Value Added Conversational AI and Digital Health: An Ontology-Driven Approach

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Abstract

AI-based assistants, such as conversational agents (CAs) and social robots, are becoming increasingly important in healthcare organizations. CAs provide a scalable and cost-effective platform for organizations supporting their employees by retrieving, structuring, and analyzing information to assist work processes. This study targets how knowledge graphs as ontological models manage CA that help improve the patient flow processes and reduce patients' waiting time in the emergency departments (EDs). We tailored the design thinking (DT) method with modelling workshops employing conceptual modelling (CM) techniques to address these issues. We incorporated a hybrid formal approach of Methontology and Tove methodologies to build design artifacts, develop a goal-oriented interactive conversational system between humans and machines, and support information systems (IS). As a result, this ontology-driven approach contribution helps developers build value-added CAs to facilitate healthcare practitioners and patients. It is helpful for quality care delivery experience and improves bottlenecks in information flow within Eds.

Keywords: *Conversational Agent, IS, Ontologies, Knowledge Graphs, Digital Health*

1. Introduction

AI-based assistants such as conversational agents (CAs), chatbots, social robots, and avatars are increasingly significant in healthcare organizations. New application areas for developing CAs and their implementation are emerging due to the exponential growth of digital inter-disconnectedness, an influx of information availability, and technological breakthroughs in computing, especially artificial intelligence (AI) and machine learning (ML) paradigms and computation linguistics [1, 2]. In this context, CAs appear as social and AI-based actors transforming healthcare workers' interactions with information systems (IS) as part of internal corporate communication structures, especially in healthcare organizations [3]. Information systems (IS) are intended to support healthcare professionals and make their work more efficient.

Nonetheless, there is room for enhancement in the utilization of IS within the healthcare sector [4]. An enormous amount of information influx leads to healthcare workers growing workload and stress traumas [5]. AI-based assistants have the potential to automate repetitive tasks, offer decision support, and provide cognitive relief to healthcare workers by retrieving and structuring information, identifying solutions, and offering vocational training [5, 6]. The current state of health information systems (HIS) occasionally needs to meet the needs of healthcare professionals and patients. It is crucial to improve their use in generating and organizing information and knowledge for planning, enhancing, and decision-making among various healthcare stakeholders [7]. We need to understand the work processes supported by HIS, user requirements (*e.g., who will use HIS*) and the specific healthcare domain knowledge for context. The IS community is actively seeking novel approaches, methods, including integrating *Industry 4.0* (I4.0) standards and application landscapes like CAs and their paradigms, to meet the needs of healthcare unit actors [8] to address the challenges, especially information flow bottlenecks in healthcare organizations, primarily in hospital emergencies.

Here, the concept of Health 4.0 has established a new promising vision for the healthcare industry because of the transformation from the traditional healthcare paradigms to the new era of smart and connected healthcare [9]. This transformation shift encompasses integrating and utilising innovative technologies, including CAs, the Medical Internet of Things (MIoT), AI, ML and intelligent algorithms. As per the data [10], patients historically spent 70% of their time in the emergency department (ED) waiting rooms, encountering challenges including bed capacity problems, extended wait times, overcrowding, information flow bottlenecks during

URI: https://hdl.handle.net/10125/106869
978-0-9981331-7-1

peak hours, a significant number of patients leaving without diagnosis or treatment, safety concerns, and patient and family dissatisfaction, especially in the Emergency Departments (EDs). CAs help to develop an interface layer between humans and machines to deliver optimal results from their knowledge bases (KBs) in response [11]. This study only targets **RQ:** *How can knowledge graphs, based on ontological models, be used to develop conversational agents (CAs) to improve patient information flow processes and reduce waiting times in emergency departments (EDs)?*

The study aims to develop an ontology-driven intelligent AI-based assistant (*e.g., CA*) as a solution that integrates contextual knowledge, provides contextual services, and enhances information flow, provision processes, and healthcare outcomes within the PED. To achieve these objectives, the enterprise modelling (EM) techniques [12, 13] offer a way to depict the present state within the medical unit, particularly in the PED context, and delineate work processes, tasks, roles, and resources.

Thus, EM can enhance the effectiveness of IS in healthcare by creating ontological models reflecting a specific healthcare unit [14]. Additionally, It designs and develops intelligent solutions using knowledge graphs (KGs) techniques based on an ontology-driven approach to automate various tasks and processes within PED. However, successfully designing a CA with KG remains a notable challenge [15].

