:

i. Modular design. Generating modular ontologies is an essential requirement towards ontology reutilization and preservation.

ii. Domain-based. The considered cluster of concepts can be perfected when all domain-related terminologies have been allocated and combined with a class certification.
iii. User- centered procedure and appraisal. The method applies considerable attention to the discrete requirements based on the users experience with respect to the competency questions starting from the beginning to the end.
iv. Incremental refinement. The method is described as a categorization of steps that describes the method for an incremental development.
v. Quality-oriented. Value necessities are set at the foundation of the project; to ensure the quality is maintained throughout execution, they is a resort to the initial specification.

Ontology Requirements Description

The main goal of specifying requirements for the ontology is to outline its scope, define potential scenarios and users, determine the competency of the ontology, and establish the quality characteristics it should possess. Two clear tasks must be performed to achieve this are:

a. Clearly articulate the motivation behind developing the ontology and elaborate on the potential scenarios, users, and applications that will benefit from its implementation.
b. Establish the competency of the ontology through a consensus reached among a group of domain experts. Collaboratively, they will generate a list of competency questions, which are essentially questions they expect the ontology system to be able to answer once it is implemented and operational. The ontology engineer will work closely with the domain experts to produce this list of competency questions, which will also serve as a valuable tool for the final evaluation of the ontology.

Ontology Design

This phase of the methodology focuses on generating a formal design of the ontology, encompassing several steps: term elicitation, identification of ontology modules, individual ontology design, and formalization using Description Logics (DL) notation. Description Logics are formal languages specifically designed for knowledge representation and reasoning, representing decidable fragments of First Order Logic (FOL).

a) Term elicitation involves creating an initial list of relevant terms for the specific domain of knowledge. To accomplish this, the ontology engineer uses a list of competency questions to identify elementary concepts (nouns) necessary for the ontology model.
b) Modules identification entails determining the individual ontologies that will constitute the overall ontology system. To create these ontology modules, the list of terms serves as input, and the ontology engineer, together with domain experts, groups similar terms by clustering them. Each cluster represents a group of domain-related terms and is assigned a singular class identification, resulting in a set of ontology modules. Each group is then converted into a distinct ontology, facilitating reusability for other applications. This process leads to a global scheme of individual ontologies integrated into the system.
c) Formulating and designing individual ontologies involves establishing the fundamental terminological axioms for each ontology using Description Logics (DL). This design process includes the following activities:

i. Definition of hierarchical relationships: For each group of terms belonging to the same ontology, hierarchical relations are defined, allowing for the addition of concepts to the hierarchy as needed.
ii. Definition of data properties relationships: Data properties represent the data attributes of each concept, such as a Person having a name, age, weight, etc.
iii. Definition of object properties relationships: Object property relations connect concepts semantically within an ontology. Unlike data type properties that relate a concept to a data type, object properties relate two concepts. To define these relations within individual ontologies, the knowledge engineer evaluates if there are any semantic connections between concepts.
iv. Axiomatization involves establishing essential criteria that individuals must meet to belong to specific classes or concepts. This process involves formulating various types of axioms, such as class axioms, cover axioms, closure axioms, data, and object property axioms. These axioms enable the precise specification of cardinality restrictions, existential and universal restrictions, as well as value restrictions.

Ontology Creation
The objective of this phase is to program all the ontology modules using a consensus programming language and an appropriate ontology editor. This will enable the study to apply a set of OWL-DL with identifiers and axioms to represent the structure and instances of the ontology.
Below is the axiom for the business process ontology.

Axiom
Business process ontology
$Bussiness\_Process$ ⊆ Medicine
$Bussiness\_Process$ ⊆ Payment
$Bussiness\_Process$ ⊆ Prescription
$Bussiness\_Process$ ⊆ Registration

Domain Ontology Axiom

$Domain\_Ontology$ ⊆ Doctor
$Domain\_Ontology$ ⊆ Patient

Regulatory Ontology Axiom
$Regulatory\_Ontology$ ⊆ Health_Record
$Regulatory\_Ontology$ ⊆ Data_Collection
$Regulatory\_Ontology$ ⊆ Online_transaction
DisjointClasses(a: Bussiness_Process a: Domain_Ontology a: Regulatory_Ontology)

Evaluation
Ontology validation refers to the accurate construction of ontology components, ensuring that the description correctly represents the ontology's requirements and competency questions. Validation relies on the competence of the ontology and quality requirements. The ontology should be reusable, ensuring quality and correctness.

According to Raad and Cruz (2015), two conditions are addressed:

1. Competence of the ontology model: This is based on Gruninger and Fox's (1994) six features for evaluating a business model.
2. Quality requirements: Over the years, researchers have proposed ontology design principles as objective criteria for evaluating ontology models, according to Gruber (1993). The value of an ontology model is assessed by the extent to which it adheres to these standard principles.

