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Decision support system for in-flight emergency events

Alsane Sene[1,2] · Bernard Kamsu-Foguem[1] · Pierre Rumeau[2]

Abstract

Medical problems during flight have become an important issue as the number of passengers and miles flown continues to increase. The case of an incident in the plane falls within the scope of the healthcare management in the context of scarce resources associated with isolation of medical actors working in very complex conditions, both in terms of human and material resources. Telemedicine uses information and communication technologies to provide remote and flexible medi-cal services, especially for geographically isolated people. Therefore, telemedicine can generate interesting solutions to the medical problems during flight. Our aim is to build a knowledge-based system able to help health professionals or staff members addressing an urgent situation by given them relevant information, some knowledge, and some judicious advice. In this context, knowledge representation and reasoning can be correctly realized using an ontology that is a representation of concepts, their attributes, and the relationships between them in a particular domain. Particularly, a medical ontology is a formal representation of a vocabulary related to a specific health domain. We propose a new approach to explain the arrangement of different ontological models (task ontology, inference ontology, and domain ontology), which are useful for monitoring remote medical activities and generating required information. These layers of ontologies facilitate the semantic modeling and structuring of health information. The incorporation of existing ontologies [for instance, Systematic Nomen-clature Medical Clinical Terms (SNOMED CT)] guarantees improved health concept coverage with experienced knowledge. The proposal comprises conceptual means to generate substantial reasoning and relevant knowledge supporting telemedicine activities during the management of a medical incident and its characterization in the context of air travel. The considered modeling framework is sufficiently generic to cover complex medical situations for isolated and vulnerable populations needing some care and support services.

Keywords Information processing · Knowledge-based system · Ontologies · Safety · Aeronautics

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1 Introduction

1.1 Relevance

At this time, the practical and straightforward implementations of safety management systems are a key factor in a proactive view of flight safety with shared obligatory guidelines defined by the international civil aviation authorities (Cacciabue et al. 2015). In critical situations, the determination of an appropriate airport and an optimal path planning in detail all the way during the flight until the landing is a challenging task to do well, particularly in emergencies (Pritchett and Ockerman 2016). Ground personnel performing more enriched flight following actions may aid the flight crew personnel in assessment of any non-nominal event (Lachter et al. 2017). In complex and uncertain environments, non-routine critical events generate a high demand on cognitive resources in operators, and predictive aids are established according to relevant look-ahead times and transparency of underlying prediction mechanisms (Minotra and McNeese 2017). The design of more adaptable patterns concerning the air traffic control is useful for debriefing controllers after critical events with lessons learnt and improving future actions, such as the provision of new decision aids and role allocation (Kontogiannis and Malakis 2013).

Considering the increase in air traffic, long-haul international flights, low-fare service with reduced comfort, and the age of passenger (affluent pensioners with good activity level but chronic medical conditions), it is more than likely that in-flight medical incidents might increase. Presently, medical incidents are estimated worldwide at 350 per day, this is 1 for 14,000–39,600 passengers. In 69% of the cases a medical opinion is provided on board (Lapostolle et al. 2010). It is but over a quarter of the cases which are not properly recorded so as to be used to improve mitigation measures and safety guidelines (Mahony et al. 2011; Lapostolle et al. 2014). In Hinkelbein, et al. (2013), authors have reported that most common in-flight medical emergencies are heart problems (50.3%), infectious diseases (27%), and neurological problems (23.4%). On-board commercial passenger aircraft, passengers, and crew are isolated from outside medical intervention. Companies and their staff are required to provide "…the protection of the health of passengers and crews on international flights is an integral element of safe air travel and that conditions should be in place to ensure its preservation in a timely and cost-effective manner" (ICAO, A35-12 resolution). Therefore, flight attendants should have some level of paramedical training, and emergency boxes are provided by the companies. By chance, some passengers may have some medical training. However, even if a physician happens to be on board, it is unlikely that both of them will be aware of the aeronautic context, necessary skills for managing an emergency and knowledge of aeronautic medicine.

Developments in the information and communication technologies provide new services in various domains. The processing capacity is gradually becoming more efficient to work on challenging projects. These new opportunities for communication help increase the number of collaborative systems and online services. A variety of fixed and mobile devices and infrastructure can be included in these collaborative systems for the establishment of remote services. In light of more interactive environments, the use of ontologies in medicine is generally directed on the representation and (re-)organization of medical terminologies. Physicians established their own specialized languages and lexicons to aid them store and communicate common medical knowledge and patient-related information with effective ways. Such terminologies, adjusted for human processing, are characterized by a substantial amount of implicit knowledge. Medical information systems, on the other hand, require to be able to communicate multifaceted and comprehensive medical concepts clearly. This is evidently a difficult task and needs a deep analysis of the organization and the concepts of medical terminologies. Nevertheless, it can be accomplished by building medical domain ontologies for representing medical terminology systems.

Our contribution will be initially made to the contextual level within a knowledge-based framework in order to facilitate links between information that supports medical arguments during a flight incident. Medical services can now be provided, in time, by a remote physician who can deliver specialized medical advice to the aircraft crew and passengers with medical skills on issues related to medical events that happen on aircraft in order to help ensure the appropriate management of in-flight medical emergencies. During the use of knowledge-based system (KBS), the agents interact with the system to address a given issue. We can consider three models in designing such a system, a conceptual model and a knowledge model that defines the system and its dynamics and the organizational model that defines the interaction between actors and the system. The proposed system uses knowledge-based techniques (e.g., controlled terminologies and their semantic structuring, standards for representing clinical decision logic to enhance communication and sharing of experiences among actors) to support human decision-making. This research brings a conceptual advance (i.e., explicit knowledge representation for a thorough understanding of in-flight medical events) and a technical advance (i.e., construction process of contextual mini-ontologies for improvement of flight crew response to an on-board medical emergency).

1.2 Target research work

In this paper, we will rather work on the knowledge model. We will explore the use of some standardized vocabularies and medical terminologies for describing in-flight medical incidents. This work is a part of our research activities that promotes intelligent use of computational method to apply for information and knowledge in a target domain. In a previous paper, we have stated evidence-based analysis to assist clinicians in complex decision-making processes. We are currently intended to provide adequate knowledge-based support for our system. In addition to search appropriate knowledge, our work also takes into account problems related to the exploitation of big ontologies. In fact, as ontologies become numerous and more complex, the challenge for their management increases, so it is difficult to understand the structure and the dynamics of a whole ontology or to perform effective reasoning adequately in an unassisted manner (Mortensen et al. 2015). Many of the biomedical ontologies contain a significant number of elements and relationships among those elements. For instance, Systematic Nomenclature Medical Clinical Terms (SNOMED CT) contains three hundred thousand concepts and relations. This suggests that with the manipulation of considerable conceptual elements, it is challenging to apprehend the properties of an entire ontology or to conduct sufficient and appropriate verification procedures.

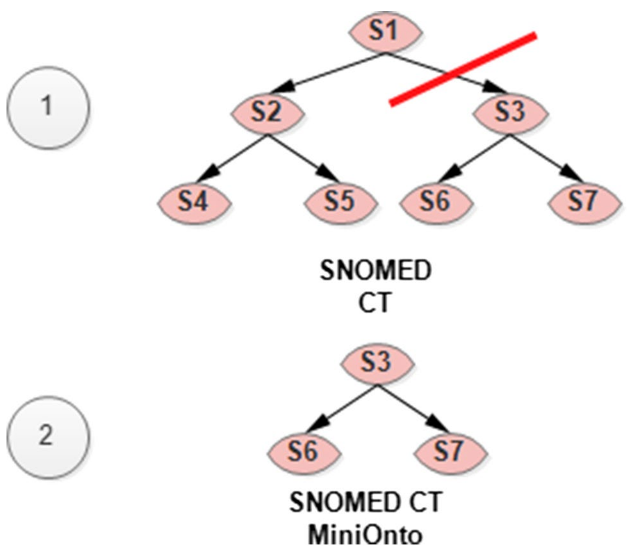


Fig. 1 Concepts reduction in SNOMED CT using the part of ontology without loss of relevant information

A lot of knowledge structures covering various medical areas exist. For instance, a Web portal called BioPortal provides access to services with a library of biomedical ontologies and terminologies (OntoUrgence, International Classification of Diseases (ICD), SNOMED CT) through Web services (Whetzel et al. 2011). So in the context of commercial airline flights, these web services can be used to download ontologies, to get ontology mappings and to search within ontologies. The benefit of the modern web services is to provide the essential information about the amount of data that will be transferred and processed for the management of medical emergencies. Indeed, the web services are very helpful for generating views of detailed content portions of a wide range of ontologies such as the ones described in International Classification of External Causes of Injuries. The medical incidents in the plane are already categorized. However, there is a need to improve the formal ontological representation of these categories of medical incidents. Such a formalization of ontological categories is useful for different reasoning purposes including information retrieval, automatic alignment procedure, and knowledge discovery. Alignment would be considered if there is a need to extract knowledge from different ontologies (Figs. 1, 2), and the complexity of this extraction tends to increase with the number of ontologies. Hence, there is a requirement to support the reduction in the number of concepts extracted from these ontologies.

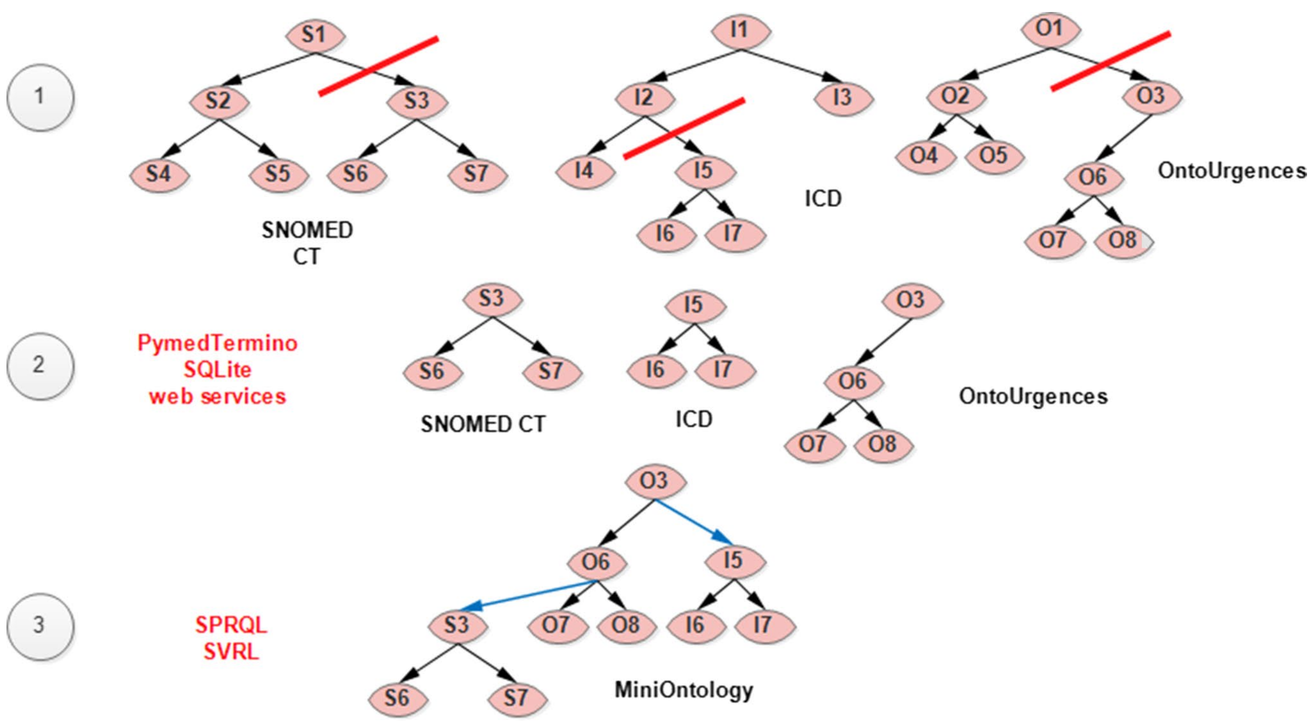


Fig. 2 Alignment of concepts on both the ontology specificities and the strategy of knowledge reasoning