The proposed work gives a state-of-the-art approach to building CA as a mediator between patients and healthcare users to enable practical and useful interaction before or upon arrival at the medical department to address some overcrowding issues. This ontology-driven approach aids in constructing a conversational model that accurately responds to questions from patients with less urgent requirements. In this context, a challenging task is to design a personalized CA equipped with domain-specific contextual knowledge to facilitate interaction between patients and healthcare physicians in PED. Furthermore, it also accommodates dialogue-based information via interaction modes, storing it in a local repository for subsequent analysis and enhancement of personalized health services across various health-related scenarios.

This paper is structured into the following sections: *Section 2* provides a brief overview of desktop research, conversational agents in digital health, modelling in healthcare informatics, and ontologies for AI-powered applications. *Section 3* presents the methodology: the research design process, the case study, and the method for ontology development. *Section 4* illustrates the anatomy of the architectural artifact of CA. *Section 5* presents the results. Section 6 describes the evaluation procedures and modelling results. *Section 7* talks about the lesson learned. Lastly, *Section 8* discusses the results and provides a conclusion.

2. Theoretical Background

2.1. Conversational Agents in Digital Health

In digital health, proactive CAs' design and implementation are trickier and more valuable regarding users' perspectives and experiences [16]. In 2020, according to the statistics, voice assistants such as *Apple's Siri, Google Home*, *Amazon's Alexa*, and *Microsoft's Cortana* and CAs were used by more than 83 million people in the United States—interactive abilities. CAs has the potential to integrate user needs, data, and health services seamlessly. In healthcare, various CAs are helpful, ranging from bi-directional dialogue systems like CAs (*e.g., a standard hospital system to triage incoming phone calls regarding severity, urgency, and pathology*) and embodied agents. The pro-activeness of these goal-oriented CAs can be demonstrated in various sections of training, education, assistance, prevention, diagnosis, and elderly assistance [17]. So, in developing goal-oriented and dedicated CAs, especially in PED, we need to incorporate some design principles (DPs) based on identified meta-requirements (MR) derived from the knowledge acquisition (KA) process (*e.g., interviews, etc.*). These identifiers include sociability, proactive communication ability, transparency, flexibility, seamless usability, and error handling in the development phase [18].

2.2. Modelling in Healthcare Informatics

The term enterprise modelling (EM) contributed significantly to the healthcare sector by helping organizations with process optimization, resource management, data integration, etc., because it promises to improve HIS and its use. EM can be used to analyze patterns of healthcare activities, ensure the fulfilment of the end user's needs and requirements, build a systematic view of patient-centric processes, and help healthcare institutions improve internal knowledge and understanding [14]. Similarly, the conceptual modelling (CM) basis for EM helps in integration [19], simulation [20], and information system designing [21]. The EM approach is used to build structured, goal-driven models for organizing organizational knowledge and developing various process modelling perspectives, including functional, informational, organizational, and behavioural. To meet the evolving business needs, organizations require more formal EM methods, such as conceptual modelling (CM) methods [12]. Ontological modelling (OM) is crucial in formal conceptual modelling as it explicitly specifies a conceptualization [23]. A variety of developed ontologies, such as *ED Work Domain Ontology* (ED-WDO) and *ED Overcrowding Management Ontology* (EDOMO), are entertained to justify the PED workflow [24].

2.3. Ontologies for Conversational Agent (CA) Applications in Healthcare Setting

Ontologies are used in many fields, especially in the healthcare industry. Its inclusion has become essential to implementing spoken dialogue systems [25] by employing ontologies as the foundational standard for knowledge representation, formalism and the common language for communication. We established a consistent framework across various conversation domains, encompassing natural language understanding (NLU), dialogue modules, and shared ontological resources [26]. Ontologies are the basis of developing personalized knowledge graphs (PKG) to capture contextual knowledge, personalized data, and their integration with background medical knowledge bases for medical diagnosis [27] and monitoring user health in a healthcare organization [28]. This research targets implementing ontology-oriented resources within real-time system engineering to address certain social challenges and foster experientially rich interaction between humans and conversational agents (CAs) in healthcare settings. In this study, a specific ontology, Convology [29], has been utilized. This implementation has been carried out using ontology design patterns (ODPs), and the details of its execution will be discussed in subsequent proceedings.