Table 1: List of Expressions

Backgrounds	Drug Reaction	Patient	Management
Analysis	Laboratory Analysis	Constraints	important Indicators
Disease	Medicine	Indications	Indications

i. The documentation of modules involves describing separate ontologies that comprise the overall structure of the ontology. To achieve this, it is essential to arrange associated terms using a list as input. This task is carried out by the ontology developer and other experts, resulting in an integrated ontology structure. Figure 2 illustrates the phases of the suggested procedure

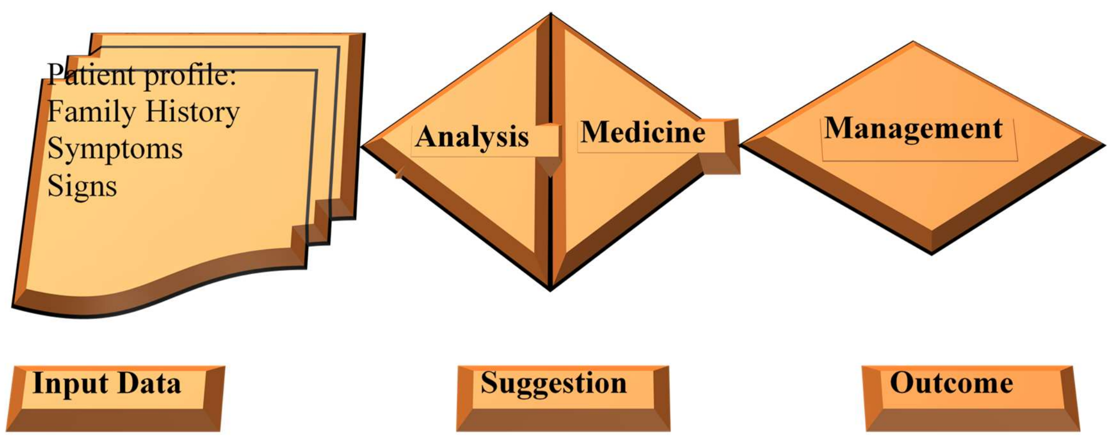


Figure 2: Phases of the proposed procedure

ii. The hierarchy within each distinct ontology module will be officially designed using Description Logic notation. The main concept of the ontology is the:

(a) Medical History, which encompasses hereditary elements, genomic factors, and acquired influences that can contribute to an individual's susceptibility to illness. The 'Medical History' is represented as an entity with a name and can be further elaborated.

The background information is classified into four categories*: Androgenic, FamilyHeritage, Ophthalmology, and Individual*. Figure 3. Shows the class hierarchy of History ontology.

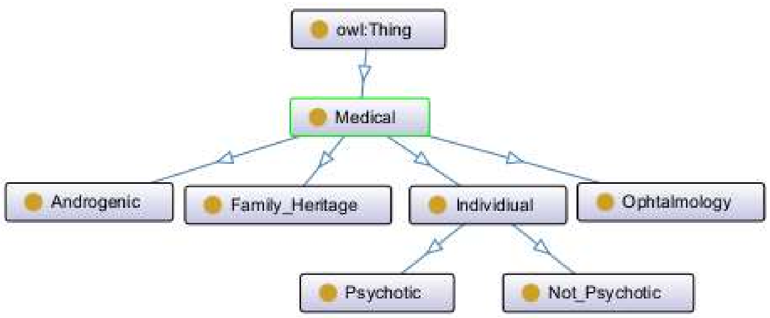


Figure 3: Subclasses of the History Ontology

The formal description of the Medical History ontology defined using Description Logic (DL):

$$\left\{ \begin{array}{l} \text{MedicalBackground} \equiv \\ \exists hasName.xsd: string \sqcap \\ \exists hasDefinition.xsd: string, \\ Androgenic \subseteq MedicalHistory, \\ FamilyHeritage \subseteq MedicalBackground, \\ Ophthalmology \subseteq MedicalBackground, \\ Individual \subseteq MedicalBackground, \\ Psychotic \subseteq Individual, \\ NotPsychotic \subseteq Individual, \end{array} \right\}$$

b) The motive for generating the diagnostic test ontology is to be able to show the numerous laboratory outcomes that were approved of the patient to better treat and management the patient.