The technical implementation is performed by combining three tools:

1. SNOMED CT datasets that we downloaded from the United States of America's National Library of Medicine (NLM) (Download the US Edition of SNOMED CT),
2. PyMedTermino (PyMedTermino documentation) that is a Python module for easy access to medical terminologies like SNOMED CT and ICD,
3. Eclipse platform with Web Ontology Language (OWL) Application Programming Interface (API) (OWL-API) to manipulate ontologies.

The remainder of this article will be organized as follows: Sect. 2 presents the related works. Section 3 provides materials, which will enable us to spread out our motivations, the choice of our tools, their organization and not only their interactions but also the state of the art necessary to understand these choices and motivations. Section 4 will provide the suggested knowledge-based method in order to support semantic reasoning. Section 5 provides two clinical case studies in remote locations. Section 6 shows discussions on the proposed method with an assessment of the results achieved. Section 7 presents the conclusions with prospects for future works.

2 Related works

Publications regarding in-flight medical events (associated with in-flight treatment and diversions) are described in the scientific literature (Mattison and Zeidel 2011; Shaner 2010; Valani et al. 2010; Sand et al. 2009; Delaune et al. 2003; Sirven et al. 2002). These events comprise an extensive spectrum of illnesses; from the trivial illnesses (e.g., mild headache) to the very serious ones (e.g., heart disease and stroke). Improved computational use of existing categorizations of in-flight passenger medical incidents will add value to the management of some in-flight medical emergencies. The idea is to include standardized vocabularies and ontologies like SNOMED CT to enrich the computational support information that will be used in the management of in-flight medical events and to use this opportunity to check the coverage of different medical scenarios by these knowledge structures.

Like medical accidents in commercial flights, medical problems in a nursing home care (nursing home for dependent elderly people) occur in an environment with limited human and material resources: The paramedical staff must decide whether the patient requires an intervention with internal or external means (call to the treating doctor or transfer to a hospital structure). Given the shortage of geriatricians, telemedicine (used both real-time and store-and-forward high-intensity approaches) would be an excellent modality to reduce the rate of visits and hospitalizations in emergency departments (Morley 2016). The demographic profile (including age and gender distribution) is different from gerontology (older adults) to aircraft (child, adult, and older persons), but senior passengers require specific attention, since they particularly are subjected to multiple pathologies and polypharmacy (taking multiple medications). However, there is not a negligence of the medical problems concerning other passengers (child and adult persons), since there is a distinction between diseases and the effects of normal aging. The differences between gerontology (long-term patients' resident in hospitals or medicated houses) and in-flight medical events including emergencies are the following:

- age distribution of concerned patients: All age groups are affected by in-flight medical events, whereas only older adults are patients in a nursing home care.
- availability of technical facilities and caregivers (medical or paramedical staff): Direct access to skilled health professionals is limited for in-flight medical emergencies (cabin crew are trained to provide first aid and limited medical assistance), while a nursing home care has a medical service consisting of qualified nursing staff and the on-duty or on-call doctor system for emergencies.
- transfer possibilities to health structures: Given the potential urgency of a medical situation, the flight crew members should consider their diversion options that require coordination with air traffic control and other parties (medical, operational and commercial partners). In nursing home care, the medical transports may use the conveyance by land, water, or air for emergency medical services (ambulance or paramedic services).
- Frequency of events: The occurrences of emergency events are potentially more numerous in nursing homes than in commercial airlines.

Flight crew responses to an in-flight medical event depend on the nature of the problem, the degree of urgency for medical intervention, and the location and stage of flight in which the situation occurs. Flight crew members are trained to provide first aid and restricted medical assistance inclusive of retrieving any required emergency equipment. They are trained to administer oxygen to passengers manifesting breathing difficulties and qualified in cardiopulmonary resuscitation (CPR), with eventually an automated external defibrillator (AED). Flight crew are not qualified to administer drugs nor diagnostic and invasive medical instruments. In the absence of a medical professional, many air carriers have a permanent agreement with emergency medical service providers for complex medical complaints. These service providers can be used both pre-flight and in-flight and can be contacted by means of digital data link systems for the transmission of messages between aircraft and ground stations. Even with a qualified medical practitioner on board, in the event of a serious medical condition with a significant risk affecting vital organs (i.e., brain, heart, lungs, liver, pancreas and kidneys) of the body, remote communications with an emergency room/trauma center physician is possible for diagnosis and advice regarding on-board treatment, continuation of the flight, or diversion.

KBSs are intended to improve the quality of care for patients. Within the context of the in-flight medical incident, these systems can help to overcome the lack of resources and ensure the pre-hospital phase. More recently, logistic drones are engaged to respond to medical emergencies through their use for the transport of medical supplies and blood during a critical demand period (Thiels et al. 2015). Pre-hospital medicine is crucial and works along these lines are realized, notably with medical drones which could play a role to improve patient condition (e.g., for improvement of cardiac arrest response times) (Pulver et al. 2016). Many methods are used to build KBS. This is often referred to Computerized Clinical Decision Support System (CDSS) in the health field (Cho et al. 2010; Osheroff et al. 2007; Wright et al. 2015). In a review 92 articles, (Fraccaro et al. 2015) show that 47.7% of identified works use knowledge representation as methodology for clinical decision support.

The principal methodologies for clinical decision support are summarized in Table 1 (Greenes 2014). According to different authors, on the one hand, ontologies are used to find information or to answer questions, and the other hand probabilistic methods, heuristic models are used to establish diagnosis, to make therapeutic reasoning. For what we are concerned, we will show that it is possible to use ontologies to establish diagnosis.

3 Conceptual system development

The system could be used in an aircraft cabin with necessary adaptations required to comply with appropriate international standards and procedures. For instance, this system must be in line with Regulation (EU) 2017/745 of the European Parliament and of the Council of April 5, 2017, on medical devices including software. Section 17 of this regulation stipulates that the software that is intended to be used in combination with mobile computing platforms shall be designed and manufactured taking into account the specific features of the mobile platform (e.g., size and contrast ratio of the screen) and the external factors related to their use (varying environment as regards level of light or noise).

Figure 3 shows different stages of KBS realization. Initially we focus on the stages of design and development,

Table 1 Methodologies for clinical decision support (reproduced with permission from Greenes 2014)

Methodology	Major uses	Key developments
Information retrieval	Finding information, answering questions	Taxonomies, ontologies, text-based methods, patient-specific context keys, automatic invocation
Evaluation of logical conditions	Alerts, reminders, constraints, inferencing systems	Decision tables, event-condition- action rules, production rules
Probabilistic and data-driven classification or prediction	Diagnosis, technology assessment, treatment selection, classification and prediction, prognosis estimation, evidence-based medicine	Bayes' theorem, decision theory, ROC analysis, data mining, logistic regression, artificial neural networks, belief networks, meta- analysis
Heuristic modeling and expert systems	Diagnostic and therapeutic reasoning, capturing nuances of human expertise	Rule-based systems, frame-based reasoning
Calculations, algorithms and multistep processes	Execution of computational processes, flowchart-based guidelines and consultations, interactive dialogue control, biomedical image and signal processing	Process flow and work flow modeling, guideline formalisms and modeling languages
Associative groupings of elements	Structured data entry, structured reports, order sets, other specialized presentations and data views such as flowsheets, dashboards, and trend plots	Report generators and document construction tools, document architectures, templates, markup languages, ontology tools, ontology languages. Also improved models of cognition and workflow, human factors, and usability

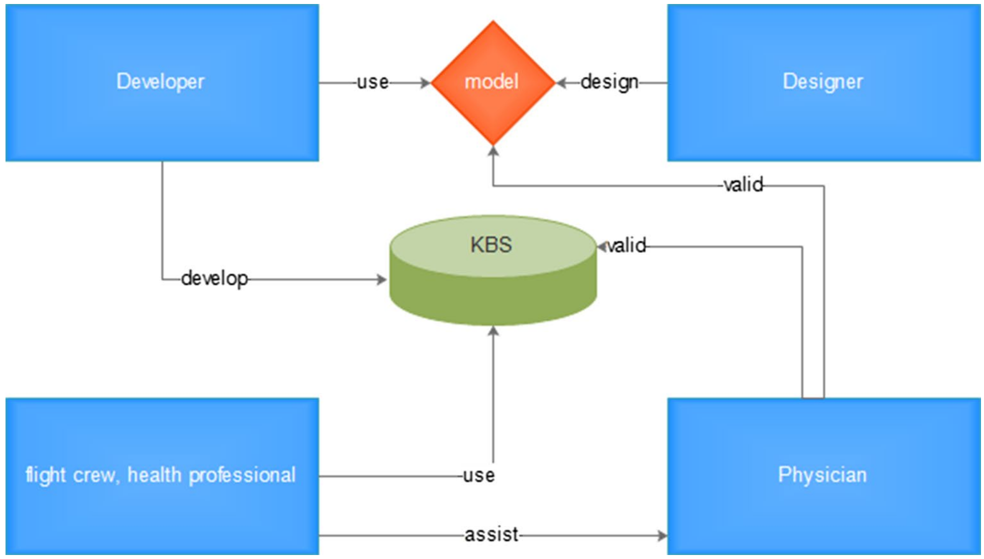


Fig. 3 Life cycle of the decision-making tool with Collaboration between stakeholders is necessary from start to finish

which is the main issue that concerns us. The designer provides a model validated by professionals to the developer. For the situation being considered, this is a KBS model that must be validated by health professionals before use.

The design phase is carried out by using models that will be studied in depth: conceptual, organizational, and knowledge models.