3. Methodology

3.1. Research Design Process

This paper presents a rigorous iterative process of *Design Thinking* (DT), a human-centred method [30]. We aimed to design a conceptual (knowledge graph) model based on an ontology-driven approach that depicts the domain's contextual knowledge and evaluates novel ontology-oriented artifacts within a PED setting. We used the DT approach and followed specific steps in modelling workshop sessions (*see Appendix-2*) [31]. These design artificats help develop a holistic understanding of the contextual knowledge of the PED and its management and explain how AI-powered applications (*e.g. CAs, Social robots, etc.*) can improve communication between multidisciplinary physicians. This approach helps patients and their relatives manage dialogue, achieving quality and efficient patient-centric care in emergency settings. It also provides a systematic way to understand the problem. It helps develop understanding through direct observations after listening to a briefing from the domain experts about the PED context. We built the narrative using *Storytelling* and *Persona writing* techniques to support the ideation process for developing prototype artifacts such as knowledge graphs (KGs). Finally, the testing procedure occurred to ensure thorough discussion captured in conceptual modelling (CM) sessions from the domain experts to justify the context of PED in the hospital setting.

Numerous modelling techniques [13] have been developed for acquiring tacit knowledge (TK) from domain experts, potential users, and patients to address the bottleneck issues of information flows within the ED's context. This research also explains the usage of an ontology-driven approach and how the knowledge graph (ontology model) is used to manage knowledge acquisition (KA) and dialogue management processes between humans and machine interactions using the knowledge management (KM) frameworks such as *Protege 5.0* and *TopBraid Composer*. We tailored the enterprise knowledge development (EKD) modelling technique [32], considering the most promising design techniques for conducting modelling workshops [14].

This study aimed to transform the current situation of PEDs from an *As-Is situation* to a *To-be situation* employing AI-powered applications (*e.g., CAs, Social robots, etc.*), according to the direct observations and modelling workshops (MW), especially at *Karolinska Hospital, Solna, Stockholm, Sweden*. Modelling of the PED case (*see section 3.2*) has been carried out as a collective activity with multidisciplinary participants of different backgrounds, such as modelling, medical, and IT. The objective was to develop a healthcare process model as a formal ontology-based knowledge graph (KG) that can be used to establish an AI-based assistant applications platform that networked with other health information systems (HIS) and supported different types of IS ecosystems [33]. During the modelling activities, we followed several steps [14, 31].

Step-1: Understand; We arranged modelling workshops with domain and modelling experts [26] to acquire knowledge for good understanding in briefing related to PED (*see Appendix-1*) at *Karolinska Hospital, Solna, Stockholm, Sweden*. *Step-2: Observe;* We initiated a KA process and called a quick closed-sessions for using qualitative methods (*e.g., interviewing with domain experts*) and linked up with the recorded tacit knowledge from the professionals along with direct observations, self-intuitions in quick mind-storming process, and again rely on the iterative desktop research process. *Step-3: Point of view;* In this phase, as a team, our priority was to engage team members on the same page for synergy in understanding, exchanging the results, and their representation using various techniques (*e.g., persona-writing* (*see Appendix-3*)*, etc.*). *Step-4: Ideation;* We draw a storyboard to compile discussion components with arguments for selecting on-demand technologies and their usage in PED. *Step-5: Prototype;* We tried to incorporate *Industry 4.0 (I4.0)* concepts (*e.g. CAs, Social robots, etc.*) to give the shape as a digital artifacts to showcase the interaction and why these would be value-creations in PED. *Step-6: Test;* After developing the first version of the knowledge graph artifacts, we showcased various models (*see Appendix-4*) in front of domain experts and users to get real-time feedback for further improvements.

Figure-1 suggested a process model defined by Thoring and Mueller [30] that was taken as a foundation for developing AI-powered artifacts as an agentive solution to achieve users-centered goals and ingrained human values. It also helps healthcare practitioners (HPs) improve their working patterns and information flow procedures and facilitates other stakeholders, such as patients and their relatives, that can interact with interactive and conversational services on demand without any inconvenience in the emergency context of PED at arrival.

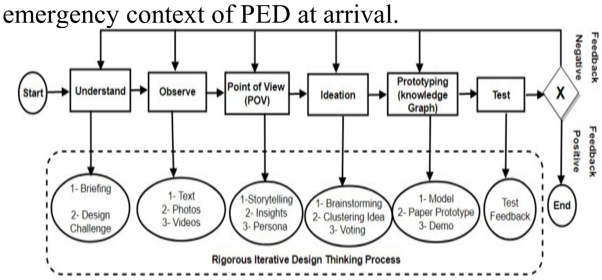


Figure 1. Process Model of Design Thinking Method

3.2. The Karolinska University Hospital Case

This study is based on real-time case observations in the PED of *Karolinska Hospital in Solna, Stockholm, Sweden* and *USACS* [34]. As a team with multidisciplinary expertise, we conducted modelling workshops. We followed specific steps [14, 31] to facilitate better communication with domain users, medical professionals and experts responsible for emergency patient treatment procedures and develop an understanding of ED workflows. Initially, We observed and tried to reverse-engineer the whole situation of the PED. We analyzed the information flow processes related to the patient's treatments and admission procedure upon arrival at PED. After assessment and establishing consensus, We traced some critical problems associated with patient-centric treatment procedures. We aimed to transform from an *As-Is situation* to a *To-be situation* in PED. From extensive desktop research, 75% of patient visits increase yearly at ED and affected patients are used to confronting unexpected experiences such as long waiting times and overcrowding issues [34].