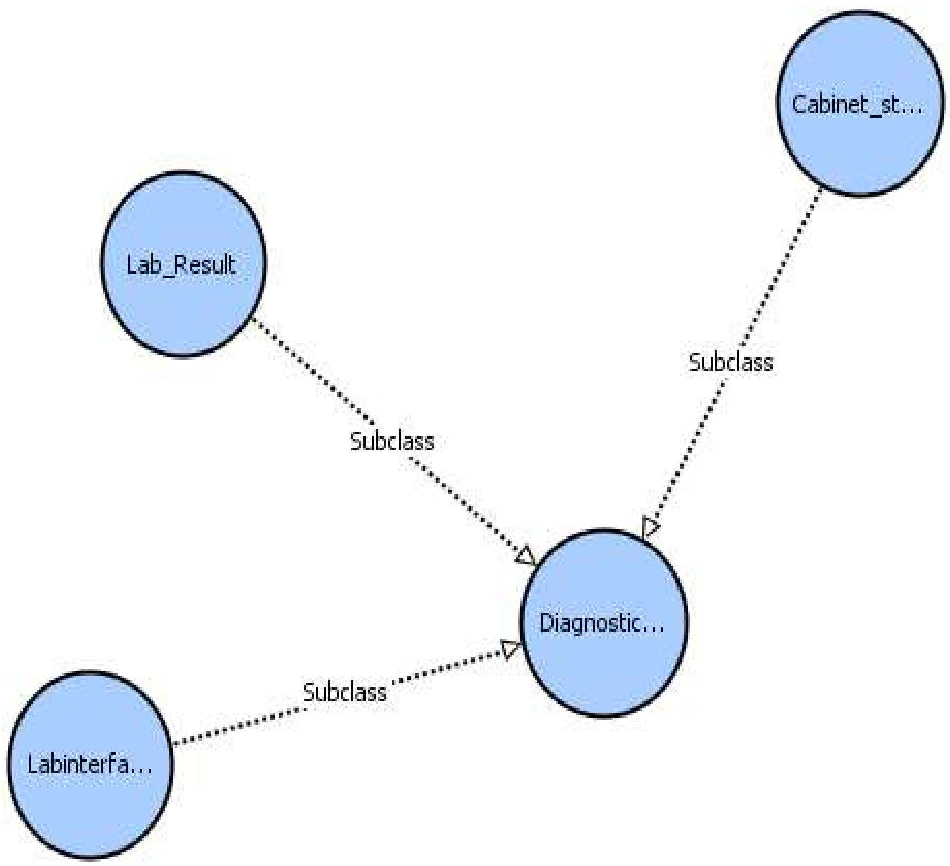


Figure 4: Subclasses of the Diagnostic Report ontology.

The study aims to call the Diagnostic Report ontology using DL:

DiagnosticReport ≡

$$\left\{ \begin{array}{l} \exists \textit{hasReportName.xsd:string} \sqcap \\ \exists \textit{hasReportDescribed.xsd:string}, \\ \textit{IsConsistOf (DiagnosticReport, labReport)}, \\ \forall \textit{isConsistOf. LabReport}, \\ \textit{LabInterface} \subseteq \textit{DiagnosticReport}, \\ \textit{LabReport} \subseteq \textit{DiagnosticReport}, \\ \textit{CabinetStudy} \subseteq \textit{DiagnosticReport} \end{array} \right\}$$

c) The note outlines the plan for a study that aims to categorize diseases using the ontology of medical ailments based on the International Classification of Diseases (ICD-11). The ICD provides a common language for healthcare professionals to share consistent information in the medical field. Figure 6 illustrates the hierarchical structure of the disease ontology class.

The study will focus on seven commonly used classifications of disease: topographic (based on bodily region or system), anatomic (based on organ or tissue), physiological (based on function or effect), pathological (based on the nature of the disease process), etiologic (causal), juristic (based on the speed of death occurrence), and epidemiological.

The integration of the ontology system involves a unified model consisting of several core ontologies. These include the Antecedent ontology, Patient ontology, Disease ontology, Medicament ontology, and Sign and Symptom ontology

Disease ≡
∀*hasAilmentName.xsd: string Π*
∀hasICDId.xsd:string,
EyeAndAdnexa ⊆ *Ailment,*
ChromosomalAbnormalities ⊆ *Disease,*
GenitourinarySystem ⊆ *Disease,*
InfectiousAnd Parasitic ⊆ *Disease,*

Mobidity ⊆ *Disease*
NervousSystem ⊆ *Disease,*
EarAndMastoid ⊆ *Disease ,*
RespiratorySystem ⊆ *Disease ,*
FindingsNotClassified ⊆ *Disease*

The development of the medical ontology aims to represent all the components and medications utilized in the care and treatment of illnesses. Each element within the medicine category should include an active ingredient, presentation, administration method, and information on its interaction with other medications. The hierarchical structure of this category is illustrated in Figure 5.