3.1 Conceptual model

A conceptual model is an abstract and finalized representation that takes into account multiple facets and types of useful knowledge for the system to respond to identified needs. System modeling is the construction of an abstract description that shows a functional, structural, or behavioral aspect of the system with an interpretable language in order to represent reality for reasoning and decision-making (Kamsu-Foguem 2014a). The generated conceptual models must be defined in terms of specific notations that provide a rich semantics. This enrichment can use logical predicates in a formal language that software applications and human actors can read and understand. In the conceptualization processes, the ontologies can be engaged in specifying the semantic meaning of the models within telemedicine systems (Kamsu-Foguem 2014b). It is for this reason that ontology specifications are one of the key elements of the proposed research work (La-Ongsri and Roddick 2015) (Sene et al. 2015). A formal ontology specification is described using a language that contains adequate mathematical semantics that provides two main advantages (1) an interpretation of descriptions that guarantees the absence of ambiguity in the models produced and (2) reasoning procedures for the analysis of the specified descriptions utilized to infer new knowledge or to verify the properties of models. Two examples of languages that allow formal ontology specifications are the Description Logics (Baader et al. 2003) with good expressiveness and Conceptual Graphs (Sowa 1984, 2000; Chein and Mugnier 2009) with its visual reasoning.

Today the most common definition of ontology is the one provided by Gruber (Gruber 1993), which indicates that an ontology is a formal specification of a shared conceptualization domain. The ontologies are increasingly acknowledged as being the basis for Semantic Web solutions, which have business applications ranging from information from mixed sources to optimal information retrieval, identification of relevant context-based information and support for decision-making (Khattak et al. 2015).

Figure 4 presents the different types of information that we will have to deal with in the rest of the paper. In a KBS, the available measurements and observations, supported by the knowledge and beliefs, are used to make decisions on how to better serve the target objectives. The decision-making process can be optimized by the use of different types of evidence (coming from meta-analyses, systematic reviews, and randomized controlled trials) (Sene et al. 2015). Given the features of the different types of evidence, the information can be weighted differently in order to yield informed decisions with associated recommendations.

In the area of medical information representation, it is noted that the word terminology is used very often. On the correspondence between terminology and ontology, some authors like (Ben Abacha and Zweigenbaum 2015) (Burgun et al. 2011) see ontology as the formal outcome of the definition of terminology. Other researchers such as (Doumbouya et al. 2018 and Sene et al. 2018) saw third-generation terminologies as a base for a formal model with symbols, which is used to denote concepts and a set of rules to manipulate them. Therefore, terminologies can sometimes meet the

Fig. 4 Nature of the information treated in KBS tools

definition of an ontology. In this article, the use of the word terminology will denote ontology (regardless of its level of expressiveness and formalization).

3.2 Interaction-oriented software system

We will quickly review the structural organization of the proposed system that defines the interactions between the components of the software application. This is necessary, in order to have a better understanding of the whole system. This interaction-oriented software structuration defines how the system works, the interaction with agents that have knowledge, and preferences. The ontologies provide a way to organize the agent's knowledge. They also permit us to take into account the agent's preferences in an easier way. The organizational model integrates the social and cooperative nature of the design process through the representation of actors' roles that also have an impact on the knowledge reuse process (Ben Miled 2014).

Figure 3 shows the process of building a KBS with associated decisions. In the model of organization, we will explain how it works, by using the different agents involved and their interactions. Figure 5 shows the functioning of a decision-making tool. We reason about the formal model built from different types of information.

Table 2 shows the actors involved in the construction and utilization of the KBS.

The most broadly renowned nomenclature and medical classification in healthcare are, respectively SNOMED CT and ICD. In the context of medical documentation and information, SNOMED CT provides the logical definition of concepts with their attributes, whereas ICD delivers textual descriptions of rules and definitions.

During the phase of use, clinical signs observed on the patient, coded in natural language or not, are sent to the system. On the basis of the collected information (clinical state, medical history and behavior), and in connection with the information process, the KBS system will be in charge of providing indications related to a diagnosis and the associated treatment if it is possible (Fig. 6).

3.3 Knowledge model

The knowledge model that will be the focus of the implementation section describes the system reasoning. It defines the knowledge that may require the system to function properly. Most of the existing works separate knowledge models into three layers (Schreiber et al. 2000). This subdivision facilitates the reuse of KBS because it separates the data and the tasks used to manage them.

- Domain layer: It essentially consists of multiple domain patterns and multiple knowledge bases.
- Tasks layer: It describes what must be done by the KBS (processing and modeling tasks).

Table 2 Actors and their involvement in the KBS

Actors	Level of involvement
Designer	Construction of the model
Developer	KBS development
Health professional	In all parts
Aircraft crew	During use

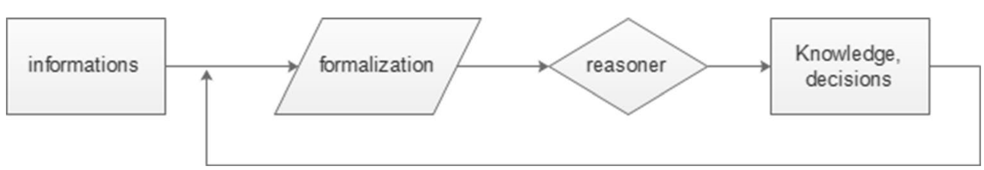


Fig. 5 From information to knowledge and decisions

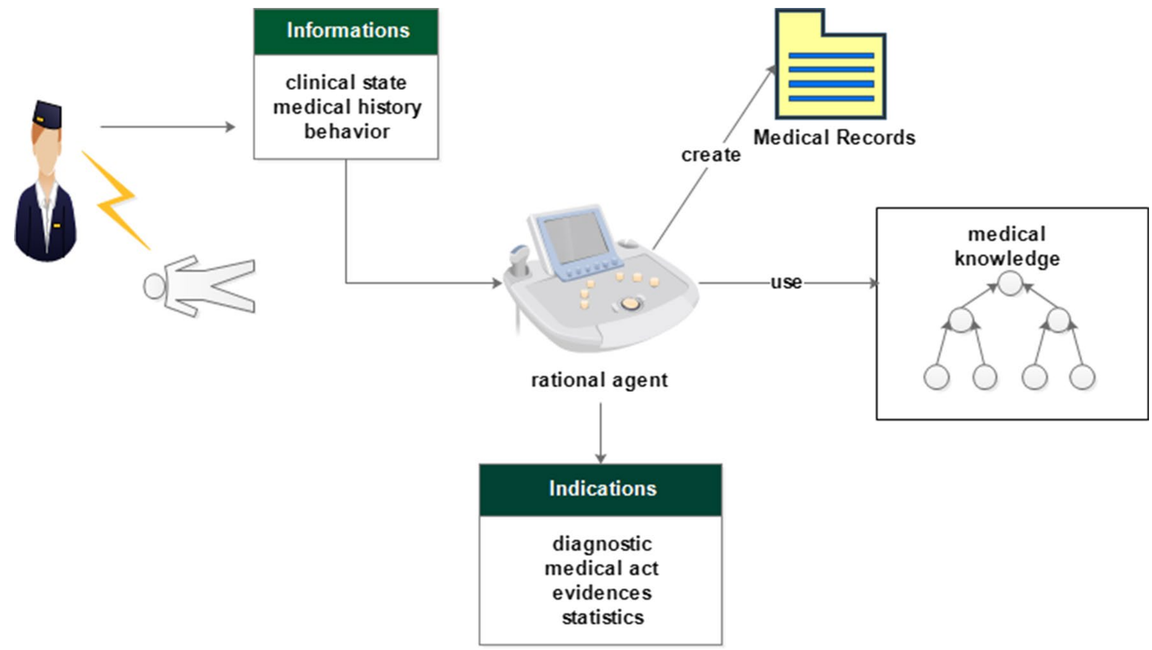


Fig. 6 Diagram of interactions with the proposed system

- Inference layer: It describes how the domain pattern structures are used to run a reasoning process (e.g., primitives: get, receive, submit, and provide).

In knowledge modeling, the choice of terminology resources is imported to support the development of consistent information exchanges and collaborative programs. Knowledge resources can facilitate electronic communication services and reasonable management procedures with transparency requirements. As stated above, we will explore SNOMED CT possibilities to support knowledge representation and reasoning.

3.3.1 SNOMED CT

SNOMED CT (Systematized Nomenclature of Medicine Clinical Terms) is a comprehensive clinical terminology. It was created by merging of SNOMED RT (Reference Terminology) developed by the College of American Pathologists and the third version of "Clinical Terms" developed by the British National Health Service. SNOMED CT has an ontological basis with active concepts (more than 310,000) and relationships. It is used for the coding of clinical information, indexing and for the pragmatic description of medical documents, SNOMED CT presents a multiaxial nomenclature covering the fields of human medicine and dentistry. It is used to capture and represent patient data for clinical and administrative purposes. SNOMED CT is currently available in different languages including English, Spanish, and French (interfaced with ICD). It transmits information input to the Electronic Health Record (EHR) during the course of patient care, and therefore it could be used to develop decision support tools.

The highest level concepts in SNOMED CT are structured into 19 different conceptual elements (clinical finding, procedure, observable entity, body structure, organism, substance, pharmaceutical/biologic product, specimen, special concept, linkage concept, physical force, event, environment or geographical location, social context, situation with explicit context, staging and scales, physical object, qualifier value, record artifact). Each of the elements covers different facets of healthcare.

In this context, we provide a brief description of certain highest concepts of SNOMED CT. They are selected according to their general use. Figure 7 shows some relevant concepts that are used in clinical records without further elaboration. For instance, the concept of clinical finding covers all clinical disorders and examination findings. The particular characteristics of a conceptual element can be used to express relationships between it and other concepts. For example, in order to describe some attributes in the characterization of patient condition, the linkage concept *Finding site* indicates where a disease is located in the body (e.g., the disease pneumonia has *Finding site* equals to lung structure).