From the *Hospital's perspective*, a poorly functioning ED affects overall activities and workflows within the emergency unit, so it must be well organized [35]. To get appropriate medical assistance, we need to deploy classified information systems (IS) such as Triage [(*e.g., decision support system (DSS))*] [35], electronic health records (EHR), and electronic medical records (EMR). The EHR focuses on the patient's health and sharing information with other healthcare practitioners (HPs). Similarly, the EMR maintains the medical and treatment history of the patient. Here, the Triage's role is quite promising because it helps prioritize the patients for care and treatment. Unfortunately, a massive number of patients and a long waiting queue creates a bottleneck at Triage in EDs. So we need supporting technological solutions (*e.g., chatbots, social robots, etc.*) that help to improve multiple steps in front-end Triage procedures with inconsistent practices and minimize the high percentage of patient handling in the waiting room during peak hours in ED. They also help to initiate single-window operations to improve communication issues and harbor data silos within departments and treatment areas [34].

From the *Patient's perspective*, the long waiting times in the EDs, often accompanied by high anxiety levels, can cause the patient's lose trust in health services. When EDs function poorly, this jeopardizes not only the mental health and safety of the Patient but also deteriorates public confidence in healthcare systems as a whole [35].

3.3. Hybrid Method for Ontology Development (HMOD)

For ontology development (OD), we have chosen a hybrid approach to express the discussion of PED and the inclusion of AI-based applications in healthcare settings. This hybrid approach is highly customized with *Methontology* [36] and *Tove* [37] techniques. This hybrid approach is used to develop a personalized knowledge graph (*ontology-based models*) in healthcare. During the modelling activities, we followed several steps and actions related to management, development and support activities. These management activities are based on scheduling and controlling activities. Ontology developers carry out these activities using various resources to perform certain actions. These controlling activities are carried out to ensure that all development activities are governed according to the set plan by the researchers during modelling sessions. In the development activities, specific steps are involved in the requirement specification phase in the light of the software development life cycle (*see figure-2)*:

1) Motivating scenario, 2) Informal competence questions, 3) To build the glossary and taxonomies of terms, 4) To define the ad-hoc relations, 5) To define constants in detail, 6) To define formal axioms specification, 7) To define classes, objects and data properties using a top-down approach, To define formal axioms, and To define some production rules [36, 37] (*see figure-2*).

Similarly, supportive activities related to the knowledge acquisition (KA) process and ontology reusability phenomenon. This ability helps the developer with reusability and modifying existing ontologies according to a particular context. Different reuse processes are involved in reusing existing ontologies, such as integrating and merging ontologies in developing an ontological domain model (PEDology) [38] (*see appendix-4*). We have conducted two modelling workshops. The 1st modelling workshop intended to acquire the most relevant knowledge from the domain experts. It helps to create a domain conceptual model of the PED context. During the 2nd modelling workshop, we tried to showcase the formal ontological models to domain experts and IT professionals for developing AI-powered applications and improving healthcare IS. We also discussed different roles, goals, tasks, activities and resources used in the PED.

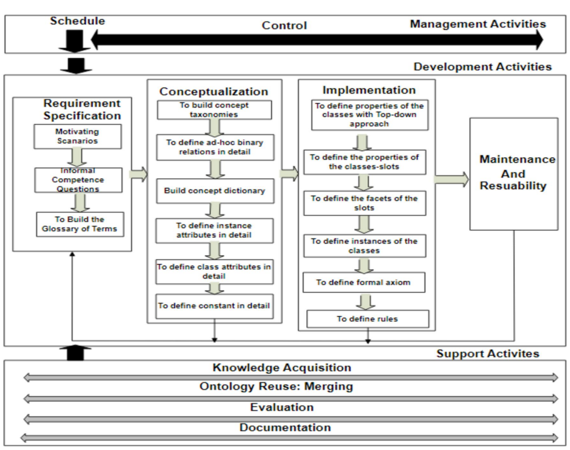


Figure 2. Hybrid Methodology for Ontology Development (HMOD) Process

4. Anatomy of AI-driven Conversational Agent Architectural Artifact

The section illustrates the proposed layered-based architecture for designing and managing AI-based assistants such as CA, which can be seen in figure-3. The *first layer* is reserved for the acquisition of cognitive and tacit knowledge using data-acquisitive methods (*e.g., modelling workshop techniques, interviews, etc.*) from the domain experts/practitioners. Knowledge modellers are responsible for developing conceptual models using modelling techniques (*e.g., EKD*) [32] to showcase them to domain experts. The *second layer* is reserved for establishing intent files based on dialogue management between humans and machines. These intent files help write AIML [39] scripts following XML format in an AIML-based editor (*e.g., Pandorabots AIML editor, etc.*).

