Bridging the Narrative Gap in Healthcare: One Framework at a Time

Udaya Varadarajan* and Biswanath Dutta**

* Documentation Research and Training Centre, Indian Statistical Institute Bangalore Centre, 8th Mile, Mysore Rd, RVCE Post, Bengaluru, Karnataka 560059, Department of Library and Information Science University of Calcutta, 87, 1, College St, Calcutta University, College Square, Kolkata, West Bengal 700073

** Documentation Research and Training Centre, Indian Statistical Institute Bangalore Centre, 8th Mile, Mysore Rd, RVCE Post, Bengaluru, Karnataka 560059

* udayav@drtc.isibang.ac.in, ** bisu@drtc.isibang.ac.in

Udaya Varadarajan is a research fellow at the Documentation Research and Training Centre (DRTC), Indian Statistical Institute, India. She is a doctoral student in the Department of Library and Information Science at the University of Calcutta, Kolkata, India. Her current research interests are in ontologies and knowledge graphs.

Biswanath Dutta is an Associate Professor at DRTC of the Indian Statistical Institute Bangalore, India. He holds a Ph.D. in LIS from the University of Pune for his research conducted in ISI Bangalore. He was a Post-Doctoral Fellow at the Department of Information Engineering and Computer Science of the UniTn, Italy (2009-2012). He worked as a research assistant at the Department of Computer Science, Dalhousie University, Canada. He actively worked on EU-funded research projects. Currently, he is handling research projects on "COVID-19 and knowledge graph" (https://www.isibang.ac.in/~) and on "Facility for transforming library data to linked library data" funded by ICSSR, Govt. of India. His current research interests lie in ontology, metadata, knowledge graph, data science, and semantic technologies.

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Abstract: The goal of this study is to develop a semantic artifact for capturing and inferencing medically significant information from the patient narration. The motivation for such a framework emerges from the understanding of the significance of patient narration and its underutilization. The ontology which borrows from the theories of narration and its components, supports the capture of the narrative detail in medicine. Existing ontology-based narrative models also contributed to this study. A phased approach was adopted to fulfill the objective. A foundational framework was established during the initial phase, while the subsequent phase involved data modeling. A three-way evaluation was also performed to validate the model.

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1. Introduction

Electronic health records (EHRs) are a major tool for data capture in the medical domain. Applications such as OpenEMR, OpenMRS, etc. capture medical data. The medically significant data captured by such a system include demographic details, vitals, reason for visiting, medications, allergy details, and so on (Dick et al. 1997). These medical data captured in EHRs are mostly structured data. Another area of medically significant data is the clinical narration. This narration is mostly unstructured and capturing unstructured data in the medical domain is challenging (Stewart and Roter 1989).

The narrative data is often not captured. If such data is captured, they are often recorded in the notes section of software systems as free text. These narrative data encompass various aspects such as concerns, expectations, feelings, and thoughts (Robertson and Clegg 2016; Stewart and Roter 1989). Narrative information helps clinicians (i) work more efficiently, (ii) obtain a better understanding of their patients and (iii) deepen the "therapeutic, personal, and social dimensions of patients' and doctors' lives. They can also supplement existing evidence-based care in medicine (Barber and Moreno-Leguizamon, 2017).

According to Charon et al. (2017) narrative medicine "began as a [...] discipline to fortify healthcare with the capacity to skilfully receive the account persons give of themselves, to recognize, absorb, interpret, and be moved to action by the stories of others". Narrative medicine finds a place in various medical specializations such as veterinary study (Ware 2017), nervous system, pulmonary diseases (Cappuccio et al. 2018; Cappuccio et al 2019), genetic conditions (Ragusa et al. 2020), gastrointestinal (Zhang et al. 2020), oncology (Mohanti 2021), dental practice (Huang et al. 2021), and psychiatric practices (Dosani 2021). It has also affected the practices of clinical notes and records. Patients now add to the record by sharing their experiences, thoughts, and feelings concerning the disease (Murphy et al. 2017). Other studies (Ciotti et al. 2018; Lemogne et al. 2020; Wesley et al. 2018; Yang et al. 2018; Zaharias 2018) detail the impact of narrative in medicine including the personalization of rehabilitation goals and programs, increase in the care and concern, and emphasis on factors such as communication, movement, personal care, people and social life (Muneeb et al. 2017).

Domains such as literature and cultural heritage have adopted ontologies to capture the narrative information [1] . Certain works are detailed in the literature review section. However, despite the significance of narrative information in medicine, the capture of the narrative data is unorganized and is regrettably underutilized beyond its immediate use in patient treatment (Varadarajan and Dutta 2021). Such information has the potential to provide valuable conclusions or inferences.