Hierarchy	Description	Examples
Clinical finding	***What phenomena are observed*** Contains the sub-hierarchies of Finding (symptoms) and Disease. Important for documenting clinical disorders, symptoms and examination findings.	• Swelling of the arms (finding) • Pneumonia (disease)
Procedure	***What is being done*** Purposeful activities performed in the provision of health care.	• Biopsy of lung • Diagnostic endoscopy • Chest x-ray
Event	***What is taking place*** Describes the situation around the individual at a specific time which is relevant to their healthcare. This does not include procedures or interventions which are in the Procedure hierarchy.	• Flash flood • Motor vehicle accident • Exposure to measles virus
Observable Entity	***A quantitative observation*** Terms that are used to record measurements, readings, numerical results or dates and always have an associated value entry.	• Body weight • Tumor size • Date of admission • Range of hip abduction
Situation with Explicit Context	***Phrases that need to be recorded in the patient record but change the default context.*** So for example, about another family member, is absent, has happened in the past. (Note. See glossary for DEFAULT CONTEXT)	• Family history of stroke • No nausea • Blood transfusion declined • Aspiration pneumonia resulting from a procedure • Has infirm partner
Pharmaceutical/ biologic product	***A drug or other substance that is used to treat a patient*** This hierarchy is separate from the substance hierarchy in order to clearly distinguish drug products (products) from the chemical constituents (substances) of drug products.	• Tamoxifen (product) • Tramadol (product) • Multivitamin tablet (product) • Sex hormone product

Fig. 7 SNOMED CT concepts habitually used in clinical records without further elaboration (reproduced with permission from SNOMED CT 2012)

4 Knowledge-based method supporting medical reasoning in remote locations

Temporal data representation and reasoning are very important in order to extract knowledge from massive data and therefore for constructing the timelines for the medical histories of patients (Madkour et al. 2016). Medical knowledge is very concerned by diverse aspects of uncertainty, and hybrid frameworks (including Bayesian probability theory, evidence theory, and fuzzy set theory) are suggested to manage the epistemic uncertainty of medical prognosis and diagnosis (Janghorbani and Moradi 2017). Through combining the properties of fuzzy logic and neural networks, fuzzy cognitive maps (FCMs) are efficient models in designing medical decision support systems (MDSSs) and their applications for the decision-making, diagnosis, prediction, and classification (Amirkhani, et al. 2017). Representing case-based reasoning (i.e., a problem-solving paradigm that uses past knowledge to solve new problems) knowledge using the fuzzy ontology and building a fuzzy semantic case retrieval algorithm using an SNOMED CT fragment improves the accuracy of the resulting systems (El-Sappagh et al. 2015). Table 3 illustrates a situation of teleconsultations with using the system are possible through interactive telemedicine services that deliver real-time interactions between cabin crew and the physician on the ground. Many potential advantages of telemedicine can be envisaged, including: improved access to information; improved access to medical services (i.e., advanced diagnostic methods); reduction of the intervention times; improvement of the quality of interventions, increasing efficiency in care delivery (e.g., therapy delivery in the most efficient way); and reduced healthcare costs (AlDossary et al. 2017).

To build knowledge, we need patterns which will allow the characterization of patients, diseases, and treatments because it should be noted that our goal is to link each

Table 3 This table shows the improvement in healthcare circuit care using our tool

	
Stroke (CVA) diagnosis remains to be confirmed	Stroke (CVA) diagnosis confirmed during teleconsultation Can be improved using KBS which provides sufficient and adequate information to link symptoms to right disease
Revascularization with thrombolysis is required	Revascularization with thrombolysis is required Using KBS weights this assertion by providing knowledge
Stroke confirmed by physician after direct observation	Can be deleted with KBS The system produce adequate data to confirm pathological state
Direct observation of vital functions	Overview of vital functions during teleconsultation Can be deleted with KBS
NIHSS evaluation	It can be incorporated in KBS (CDS) tool Can be improved using KBS
Taking over: patient in hospital	Can be improved using KBS serving as a log for previous actions

Steps are deleted without being detrimental to the effectiveness of care services. The assistance with such a tool promotes the best medical care available

patient suffering from diseases to a set of treatments validated by evidence. Working with such approach facilitates the mixture of reasoning operations and eases the processing of contextually pertinent information.

A person (P) with symptoms (S) suffers from a disease (D) that can be managed with a treatment (T). The description of this knowledge can be represented in formal logic using the implication and conjunction:

- $(P \bigwedge S) \Rightarrow D$
- $D \Rightarrow T$

It is mainly on the basis of these concepts that the reasoning will naturally be done, but at the same time it will take into account the context and the requirements of the concerned situations. It should be noted that in the field of medical knowledge representation, the modeling and the structuring of these concepts is done separately. One of our contributions is to link these concepts in the design phase of KBS.

4.1 Technical architecture

This part will serve to show how our different tools will be used in practice. The first task is the construction of our data and pattern structures. As stated earlier, these models will have certain characteristics of SNOMED CT in order to benefit from the expertise contained in them (Fig. 8).

Once the process of structuring concepts is made, we can reason with the data of patients to find solutions. Looking at the target context (flight), we will have to assess the necessary medical resources. Reasoning methods and decision procedures are facilitated via the assessment of the medical expertise and resources.

In the previous sections, the main characteristics of the proposed KBS are given through the specifications of associated models. For this rather technical phase, the focus will be on the ability to automate the stage of diagnosis with SNOMED CT and to introduce its core components (concept codes, descriptions, relationships and reference sets) to characterize the patient and treatment.

In the assessment phase, we will first consider the ability of SNOMED CT to cover and present signs and symptoms of a patient. Since its creation, SNOMED CT has sought to cover the maximum of clinical terms to express any clinical scenarios (Sampalli et al. 2010).For some works, it is considered as a basis to evaluate the richness of medical terminologies (Yu et al. 2012).

Already before 2003, with textual requests and SNOMED CT data base, the clinical Information System of Cedars-Sinai Medical Center (USA) enabled us to obtain a set of possible diagnosis of medical problems. The place of SNOMED CT in an application is well defined in SNOMED

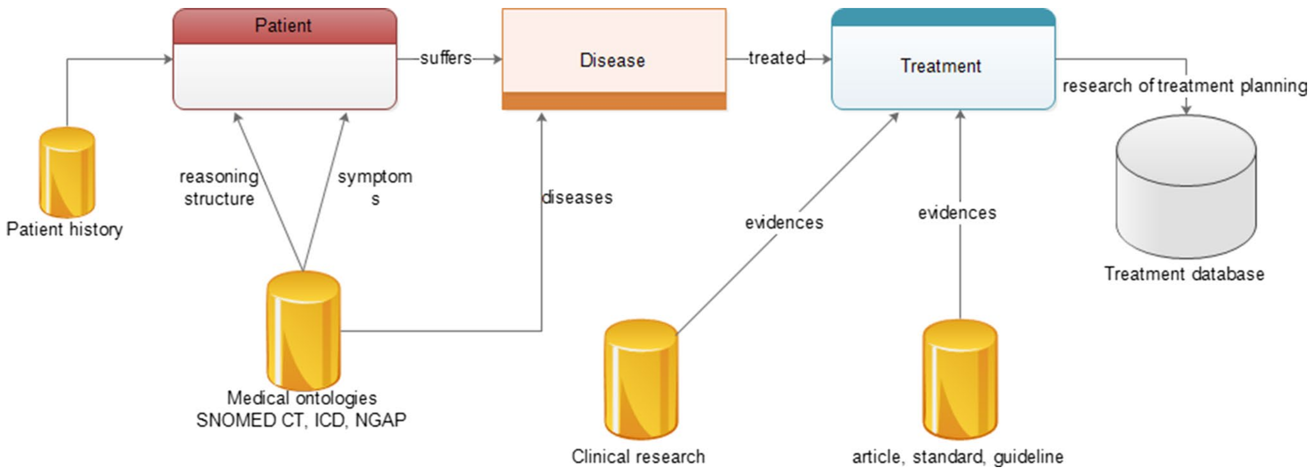


Fig. 8 Medical ontologies characterize patients, diseases, and treatments. Clinical research, articles, standards weight treatments. Case-based reasoning method permits us to use the solutions of similar past cases for treatment planning

CT Technical Implementation Guide, (SNOMED CT 2014) (Fig. 9). The accessibility of open programed services and coding tools, which can yield a categorized list of SNOMED CT descriptors to express in code any clinical information, could aid healthcare professionals to handle the terminology. The formal model underlying SNOMED CT ensures the semantic content and knowledge representation.

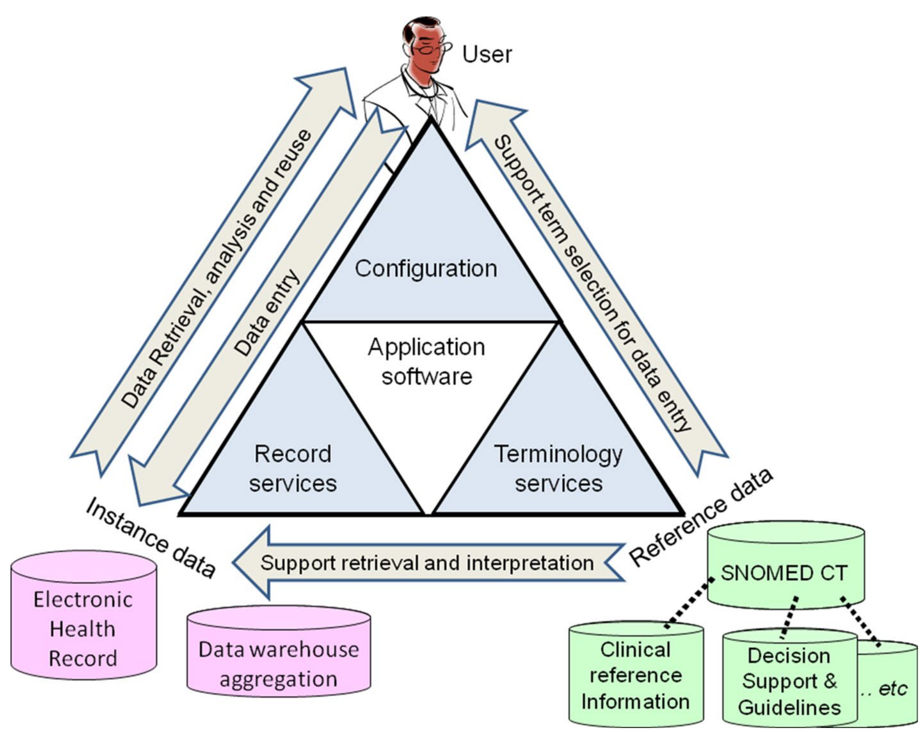
Because of his benefits for Electronic Health Records and Knowledge representation, SNOMED CT can be used in different implementations:

- Clinical records to represent clinical information of patients (Duarte et al. 2014).
- Knowledge representation to model clinical knowledge.
- Aggregation to analyze medical information systems.