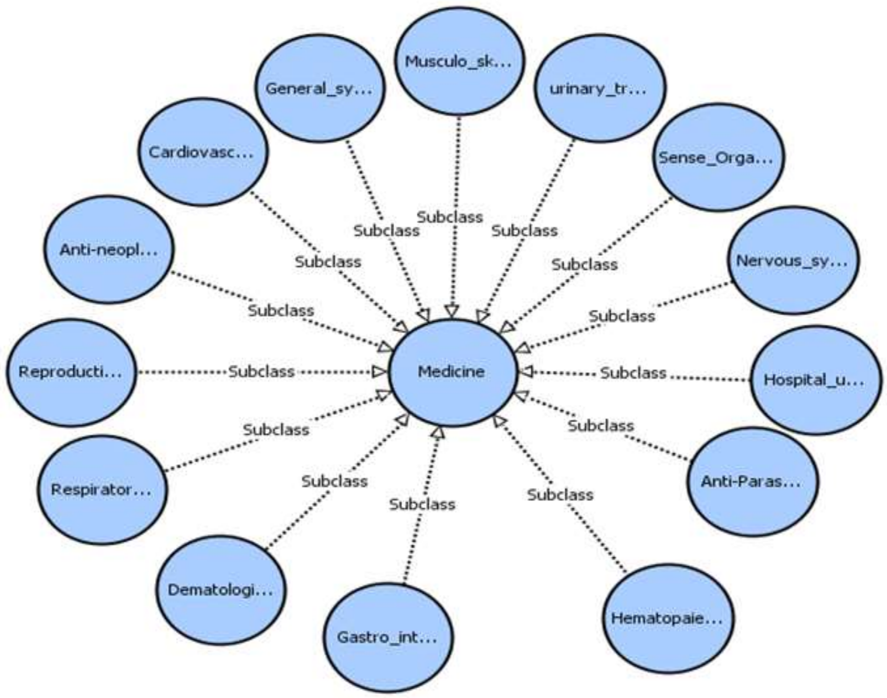


Figure 5: Class of Medicine ontology

$$\left\{ \begin{array}{l} \text{Medicine} \equiv \\ \forall \text{hasActiveElement.xsd: string} \sqcap \\ \forall \text{hasDemonstration.xsd: string} \sqcap \\ \forall \text{hasMethodOfAdministration.xsd: string} \sqcap \\ \forall \text{hasMedicineInterface. Medicine} \end{array} \right\}$$

e) The purpose of the patient ontology is to depict an individual requiring medical attention from a healthcare professional. In order for a patient to be admitted, they must fall into one of two categories: registered or unregistered. The definition of a registered patient is as follows:

$$\left\{ \begin{array}{l} \text{RegisteredPatient} \subseteq \text{Patient}, \\ \text{UnregieteredPatient} \subseteq \text{Patient} \end{array} \right\}$$

$$\left\{ \begin{array}{l} \text{RegisteredPatient} \equiv \\ \forall \text{hasPatientName.xsd: string} \sqcap \\ \forall \text{hasLastName.xsd: string} \sqcap \\ \forall \text{hasBirthDate.xsd: date} \sqcap \\ \forall \text{hasGender} \in \{\text{Female, Male}\} \sqcap \\ \forall \text{hasCURP.xsd: string} \sqcap \\ \forall \text{hasLifeSituation} \in \{\text{Alive,Dead}\} \end{array} \right\}$$

The distinction to bear in mind is that symptoms serve as a subjective indication of the presence of a disease, while signs offer an objective confirmation of its existence. Consequently, the definitions encompass the identification of both symptoms and signs.

$$\text{VitalSigns} \equiv \left\{ \{\text{Heartrate, breathingFrequency, BloodPressure, temperature, pulse,}\} \quad \text{VitalSign} \subseteq \text{Sign}, \quad \text{ClinicalSign} \subseteq \text{Sign}, \quad \text{Somatoscopy} \subseteq \text{Sign} \right\}$$

$$\text{Symptoms} \equiv \left\{ \forall \text{hasIdentification.xsd: string} \sqcap \quad \forall \text{hasSymptomsName.xsd: string} \sqcap \quad \text{Symptom} \subseteq \text{SignSymptom} \right\}$$

The compliance management model used in this work acknowledges the importance of ontologies in addressing compliance challenges. Before providing solutions, it is necessary to establish three fundamental ontologies for this purpose.

4. DISCUSSION

Domain Ontology (DO): The DO focuses on understanding the concepts and relationships within the specific domain, which in this case is Health. (b) Business Process Ontology (BPO): The BPO captures the semantics of the chosen business process language, such as BPMN (Business Process Model and Notation). (c) Regulatory Ontology (RO): The RO ensures that compliance requirements are validated by incorporating the necessary controls and guidelines. Therefore, in this work, these three ontologies are essential components that contribute to the development of an ontologically-enabled compliance management model.

Below is the class and object property hierarchy

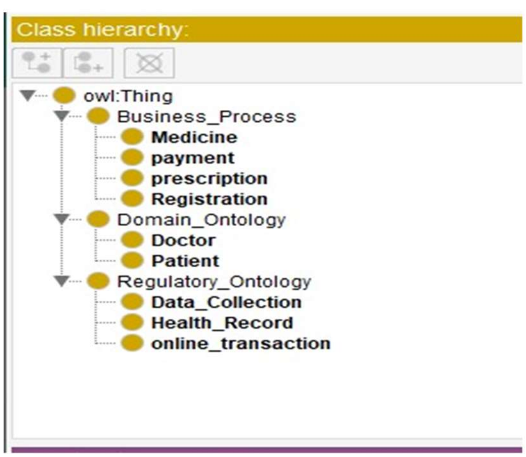
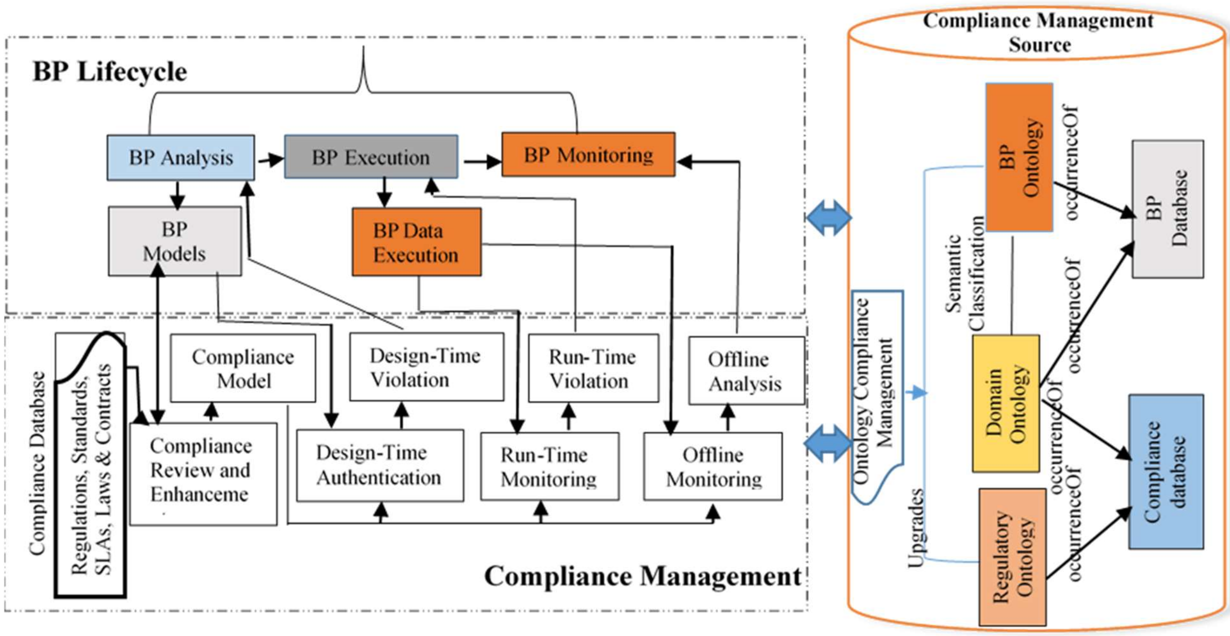