The *third layer* is based on an ontology-driven approach that helps incorporate contextual, domain, and tacit knowledge (TK) as competencies models into PEDology. It also helps to include external knowledge for re-usability purposes for developing domain-oriented ontology that reflects domain discussion and relevant concepts, entities, object properties and relationships between them.

The *fourth layer* explains the role of the startup file with extension "*std-startup.xml*", which is used as the main entry point for loading aiml files. The *fifth layer* is reserved for creating the human-machine interface (HMI) for voice-enabled conversation and text-based messaging using CAs and ML API in programming language platforms (*e.g., Python*). It is reserved to load the CA brain. It is written in the development phase in the editors of the Python programming language (*e.g., Jupyter Notebook editors, etc.*).

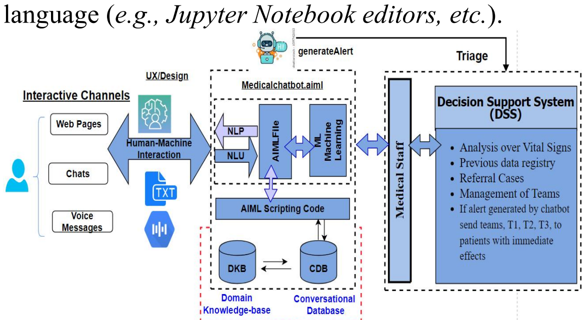


Figure 3. Multiple Layers Framework for Developing AI-driven Conversational Agent (CA)

5. Results

5.1. Process View Model of the PED Artifact

In this section, we utilized the EKD modelling technique [32] to design the model related to PED.

This section employed the EKD modelling technique [32] to craft the PED-related model. This section encompasses essential processes, external processes, and information sets visually presented in Figure-4. Using the EKD modelling technique, we illustrate a comprehensive workflow overview of the PED processes. Here, an external process is defined as a collection of activities beyond the organization's activity scope, interacting with processes or actions in the problem domain area. An information set represents information exchange between processes to facilitate information flow [32]. *Patient Arrival at ED (External Process):* This process highlights the procedures or patterns for reaching the ED to get medical assistance. *Triage (Decision Support System) Process:* Triage is a decision support system (DSS) that helps improve the patient care decision-making process after a critical analysis of medical tests, symptoms, and conditions data.

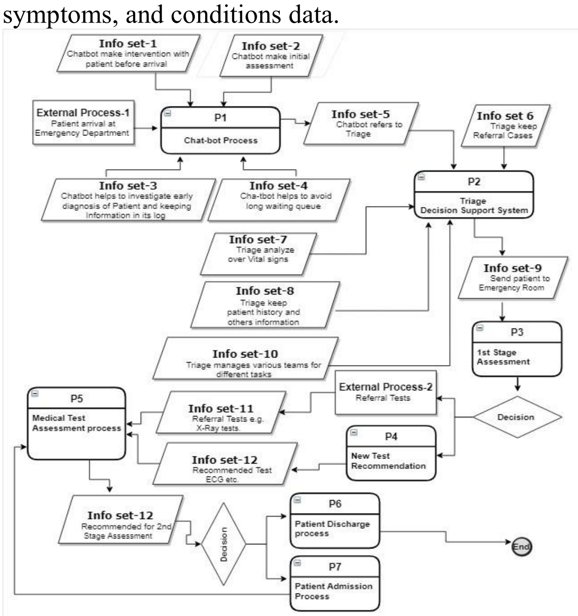


Figure 4. Process Modelling in the PED

1st Stage Medical Assessment Process: In 1st stage medical assessment process, the CA asks some essential questions to the patient relative to assess the need for serious medical help or to avoid long queues. *Referral Tests (External Process):* Triage also handles referral tests referred from secondary or primary medical centers. *New-Tests Recommendation Process:* After a critical analysis of the patient, Triage refers to medical trials for new patients. *Medical Tests Assessment Process:* After receiving the result of the new tests and referral tests, the medical professionals make assessments for further medical actions. *Patient Admission Process:* This process includes some steps required for admission purposes to treat the patient. *Patient Discharge Process:* The medical staff follows some necessary steps for discharging the patient from the medical unit.