4.2 Support for consistent use of SNOMED CT

As with each knowledge representation tool in a medical domain, SNOMED CT needs perfect medical concept

Fig. 9 SNOMED CT takes its importance once implemented as part of an application (reproduced with permission from SNOMED CT 2012)



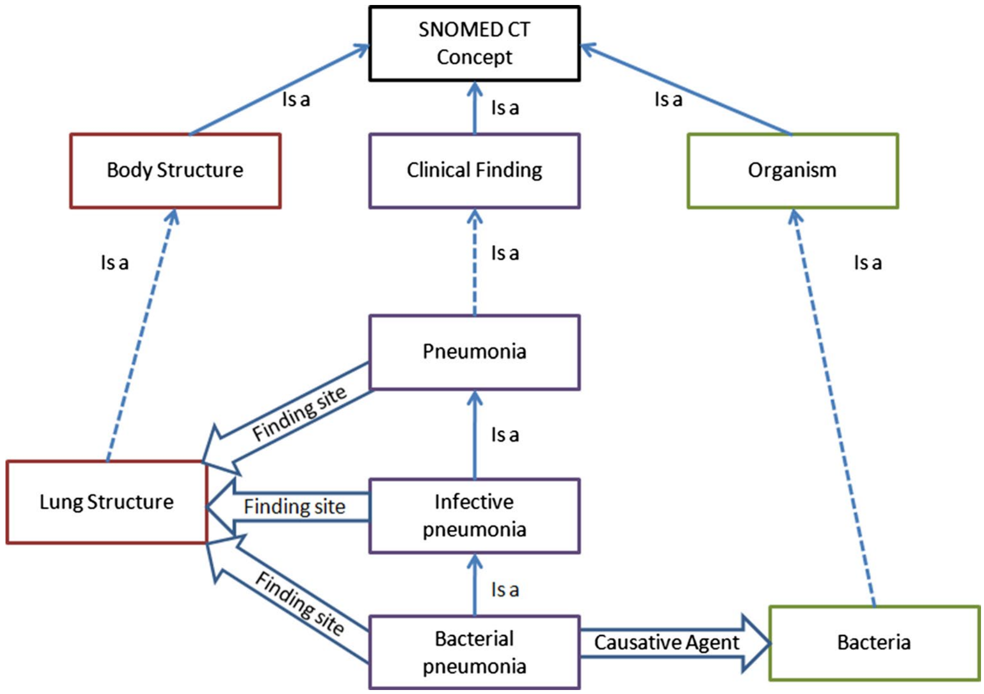


Fig. 10 Relationships in SNOMED CT, this figure shows three relations, is a, finding site, causative agent

coverage (Fig. 10), well-structured concepts and relations which ensure the semantic formalization of models.

In our case, SNOMED CT will serve to characterize the strong links which we want to make between patient, disease and treatment. This is achieved by the use of one SNOMED CT implementation:

- Knowledge representation.

At this level, our contribution will be to tackle the implementation challenges of SNOMED CT (Lee et al. 2013):

- Subset

In this work, we target the causes of medical incidents during flights, not all SNOMED CT content. The main challenge is the creation of substructures respecting the model of SNOMED CT.

- Data retrieval

The accuracy of this data retrieval will depend upon the quality of the model and the knowledge representation.

- Post-coordination

The goal of such a tool is to be used depending on its intuitiveness and unobtrusiveness.

In its structure, SNOMED CT defines two main relationships between concepts:

- The subsumption relation (IS-A) that defines the expressivity level (specialization/aggregation).
- Attribute relationship defines features which characterize concepts and make them different from one another.

Figure 11 shows some indications for consistent use of SNOMED CT in our system.

Regarding its coverage capacity, SNOMED CT offers many benefits (Lee et al. 2013):

- Direct data entry: The mechanism of synonymy and the level of concept coverage offer more possibilities for users' requests.
- Data reuse: Mapping and alignment allow using a part of SNOMED CT or binding concepts with ontology.

For Diagnosis of the Disease State process, SNOMED CT can be used in two main ways.

- Import of the totality of SNOMED CT concepts and relations with tasks in a local environment
- Usage of Web services to have access to SNOMED CT browser available on the Internet.

4.3 Technical implementation

To evaluate the embedded knowledge in SNOMED CT, we downloaded its data from the United States of America's National Library of Medicine (NLM). In order to browse

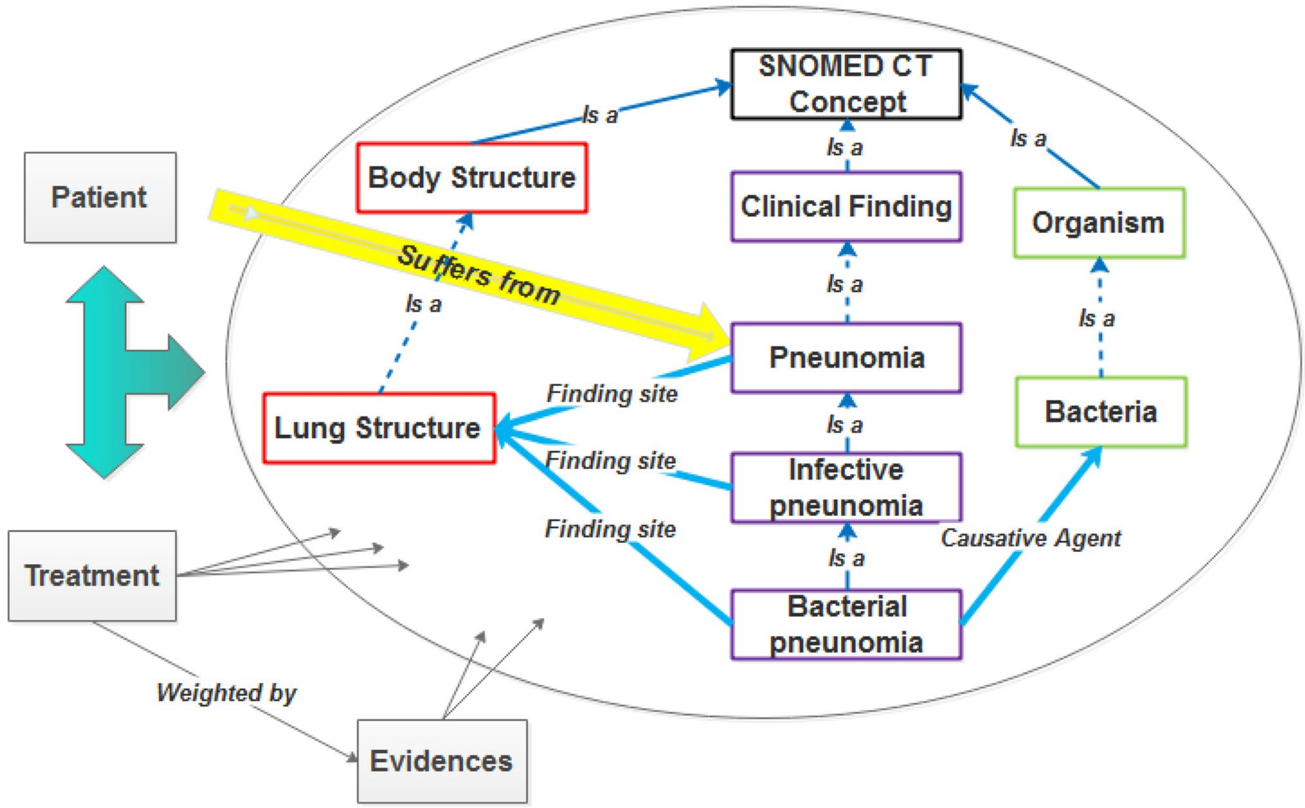


Fig. 11 Use of SNOMED CT across a broad scope of information types (e.g., patient, treatment and disease)

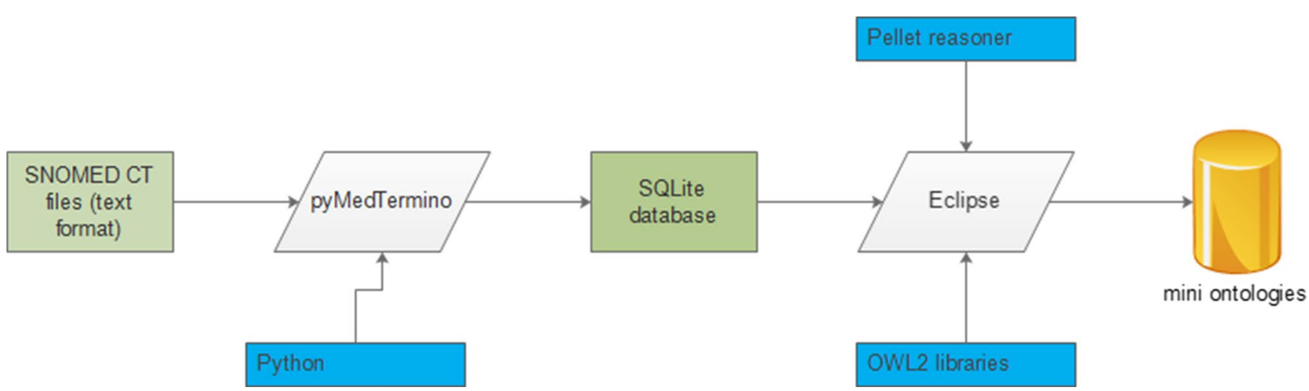


Fig. 12 Construction process of contextual mini-ontologies

concepts in an easier way, the target data were entered into the SQLite software by implementing a transactional structured query language (SQL) database engine. The result is a big knowledge base with approximately a half gigabyte.

The construction process of mini-ontologies is done by using the following tools (Figs. 12, 13, and 14):

- *PyMedTermino* (Medical Terminologies for Python) (PyMedTermino documentation) that is a Python module for easy access to the terminology used and described in SNOMED CT files. The main features of PyMedTermino are: (i) a single application programming interface (API) for accessing all terminologies, (ii) optimized full-text search, (iii) access to terms, synonyms and translations,