Figure 6: OWL Class Hierarchy

Figure 7: OWL object property hierarchy



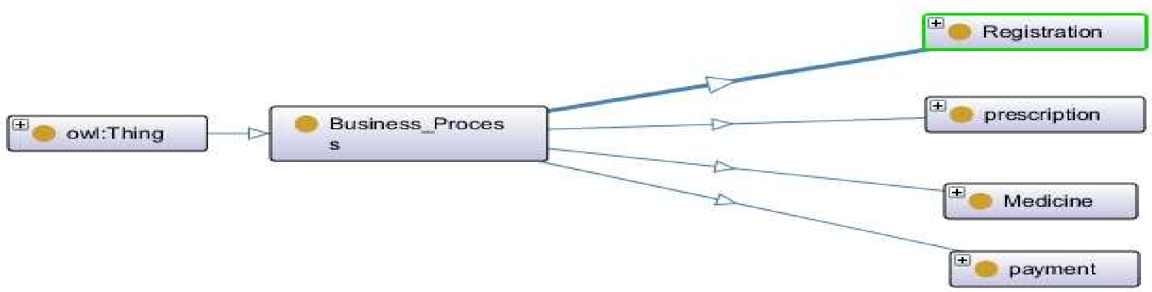


Figure 8: Business Process Ontology Class and Subclasses

Business process ontology; Figure 8 shows the class hierarchy of the BP ontology. The domain ontology: Figure 9 illustrates the hierarchical structure of the Domain ontology

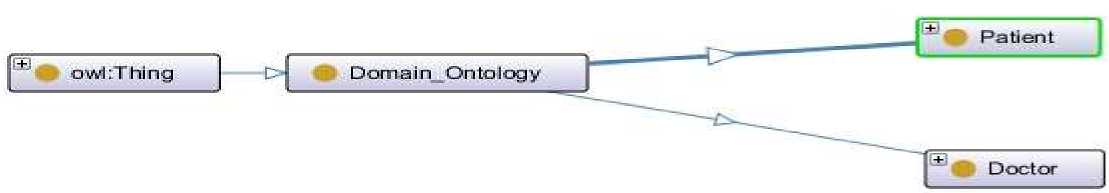


Figure 9: Domain Ontology Class and Subclasses

The regulatory ontology: Figure 10 shows the structure of classes in the Regulatory ontology

Ontology metrics

Ontology metrics: The ontology component parts are populated and reintegrated into the system ontology. The resulting ontology consists of 42 axioms, with 23 logical axioms, 10 declaration axioms, 12 classes, 7 object properties, and 9 subclassOf relationships. Refer to Figure 3 for visual representation of these metrics. It serve the purpose of assessing and gauging the excellence, organization, and efficacy of an ontology.

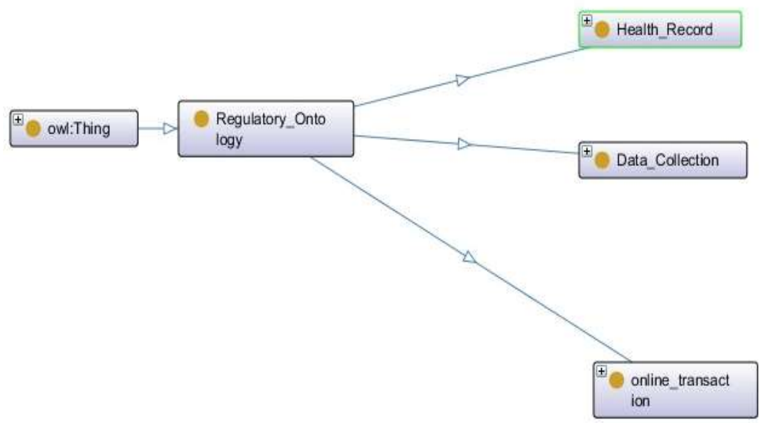


Figure10: Regulatory Ontology Class and subclasses

Consistency Check

The study ensured that the ontology consistency checking was performed to ensure that all the class definitions and axioms had no logical contradictions. This is achieved using the built-in consistency checking features present in protégé.