5.2. Ontological Model Artifact of Pediatric Emergency Department (PEDology)

This section briefly explains the implementation of the ontological model of PED called PEDology. A hybrid formal approach is used, which results in knowledge graphs (ontological model). We used the web ontology language (OWL) and ontology development editors (*e.g. protege 5.0*) to develop the ontology-based implementation that is based on case studies and *USACS* for better understanding and realization of the emergency department's (EDs) situation. Figure-5 illustrates a semi-automated mechanism for transforming textual or contextual knowledge, especially pertaining to PED discussions, and integrating it with *United States Acute Care Solutions* (USACS) data related to the ED's context. This transformation results in standardized structured data that can be adopted in various data formats and is readily reusable for achieving data interoperability with other interconnected healthcare systems. During the ontology development process, we employed a hybrid approach combining elements of Methontology and Tove methodologies. This approach guided the creation of an ontology-driven model referred to as PEDology. Within this model, we identified and established essential concepts, entities, and relationships (object properties) among these concepts, along with data properties, business rules and class axioms. These components collectively formed the foundation for constructing an intelligent knowledge base (KB). The aim of this knowledge engineering (KE) endeavour is to develop a personalized knowledge graph (PKG) - an integrated repository of knowledge with a specific emphasis on the emergency context.

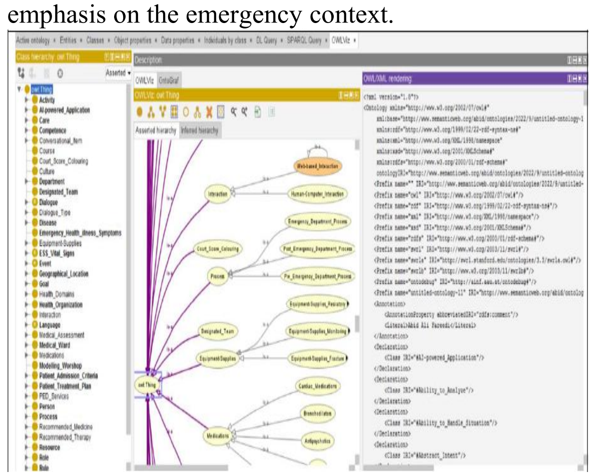


Figure 5. Ontological Model (OntoM) of Pediatric Emergency Department (PEDology)

The statistics of the PEDology model consist of *271* classes, *6242* axioms, *5273* logical axiom counts, 959 declaration axiom counts, *247* object property counts, *26* data property counts, *413* individual counts and *six* annotative property counts. We used a formal hybrid approach using ODPs and other ontologies such as competence models, diseases models and Convology to develop the conceptual models as a machine-readable structure. The PEDology model depicts the ED situation and rationally targets overcrowding with improved information flow processes and information provision (IP) is presented in figure-5. As a novel data paradigm, the ontological models (PEDology) combine various technologies, terminologies, and data cultures that reflect domain knowledge in a human and machine-readable format. Here, the ontology-driven framework is one of the potential solutions to develop standard vocabulary. It helps with data interoperability and reusability in different formats, such as Turtle, RDF/XML, OWL/XML, and JSON-LD, developing health-related services used in CAs (a new class of IS).

5.3. Personalized Knowledge Graph (KG) Construction Pipeline based on Ontology-driven Approach for CA

The section explains a systematic way to develop AI-based assistant such as CA in different phases (*see figure-6*). This KG pipeline based on an ontology-driven approach is followed by some layers structures such as the knowledge acquisition (KA) layer, the knowledge representation (KR) layer, the knowledge representation and reasoning (KR^2) layer and the knowledge embodied (KE) layer. The *KA layer* consists of various data acquisition (DA) techniques (*e.g., interviews, direct observations, surveys, archived data and focus groups*) gathered from domain experts, health stakeholders, and physical notes and documents. The DA process can be driven using KA methods such as modelling workshops, and the step can be seen in detail [14, 31].