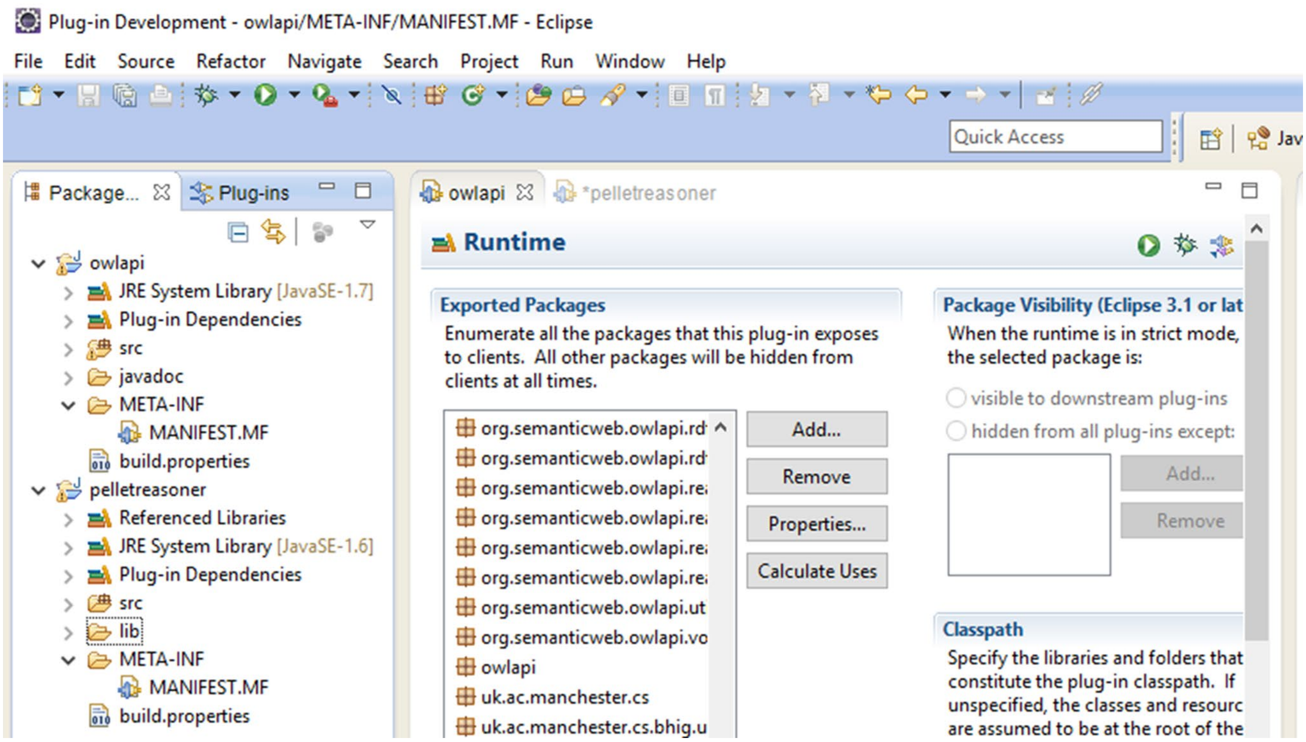


Fig. 13 A java OWL API plugging is added to build mini-ontologies

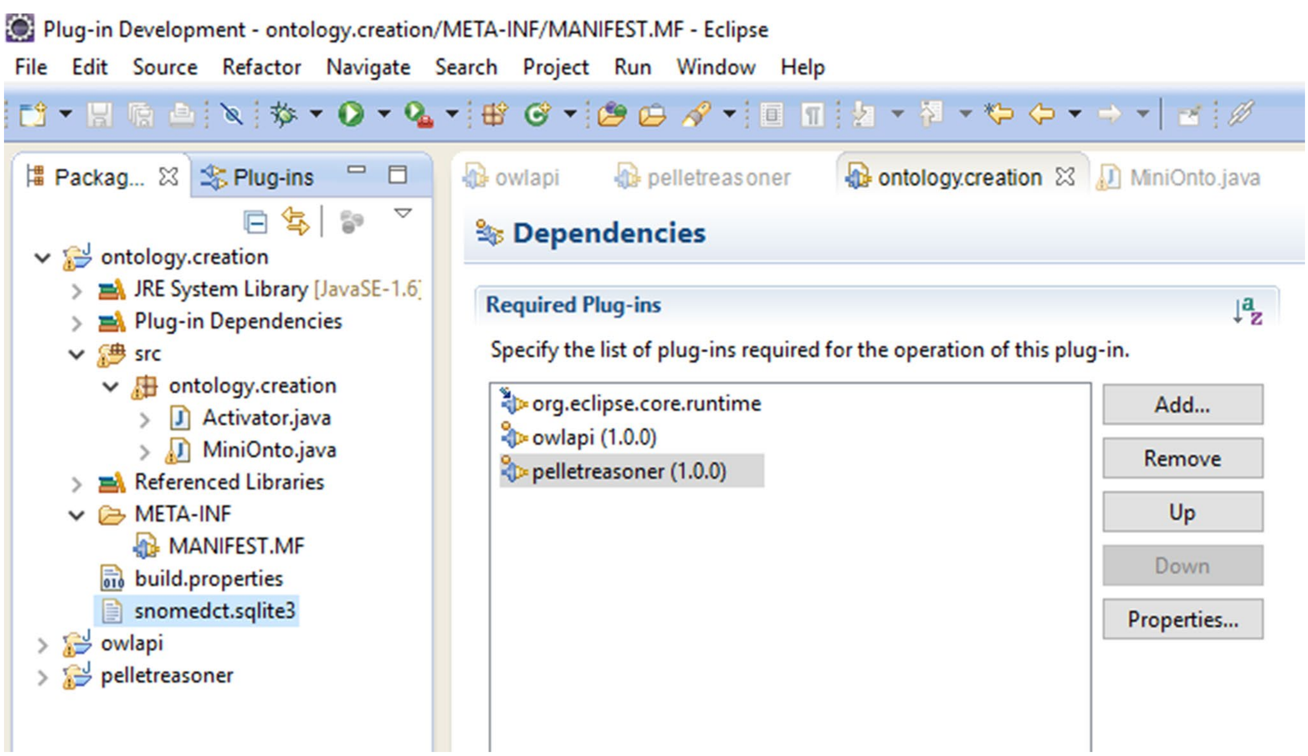


Fig. 14 OWL API, PELLET, and SNOMED CT SQLite database connection. (1) The file snomedct.sqlite3 contains knowledge (2) OWL plugin to build mini-ontologies (3) pellet plugin to check consistency, robustness of new ontologies

(iv) Manage concepts and relations between concepts, and (v) mappings between terminologies.

- *SQLite* (SQLite) is a relational database management system that implements most of the SQL (structured query language) standard. It stores the complete database (definitions, tables, indices, and the data itself) as a single cross-platform file. SQLite supports SQL core functions, Date & Time functions, aggregate functions, and it is connected to the Eclipse programs. It facilitates the usage of data manipulation functions in SNOMED CT files.
- *Eclipse* is an integrated development environment (IDE) that holds a base workspace and an extensible add-on system for adapting the environment. It easily adds new features such as reasoners (e.g., Pellet), or it has the ability to formalize a description of ontologies with a specific language (e.g., Web Ontology Language (OWL)). OWL 2 ontologies deliver classes, properties, individuals, and data values and are put in storage as semantic Web documents. Pellet is at rigorous and comprehensive OWL-Description logics (DL) reasoner with extensive support for reasoning with individuals (containing nominal support and conjunctive query), user-defined data types, and debugging support for ontologies. Pellet is used to perform ontological reasoning such as the consistency checking of the target models or the verification of a subsumption relationship among the concepts. In order to build the contextual mini-ontologies, the subsumption relations between the causes and consequences of medical findings are computed to retrieve semantic matches. This can serve to justify the application of specific rules to these findings.

5 Clinical cases

These clinical cases will show the level of coverage of clinical scenarios used by SNOMED CT and the ability to automate the analysis of care processes by the proposed tool.

This work serves to ensure the efficiency of care processes with the effective categorization of medical incidents during flights of aircraft (Mahony et al. 2011). In fact, in view of the potentially large number of concepts and relationships provided by SNOMED CT, it serves as a reference point in setting a comparison and an aggregation of medical data across different healthcare sites.

Therefore, it is possible to remotely capture and share information and knowledge concerning complex medical cases from isolated areas, even in the case of passengers who are aboard an aircraft. In addition, most of medical flight incidents pose a limited risk because of their nature (e.g., gastrointestinal symptoms such as nausea and abdominal pain), and an appropriate local management of the situation is provided by the aircrews who operate on the aircraft. So, the light medical incidents are exempted from telemedicine and remote assessment to preserve the availability of critical resources and to focus on the technical support on complex and important medical cases of more concern. The emphasis is mostly medical emergencies with the incorporation of pragmatic reasoning mechanisms that take into account clinical experiences, patient preferences and information retrieval.

Case 1 Malaise during a cruise of a 65-year-old woman. One observes right hemiplegia and aphasia (Lambert et al. 2008).

Observations: Malaise, Aphasia, Hemiplegia.

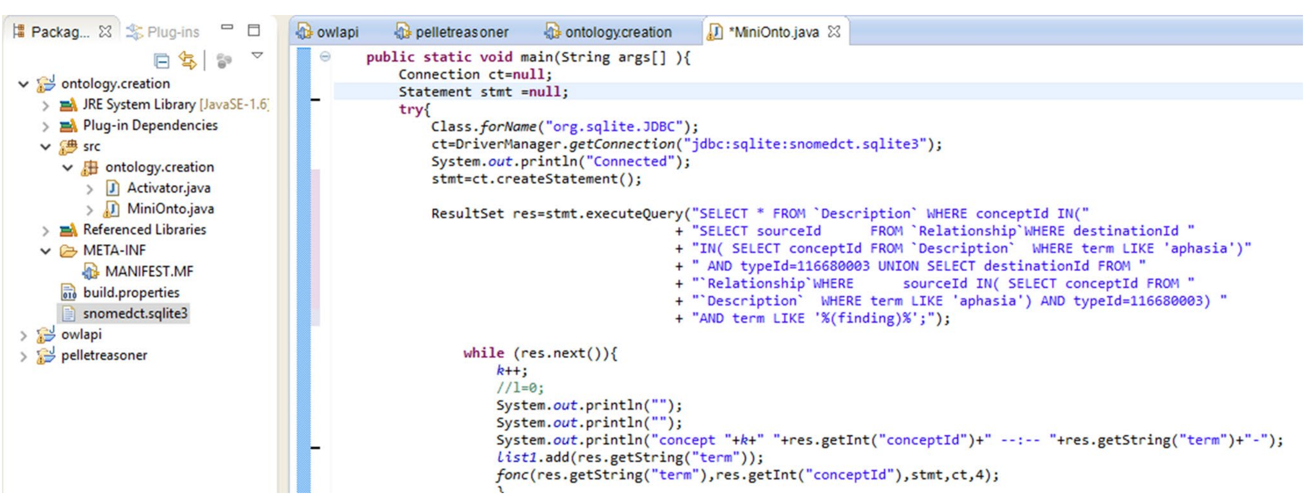


Fig. 15 Aphasia query execution

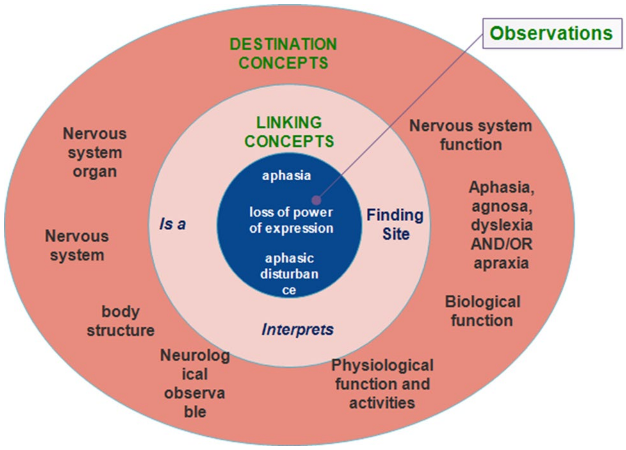


Fig. 16 This figure shows interpretation of observed symptoms related to aphasia

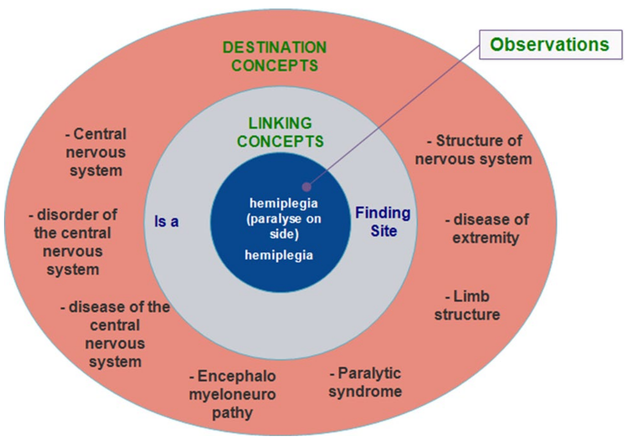


Fig. 17 This figure shows interpretation of observed symptoms related to hemiplegia

According to the process described in Fig. 12, we execute the following query with Eclipse:

```
SELECT * FROM `Description` WHERE conceptId IN(
        SELECT sourceId      FROM `Relationship` WHERE destinationId IN( SELECT conceptId FROM `Description`  WHERE term LIKE 'aphasia')
        AND typeId=116680003 UNION
        SELECT destinationId FROM `Relationship` WHERE      sourceId IN( SELECT conceptId FROM `Description`  WHERE term LIKE 'aphasia')
        AND typeId=116680003) AND term LIKE '%(finding)%';
```

Figure 15 shows the execution of the query in java.