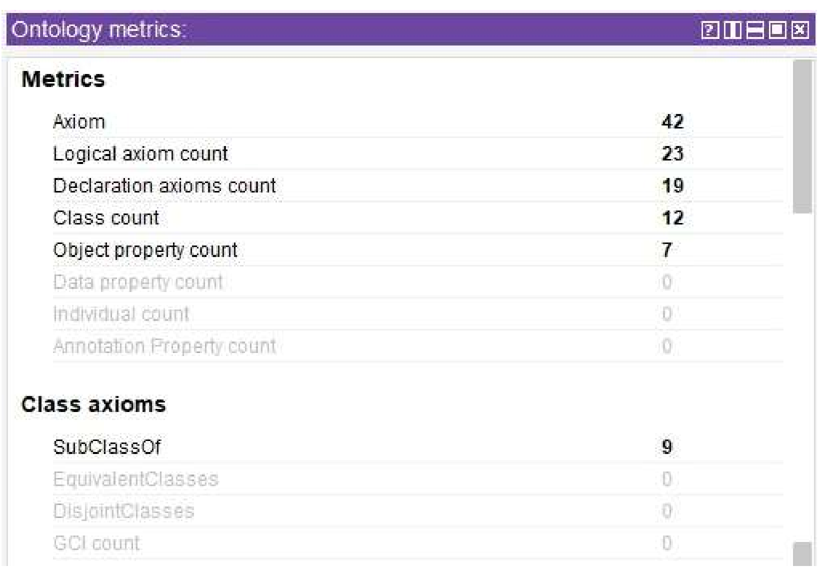


Figure 11: Ontology Metrics

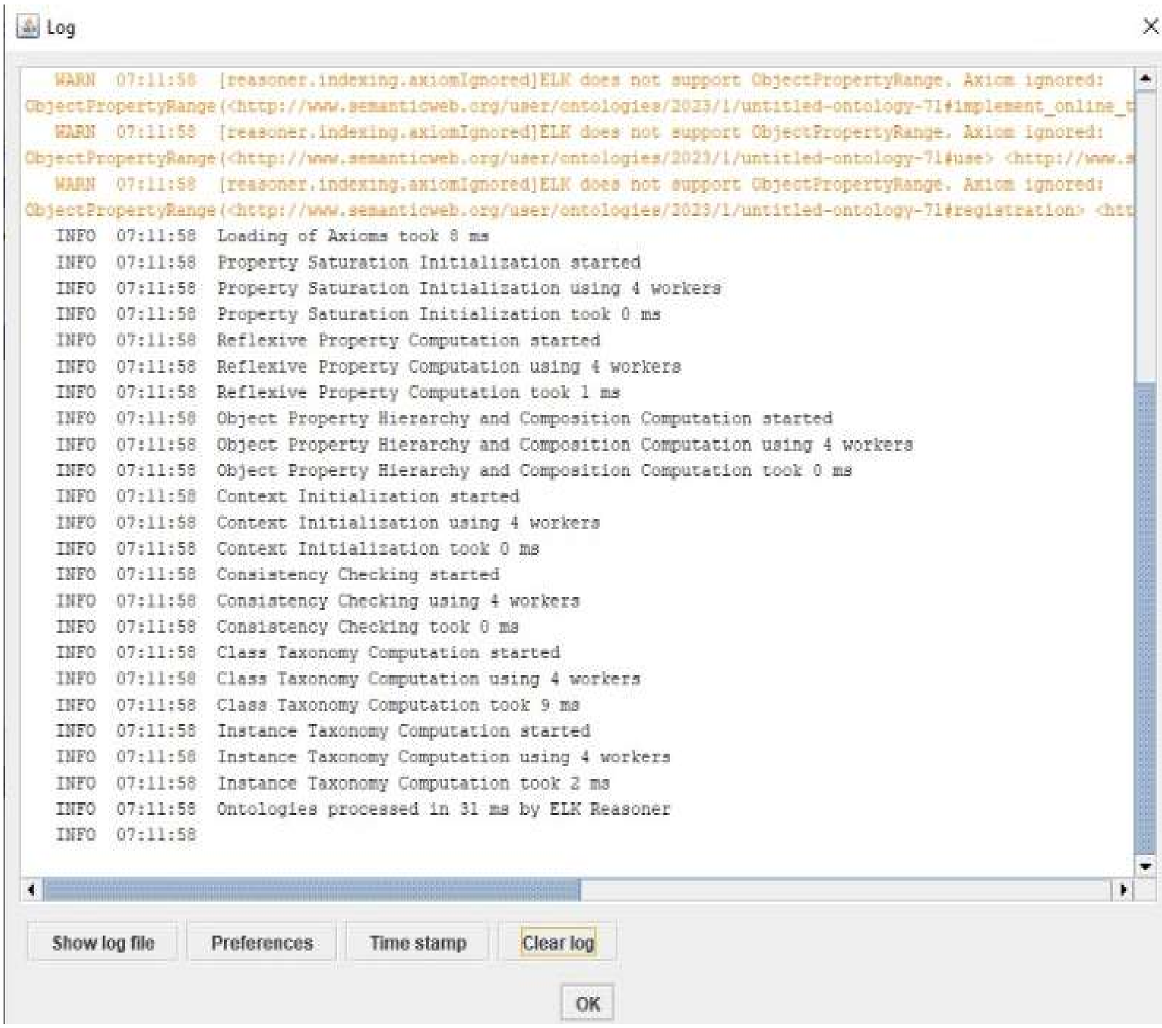


Figure 12: Consistency check

Cloud Compliance Standard Ontology:

The developed ontology, displayed below, consists of six classes: cloud compliance standard, cloud security, business, service contract, adoption framework, and cloud provider. The class "compliance standard" is further categorized into four subclasses: data collection, financial institution, payment, and health record.

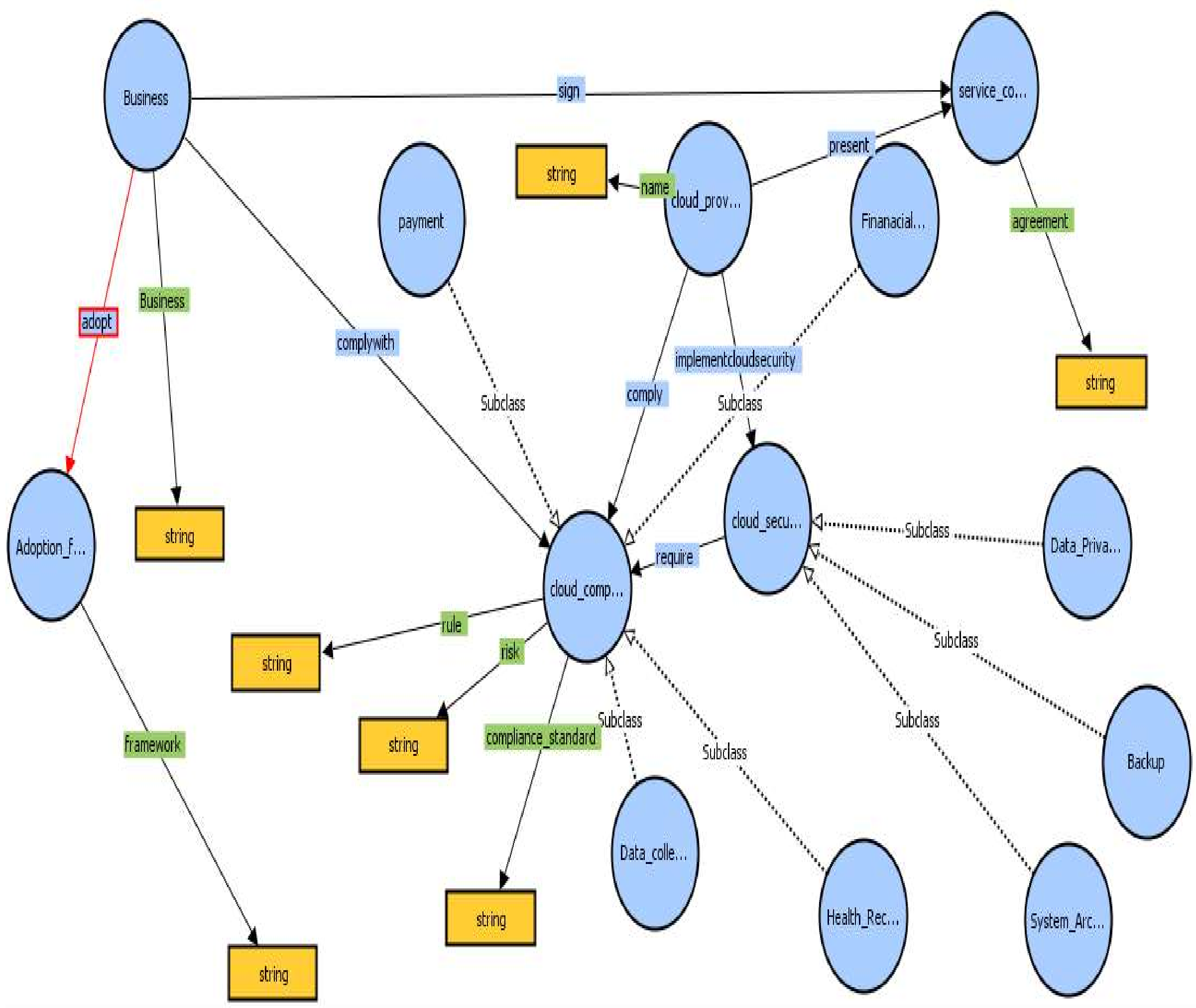


Figure 13: Cloud Compliance Ontology Visualization

Cloud compliance requirements modeling involves the analysis and comprehension of relevant compliance regulations and standards pertaining to cloud services. The objective is to align these requirements with the specific cloud infrastructure and services offered by a cloud service provider. One essential aspect of this process is the identification of compliance controls. These controls encompass various measures such as data protection, access controls, data encryption, logging and monitoring, incident response procedures, and more. To illustrate, in this context, when a doctor accesses patient information from the cloud, reference is made to the HIPAA and GDPR frameworks to ensure compliance. Similarly, when conducting online payments, the PCI-DSS is also consulted to ensure compliance with online financial transactions.