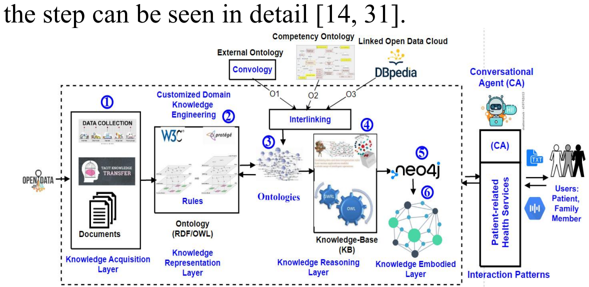


Figure 6. Knowledge Graph Construction Pipeline using Ontology-driven Approach for CA

The *KR layer* defines a systematic way of constructing ontology in an ontology editor (*e.g. protege 5.0*[1]). In the ontology development (DO) process, we have taken actual input from the KA layer and defined some concepts, entities, and relationships (*Object properties*) among concepts, and defined data properties, defined business rules and class axioms for creating intelligent KBs. It becomes the backbone of any intelligent AI system, especially CAs. This layer is also responsible for maintaining the interlinking of different ontologies and vocabularies, including ontology design patterns (ODPs)[2] as external sources.

The *KR^2 layer* explains the business rules' design and illustration and how they look, and we can write business rules in the ontology editor using semantic web rule language (SWRL[3]). These rules symbolic expressions can be integrated with a dump knowledge base (KBs) to make it more intelligent and generate new inferences according to the base facts. Generating new inferences is only possible because the inference engine (IE) makes the KBs more intelligent and gives the information according to the query with optimal answers. The IE is a powerful tool that interprets and evaluates the facts and applies logical rules in the KB to answer. The prominent role of the IE is to develop knowledge classification, diagnosis, and check inconsistency and non-coherent attitudes among concepts and monitor their object relationships in ontologies development process. This work uses various tools, including reasoning abilities, like Pallet and Drools[4]. The Pallet is a built-in plugin used within the *Protege 5.0* environment and recommended reasoner, which takes rules and axioms and generates logical inferences about properties or class definitions. Similarly, *Drools* reasoner follows the structure like [((OWL+SWRL→Drools) →Run Drools→Drools→OWL))]. This structure explains the *First session* of the expression transfer SWRL business rules and relevant OWL knowledge to the rule engine. The *second session* defines its execution process, and the *third* describes the transformation of inferred rule engine knowledge into OWL knowledge. This reasoning ability helps KBs to answer according to query with data inconsistency or lack of coherence.

The *KE layer* narrates the execution of a semi-automated way of processing ontologies with OWL[5] or RDF[6] extensions parsed through IE and stored in KG databases such as Neo4J[7] and Stardog[8]. Here, we used Neo4J as a KGs database to store RDF triples of domain ontology (DO) and qualify for the KE with

[1] https://protege.stanford.edu/
[2] http://ontologydesignpatterns.org/wiki/Main_Page
[3] https://www.w3.org/Submission/SWRL/
[4] https://www.drools.org/
[5] https://www.w3.org/OWL/
[6] https://www.w3.org/RDF/
[7] https://neo4j.com
[8] https://www.stardog.com/

inference power. We also used cypher query to get the answer according to competence questions (CQs).

6. Evaluation

The section demonstrates the goal of the evaluation, which is to achieve the quality of the work and gain confidence that the knowledge graph (KG) build-up model with a quality ontological structure following the principles of ontology methodologies such as Methontology [36] and Tove [37]. It also presents the accurate depiction of PEDs systematically. The evaluation model was done differently [28]. However, to qualitatively measure, we designed in the 2nd modelling workshop, which will be explained later.

6.1. Structural Evaluation

The hierarchical structure of the PED model (PEDology) is assessed concerning the correctness of the "is_a" relationship as to whether the given concept "A" is a particular type of the given concept "B" in this phase. For instance, the "*Triage nurse role*" is a subclass of the "*Medical Practitioner Role*", and these roles are sub-classes of "*Role*" in a PED ontology model. The structural evaluation procedure is also necessary to confirm the utility of the ontology model for the classification task.

6.2. Semantic Relational Evaluation

In this phase, the PED ontology is evaluated for holding semantically correct relations between concepts and these relations are associated with "*Object Properties*" and "*Data Properties*" in ontology-based editors. The semantic relational expression follows a triplet structure (*subject, predicate, object: Node --->Node*). e.g., there is a relationship between the concept of "*Role*" and the concept of "*Goal*", referring to "*acheivesGoal*". Thus, the "*Role*" is the domain, and the "*Goal*" is a range within the model.