The result obtained allowing the identification of concepts related to the observations of aphasia is displayed in Fig. 16.

According to the process described in Fig. 12, we execute this query with Eclipse:

```
SELECT * FROM `Description` WHERE conceptId IN(
        SELECT sourceId      FROM `Relationship` WHERE destinationId IN( SELECT conceptId FROM `Description`  WHERE term LIKE 'hemiplegia'
        AND typeId=116680003 UNION
        SELECT destinationId FROM `Relationship` WHERE      sourceId IN( SELECT conceptId FROM `Description`  WHERE term LIKE 'hemiplegia'
        AND typeId=116680003) AND term LIKE '%(finding)%';
```

The result obtained allowing the identification of concepts related to the observations of hemiplegia is shown in Fig. 17.

Information on Fig. 17 is obtained from the observations of involved concepts, which are organized concentrically; in the center a main concept of the concerned disease. In addition, it is possible to achieve various forms of visual reasoning (e.g., similarity or dissimilarity) that will facilitate a deeper analysis and linkages between concepts. For example, a deeper analysis of the underlying causes of physical symptoms may reveal serious medic problems that require the involvement of the telemedicine acts. Figure 17 shows an example of a clustering of symptoms whose conceptual links help to explain the diagnostic procedure (Fig. 18).

Table 3 shows benefits from using our tool in the first clinical case.

In the considered first case study (case 1), the medical problem concerns an acute stroke management in which time is absolutely of the essence, and bringing swift treatment to the patient is a potential strategy to improve clinical outcomes after stroke (Fassbender et al. 2017). Particularly, emergency treatment with thrombolytics given into the vein for ischemic stroke in the carotid territory should be started within a maximum of three hours. Quick treatment not only improves the chances of survival but also reduces complications; in this precise case, the passenger diagnosed with stroke has received the timely and effective care measures with a complete neurological recovery. The realization of this telemedicine procedure within the recommended delays was driven by a combination of favorable factors: good anticipation, speed of mobilization, and implementation of the various medical and rescue means.

Case 2 On a more generic level, we will work with the description of the most observed symptoms (Fig. 19) of in-flight medical incidents (Mahony et al. 2011).

These symptoms are widely found in the structure of SNOMED CT. Take as an example, the case of chest pain is shown in Fig. 20.

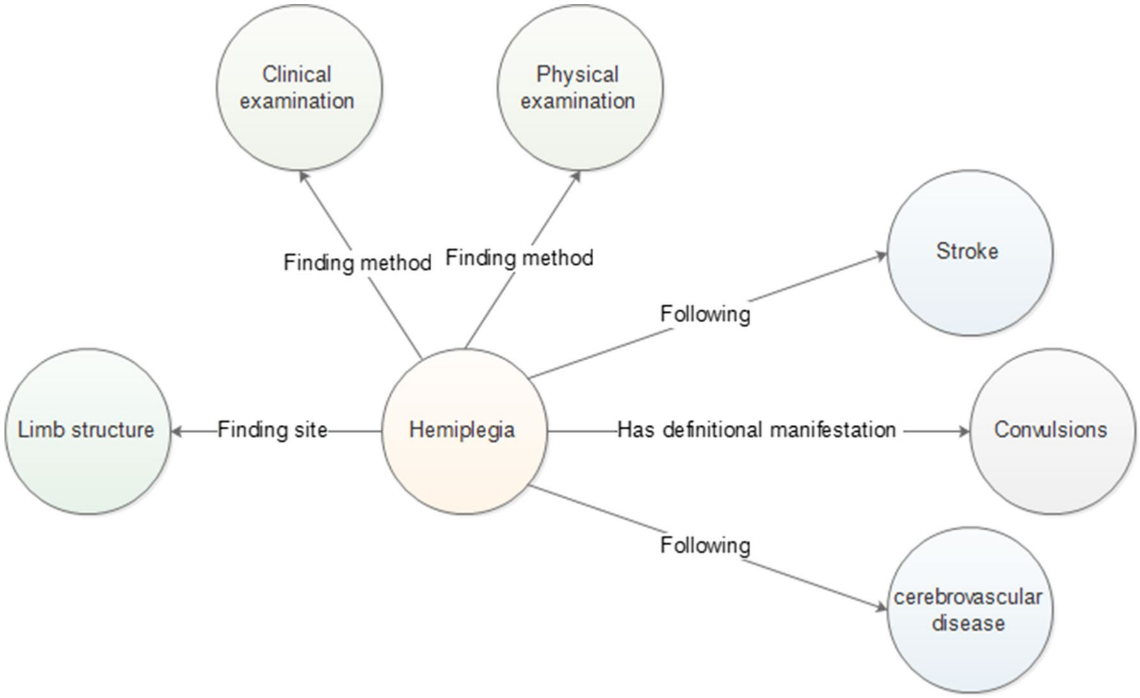


Fig. 18 We obtain all Hemiplegia concepts from the description defining the structure of SNOMED CT. This reasoning structure bounds Hemiplegia concepts to the attributes allowing the characterization of signs. Hemiplegia can be observed by clinical or physical examination. It can be a consequence of Stroke or cerebrovascular disease and is typically preceded by convulsions

Symptom Descriptors and Attributes	*N*	%
Unconscious: rapidly recovered	4648	41.1
Nausea/vomiting/diarrhea	2214	19.5
Breathing difficulty	1805	15.9
Pain–no other symptoms	569	5.0
Behavioral	367	3.2
Injuries	287	2.5
Chest pain	258	2.3
Allergic/skin	257	2.3
Unconscious: slow or delayed recovery	176	1.5
Unconscious: no recovery	135	1.9
Congested/fever	131	1.2
Seizure	120	1.1
Advice/undetermined	115	1.0
Bleeding no injury	86	0.7
Collapse-injury sustained	67	0.6
Limb swelling	60	0.5
Limb/facial weakness	19	0.2
Urinary	8	<0.1
Pregnant/in labor	4	<0.1
Total reported incidents	11,326	

Fig. 19 Most observed symptoms of in-flight Medical Incidents according to Mahony et al. (2011)

It is possible to specify and clarify the types of symptoms to better characterize this pain, its severity, location, and occurrence.

For a considered medical problem, the relationships between the concepts describing the identified symptoms

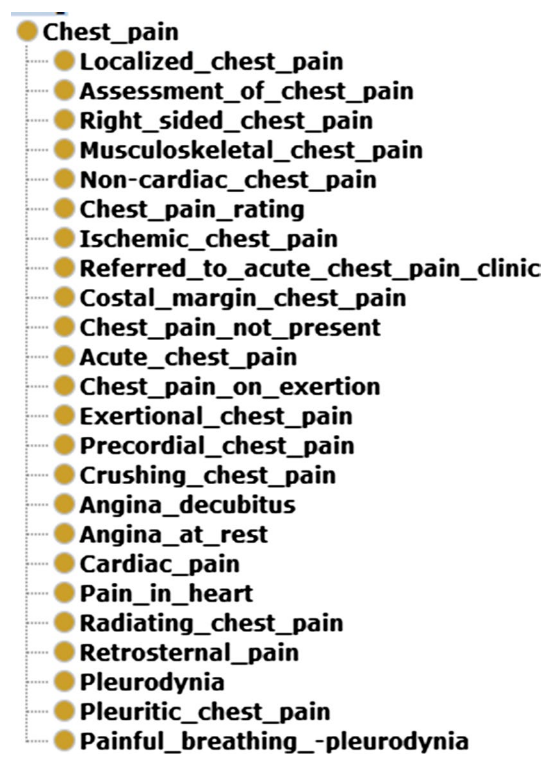


Fig. 20 Chest pain concepts

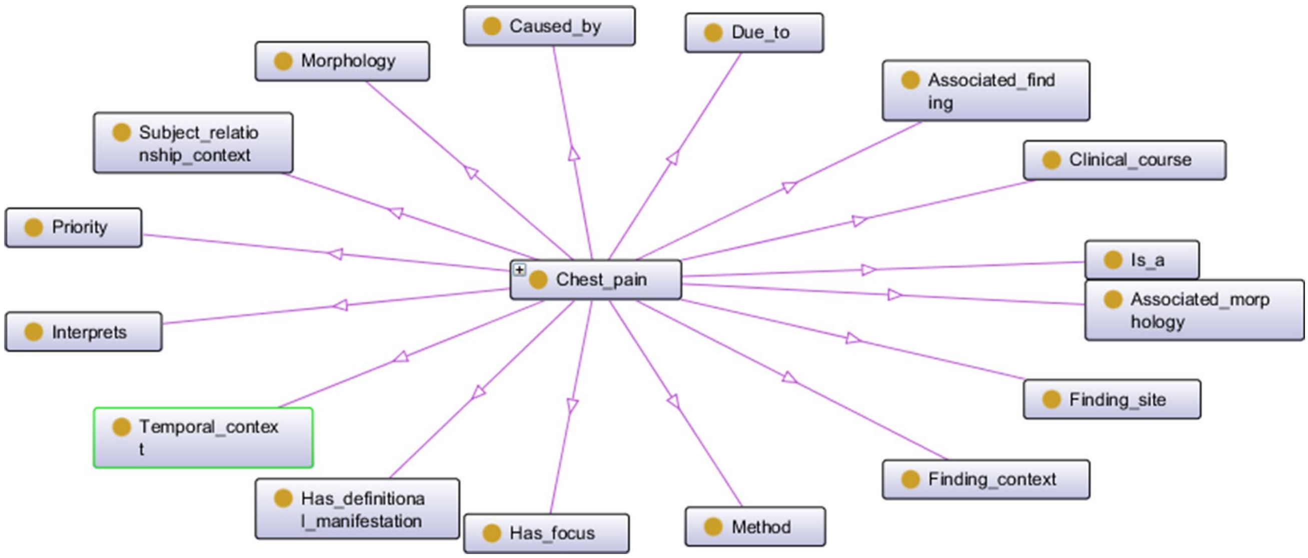


Fig. 21 A set of chest pain attributes relationships. This relation allows interpretation of chest pain signs (localization, manifestation, following)

can guide reasoning services; e.g., for diagnostic procedures of chest pain (Figs. 20, 21). This is quite useful in verifying the analysis of identified complex problems, since there may be a multitude of diagnostic choices.