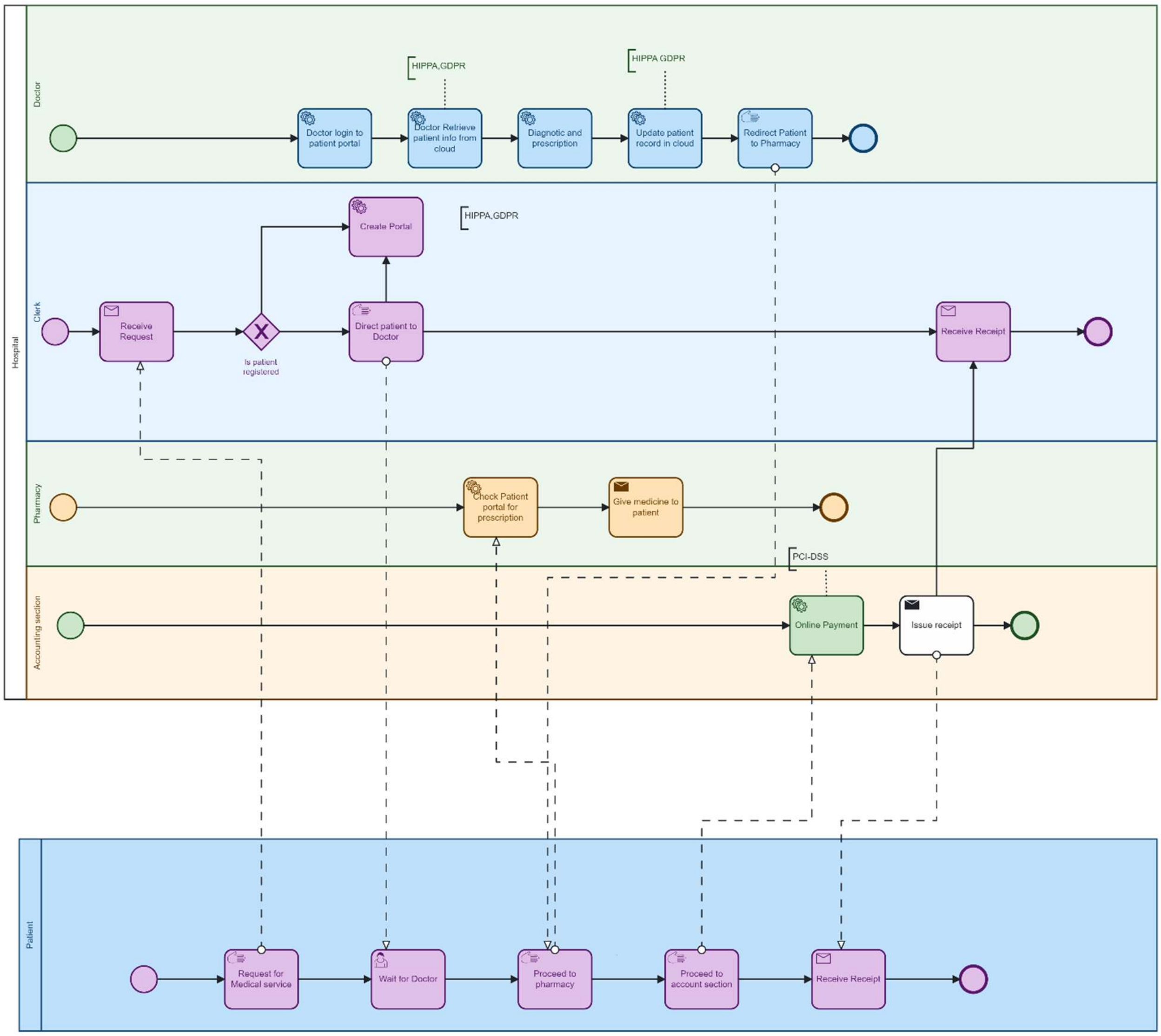


Figure 14: BPMN Model of Cloud Compliance Requirements

4. CONCLUSION

In conclusion, this study aimed to explore the potential of leveraging ontology for enhanced compliance management and business process in cloud environments. Through an in-depth analysis and evaluation of the research objectives, it is evident that ontology-based approaches hold significant promise in addressing the complex challenges faced by organizations operating in the cloud. The findings of this study indicate that the adoption of ontology-driven compliance management can greatly enhance the efficiency and effectiveness of compliance processes in cloud environments.

This, in turn, enables organizations to streamline their compliance efforts, reduce manual interventions, and mitigate the risk of non-compliance. In summary, this study highlights the potential benefits of leveraging ontology for enhanced compliance management and business process optimization in cloud environments. The findings contribute to the existing body of knowledge in cloud computing, compliance management, and ontology engineering.

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