6.3. Lexical Evaluation

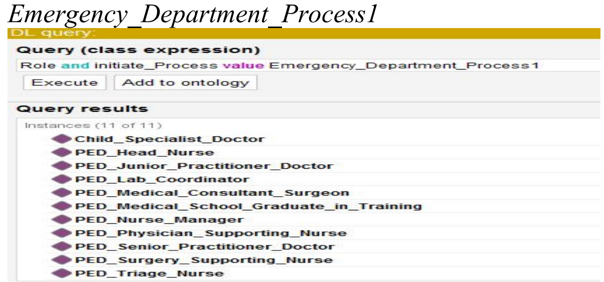
This part examines some attributes of the PED model (PEDology), expressiveness, completeness, and clarity of the annotation of a given PED ontology [28]. We presented several competence questions (CQs) to the domain experts and participants in 2nd modelling workshop and asked them whether or not the relationships are confirmed in the ontology model.

6.4. Using Description Logic (DL) Queries

We used the description logic (DL) *Query Tab* in *Protege 5.0* to verify domain-related CQs, which helped to confirm that the PKG (ontology) model has enough information to answer these questions related to PED. Table-1 shows examples of CQs with a DL query and presents the results of executing the DL queries during 2nd modelling workshop.

Table 1. Results of DL Query in Protege

CQ1: Who are the members involved in PED team?
DL-Query: *Role and initiate_Process value Emergency_Department_Process1*



6.5. Second Modelling Workshop

During this modelling workshop-II, we presented a holistic view of the domain model design artifact that illustrates how healthcare professionals (HPs) with different roles and competencies initiate different processes and perform different activities to achieve the PED goals. This session also showcases the interaction exercises between humans and machines and how CA can interact and respond according to the questions. We have also exemplified the model of the *Karolinska Hospital* case with a simple but value-added scenario that shows the representation of the practical situation of PEDs. These formal modelling results help develop the CA, which can be interlinked with health IS and improve information flows in the PED context during peak hours. Finally, we received valuable feedback and suggestions from domain experts and IT professionals for future improvements.

7. Lesson Learned

The prior learning for conducting modelling workshops was to learn the state-of-the-art development of conceptual models that can be formalized as personalized KG (ontology-based models) in a machine-readable format to support the improvement and development of IS. It also helps train and evolve CA applications for accurate responses to a patient in a healthcare setting. We learned that modelling workshops were productive in acquiring relevant knowledge about the PED to develop an ontological model (PEDology). Using modelling workshops and techniques like EKD, we developed models including tacit knowledge gained from the domain experts. Then, they implemented their competencies models to improve IS and its usage in different domains like healthcare.

8. Discussion and Conclusion

AI-based assistant applications and their usage with AI and ML capabilities are becoming increasingly important in healthcare organizations. Here, CAs play a vital role in improving information flows and IP and initiating human interaction smoothly to facilitate users in the specific context, especially PED. The study aims to raise awareness of AI-based applications such as CAs, social robots, and chatbots and their contribution to improving unexpected patient experiences and addressing exceptionally long waiting times and overcrowding during peak hours. From a *socio-technical perspective*, EM techniques help to build CAs in the healthcare unit and provide a basis, How the knowledge graphs structure (*ontology-driven approach*) can be used as a model to train and evolve conversational applications to facilitate HPs as coworkers and help make smooth interactions between patients and machines for getting on-demand health-related services.

We followed a rigorous iterative design thinking method (DTM) approach to aim to design conceptual model (ontological model) artifacts that depict the domain's contextual knowledge and evaluate novel ontology-based artifacts. Similarly, we applied a hybrid approach that combined elements of *Methontolgy* and *Tove* methodologies (HMOD) for designing and implementing the domain ontology of PED (PEDology). CM techniques provide a means to model the medical unit's current situation and describe work processes, goals, tasks, activities, roles, and resources. Thus, CM can help to make the use of IS in healthcare more effective by providing models reflecting a particular healthcare unit. It also designs and develops intelligent solutions using an ontology-driven approach to automate various repetitive tasks and procedures within PED.

The proposed work gives a state-of-the-art ontology-driven approach to building CA as a mediator (assistive technology) between patients and healthcare users to enable practical and useful interactions before or upon arrival at the medical department to address some overcrowding issues. This ontology-driven approach helps build conversational models that accurately respond to questions from patients with less urgent needs. These formal ontological models can be utilized in HIS, which allows for the use of semantic techniques to improve information flow and IP in the PED processes. We implemented the constructed models in the form of formal ontologies. These ontological models implementation have been deployed using the web ontology language (OWL/XML) and the *Protege 5.0* ontology editor. For the evaluation of the results, we utilized some ways such as structure evaluation, semantic relational evaluation, and lexical evaluation using *Protege 5.0* editor and description logic (DL) queries against CQs. In 2nd modelling workshop, we verified the constructed models. During the work, we learned that more modelling workshops are needed to create and evaluate models representing the domain more accurately. HPs are encouraged to be included in the modelling workshops from the very beginning.

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