As indicated at the beginning of this paper, we use SNOMED CT for its broadly known nomenclature in healthcare. The information gathered in this way can be used in telemedicine, but it must be restructured and contextualize, which is the objective of our proposal.

6 Evaluation and discussion

The purpose of this work is to identify potentially knowledge structure for the management of an in-flight medical incident and shows the way of semantic analysis done from symptoms observation to treatment suggestions. The reasoning system is mainly driven by the ontologies' characteristics to improve information retrieval and knowledge sharing in medical emergencies where people are geographically isolated. SNOMED CT provides a standardized terminology that covers adequately the semantic description of in-flight medical emergencies. The formalized reasoning procedures support a knowledge model proposed to deal with such cases of medical scenarios. The arrangement of the different ontological models is interesting, since it has considerable flexibility and is able to provide a coherent and multilayered response to a very challenging scientific topic. Task ontology provides a clarification of goals targeted by the application, and an explanation of the problem-solving structure for achieving these goals. Inference ontology describes the logical rules that can be applied to assertions included in a knowledge base to deduce new information. Domain ontology offers the domain specific knowledge to contextual requirement of the target application, and delivers the detailed representation. The inter-ontology relationships, as well as the gradual advance from an ontological level to the other one, are important factors in the progressive and proper implementation of the ontological arrangement. This is an important part of the research methodology for effective communication and decision support in the context of in-flight emergencies.

Three types of evaluation covering three different objectives have been made in our system. We will start considering the formal evaluation to verify knowledge structures. The evaluation of performance studies the technical criteria concerning the time of data processing. Finally, the expert evaluation is done in our case with a panel of 11 physicians to ensure realistic modeling that considers the diversity of medical specialties and the experience levels of medical professionals.

6.1 Formal evaluation

This assessment is focused on semantic reasoning including ontology alignment and information retrieval. We compute less data because this alignment will be done after the recovery of needed knowledge. In our case, we use one structure of knowledge. The entire ontology (SNOMED CT) is already validated by experts; it was only to ensure that the queries for information retrieval using provided procedures are fair and reasonable.

6.2 Evaluation of performance

The use of our system is subject to the availability of a connection and access to sources of knowledge through

Table 4 This table presents how different concepts are processed using or not our system

Incident	Without mini-ontologies	With mini-ontologies
Scalable SNOMED CT evaluation		
Aphasia	300,000 concepts	300 concepts
Hemiplegia	300,000 concepts	250 concepts

Table 5 Health professional's analysis

Advantages	Future works for total care plan integration
Health professional's analysis	
Coverage of in-flight medical incidents	Dynamic aspect management Deviation management
Scalability of medical information retrieval	Scheduling medical tasks

Web portals such as BioPortal. Today, Internet access with the wireless Internet on international flights is emerging as a service signifier for leading airlines (https://skift.com/2016/02/19/air-france-is-finally-bringing-in-flight-wi-fi-to-international-flights/). The novel systems with tap satellite links provide coverage on transcontinental flights and improve connectivity by aiding to resolve the difficulty of bandwidth reduction http://www.pcmag.com/article2/0,2817,2499722,00.asp). In-flight Wi-Fi service is provided by satellites located around the world, but satellite coverage may have outages for causes such as national regulations, weather, and switching between satellite geographic areas (https://www.united.com/web/en-US/content/travel/inflight/wifi/default.aspx).

These services support download speeds used to load the data and information, and it is typically obtained at a speed of the order of a good asymmetric digital subscriber line (ADSL) connection (in the range of 9–14 Mbps). This also underscores the importance of optimized procedures (through mini-ontologies) to ensure compliance with the volume of data exchanged during a telemedicine session. Table 4 indicates the ratio between the total number of concepts available in SNOMED CT and the number of concepts covering the target case study. Reduced volume of data exchanged increases flows of information, which provides clear benefits to the remote medical collaboration. Particularly, the construction of mini-ontologies provide significant added value for semantic reasoning with a selection of the most relevant and useful concepts for the target context. In the considered case (as described in Table 4), there is a reduction from three hundred thousand concepts to three hundred concepts with a ratio of about one per thousand.

6.3 Expert evaluation

It is the study of our system by health professionals (Table 5). As noted, this has been done by a set of 11 physicians who were asked questions about the coverage of the suggested knowledge model and the usability of the proposed tool.

The health professionals surveyed agreed with the suggested approach, but they encourage the use of an evolutionary approach in developing the models of the proposed knowledge system. This is expected to facilitate the consideration of dynamic requirements existing in the medical field, as this is an essential element for the management of evolution in patients' needs and professional practices.

Regulations on mandatory and optional emergency equipment that are carried on board commercial aircraft vary by National Aviation Authority. Medical equipment available on board includes one or more of the following elements:

- Therapeutic oxygen fitted with a regulator and mask for respiratory problems,
- Automated external defibrillator (AED) for heart related emergencies,
- Physician's Kit comprising various drugs (e.g., sedative anticonvulsant, corticosteroid, antiemetic, diuretic) and both diagnostic and invasive medical instruments (e.g., stethoscope, sphygmomanometer, intravenous fluid system, thermometer, emergency tracheal catheter).

In fact, the idea is to improve diagnostic and checking capabilities during flight to orient and improve medical services on the ground. Utilizing checklists and forms proposed by the considered system, the flight attendants can establish and record the patient's personal data (gender, age, height and weight, etc.), their medical history (established health issues, medication, known allergies, former illnesses or surgeries), their present vital signs (pulse rate, blood pressure, etc.), and the symptoms and signs that they are exhibiting. The benefits of telemedicine compared to just calling a physician on the ground are in terms of traceability of actions and the correct transmission of data. Indeed, the obligation to have access to the patient record during the implementation of the act of telemedicine is accompanied by an obligation to trace in the record, in real time, the conditions of realization of the act as well as its conclusions with medical prescriptions. Cabin crew are usually trained in emergency first aid procedures in which the proposed system can be included. The training would provide a visual presentation and some elements of video, with interactive exchanges to develop and communicate an understanding of software functionalities for medical emergencies. Concerning legal aspects, in case of medical errors related to using (or misusing) the telemedicine tool (considered as a medical device) on board an aircraft, requesting physicians, airline company, or health facilities could see their committed responsibility under French law (Article L1142-1 of the French Public Health Code). It should be noted that they have the possibility of filing a recourse action against the technological third party concerned for breach of the obligations described in the contractual documents between them. Therefore, it is important to inform users of any residual risks and to make a proper analysis about options for the elimination or reduction of risks related to use error.

7 Conclusion

In this work, our proposal relies on ontology-based reasoning that support collaborative decision-making processes to deal with potential In-Flight Passenger Medical Incidents. The architecture of the methodology being considered contains two levels:

- First at the context level, needs are defined based on the characterization of the features associated with the problems being considered. The context is important to take into account the significant parameters of situation description and problem analysis in order to provide a tool that will be effective and accepted by all concerned parties. The context can be three-dimensional, with it includes the environment, application area, and application purpose. According to the taxonomy of telemedicine proposed by (Tulu et al. 2007), delivery options and communication infrastructure are the two other useful dimensions for consideration.
- Then at the technological level, technical choices are made in order to minimize computation time (e.g., processing time or space consumption) with respect to contextual constraints affecting the efficiency of the target KBS or clinical decision support system (CDSS). In the context of telemedicine activities, the combination of knowledge base, an inference engine, and a mechanism to communicate is interesting to improve the recommendations and clinical advice for patient care.

In telemedicine acts, the context has attributes, or variables that must be taken into account. Therefore, knowledge representation and reasoning can contribute to offering an effective KBS supporting telemedicine acts. To achieve this, we will choose to use ontologies which could be understandable not only for computer systems but also for humans. They encode medical knowledge in both machine and human interpretable formats. This aspect is very important when developing applications to perform complex reasoning in critical care situations. Our choices are based on already existing terminological supports of knowledge representation such as SNOMED CT for characterizing concepts like disease and treatment. Our goal as in our previous work is the use of the most appropriate knowledge representation and reasoning tool for each task in complex critical situations.

The proposed approach is defined to describe the underlying system's characteristics in order to improve the management of in-flight medical emergencies, by providing a groundwork for semantic reconciliation between the three kinds of ontological knowledge. This is fundamental to develop operational principles and to provide practical guidance with regard to the appropriate adjustments for useful semantic links between computer process view and human interaction view. This research approach providing a system using the arrangement of multilayer ontologies can have advantages and disadvantages. The advantages are among others the high cohesion, low coupling, and ease of modification, whereas the disadvantages are often linked to the code navigability and the possible inconsistency of multiple representations. The use of reasoning tools like the formal semantic one engaged in the suggested methodology improves and streamlines the course of care. Developing such a tool is also complex. It is crucial to find computerized clinical tools that can meet the needs in the context of telemedicine as a solution to the lack of healthcare delivery in aircraft. This work shows that the conceptualization of such a tool is possible in a collaborative medical environment. The challenge is to show how to adapt this tool to each user. How to organize the content offered to the user? How to exploit the knowledge resulting from the characterization of the patient in order to perform other sub-processes of the KBS?

Characterization of the key clinical concepts facilitates the diagnosis phase that is a key step for a good medical care. Existing terminologies such as SNOMED CT can help in this characterization by facilitating the structuration of diagnosis means, and the establishment of required treatment plans. As a result, the aid suggested is transitory, i.e., it does not define a full-care pathway. The definition of care pathway is complex, so the associated problem-solving processes must really be beneficial in practical ways. As for example, by providing intelligent solutions that would be in the likeness of these treatment plans in relation to the concerned diseases, it is possible to put in place more scalable and more effective knowledge-based systems.

At this stage of development, we have described a method to design a decision support system for aircraft medical incidents (SADIMA) by proposing a solution to the issues presented by the information management and knowledge representation for procedures used in the telemedicine implementation process dedicated to the management of in-flight medical emergencies. The next steps that would be needed to increase the technology readiness level (TRL) and concretize this project are:

- benefit–risk analysis and risk management (e.g., known or foreseeable risks and warnings (ISO 14971)) consistently on the avionics conditions,
- usability analysis using an intuitive and user-friendly interface taking into account the aeronautical conditions and the stress of the user,
- software verification (testing performed both in-house) and validation (in a simulated or actual user environment prior to final release) under aviation medicine conditions,
- Surveillance activities and post-production monitoring (e.g., information concerning safety or performance generated from the practical use of the system).

Authors' contribution AS contributed to literature search and review, manuscript writing, and study conception and design. BKF contributed to analysis and interpretation of information, knowledge verification and enrichment. PR drafted and critically revised the manuscript.

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