With this motivation of capturing and inferring the patient narration, the present ontology was developed. While there are various data capture and inferring methods, ontology-based capture was selected for the current study. Gruber (1995) defines ontologies as formal and explicit specifications of a shared conceptualization. They encompass various features, including knowledge structures, conceptual definitions, relational connections, and categorization (King and Reinold 2008; Gruber 1993). They help in extracting the non-explicit relations, navigation, creation of a "web of connections" (King and Reinold 2008), reasoning the knowledge base, formally representing computable models, and so on (Dutta 2017; Sinha and Dutta 2020). Specifically, in the domain comprising narration, the ontologies are used for their ability to pull out genres and media types, support narrative argument and automatic reasoning, help AI-based systems in their early stages, express, understand, and reason about the order of events, and allow them to work together. The current study contributes towards:

– Identification of the common elements of narrative for modeling narrative information
– Ontology for patient narrative grounded on the canons of narrative theories, biomedical philosophies and principles of knowledge representation

The paper is organized as follows: the Literature Review in section 2 discusses the related work. The methodology in section 3 describes the steps followed for accomplishing the goal as well as the designed ontology. Section 4 concludes the paper by discussing the observations and future work.

2. Literature Review

A literature study was conducted to review the existing works on ontology-based narrative models. Here, we analyze literature on ontology in support of narration across domains. This study will help identify the elements required for modeling narrative information. The studies of Winer (2014) and Varadarajan and Dutta (2022) provide a review of the existing ontology models for narration. The study identified domains of cultural heritage, literature, mythology, and transmedia as major areas of application of ontology for narrative capture. Some works that have ventured into modeling the narration or have been implemented in some systems are also detailed in this section.

Some of the earliest works on ontology for narrative capture were carried out in the 2000s. Peinado et al. (2004) developed an ontology for automatic story generation using Propp's principles of fairytale narration with the following major classes of the model:

1. Roles (example, agent, donor, hero, etc.)
2. Place (city, country, etc.)
3. Character (animated objects, animal, human)
4. Description (family, human and place)
5. Symbolic object (ring, towel, etc.)

The classes were linked using the spatial, temporal, and descriptive properties such as before, after, during, starts-before, inside, outside, has a description, and so on. Mulholland et al. (2004) developed an ontology that ran in the back end of an application "Story Fountain." The ontology was constructed to map the cultural artifacts of the heritage sites with an ability to reason. The intended users of the application were tourists and guides who used the system to navigate through the artifact via stories. Swartjes and Theune, (2006) developed a character-centric model for the literary domain. The model, named the Fabula model, captured the event chronology and the causality of the events and highlighted causal relationships. It is developed on the principles of transitions in the event, spatial, temporal, tonal or character and its elements are Event, Perception, Internal Element, Action, Outcome, and Goals. Connections among these elements are established by properties such as motivation, cause, and enablement. For example, the Action of killing a dragon causes the Event, death of the dragon. Fabula model provided an understanding of the elements involved in a narration that is character-centric. Around the same time, Nakasone and Ishizuka (2006) attempted to develop a domain-independent model for narration. The model was majorly event-centric, but the intention was a generic model, as indicated by the top-level classes of the model. They are Concept, Story, Scene, Act, Agent, Event and Relation. Role is a specific topic that is a story or a part of it; Event is a single piece of meaningful information. The class Concept contains the topic or theme for the Story. Story class is the overall story, and the Scene class details the scenes of the story. The relation between these classes is established by the relation hasScene. In a Scene, there is an Act, an Agent and a theme associated with it. These classes are connected via the relations hasAct, hasAgent and hasConcept. Figure 1 provides a diagrammatic representation of the framework.

Archetype Ontology was developed by Damiano and Lieto (2013) for navigating resources in the digital archives through narrative relations. This model elevates the user experience of navigating through resources that otherwise seem disconnected. The model connects the Archetypes to the Artifacts and their relation, building a bigger picture of the story. The classes and the properties of the model are given in Figure 2.

In the domain of journalism, Structured Stories (Caswell 2015) are a platform to document the events and narrative data of journalism. Event frames, produced by the extraction of discrete journalistic events, are termed editorial artifacts. These event frames consist of EventID, Role(s) and Time. The image, audio, etc., are categorized as Discourse elements, while the relationships are categorized under Causal relationships. The ODY- Onto built by Khan et al. (2016) characterizes the narration of a fictional text. The ontology is deployed in the system developed for querying information from literary texts. The structure given in Figure 3 depicts the chief classes of ODY-Onto.

Transmedia Ontology (Branch et al. 2016) was conceptualized for the information retrieval in the context of the transmedia worlds. The ontology helps in inferring connections between elements associated with characters, objects, locations, and events. The connections enable reasoning. A glimpse of transmedia ontology is illustrated in Figure 4.

Biographical Knowledge Ontology (BK onto) captures the life account of people. Used in the StoryTeller system (*http://dlm.csie.au.edu.tw/*), this ontology contains four modular structures. They are the storyline, event, history, and timeline (Yeh 2017). Figure 5 represents sample instances and the classes.

The Drammar ontology is a formal representation of elements of drama that helps the user community by offering a formal description and an autonomous reasoning tool. The

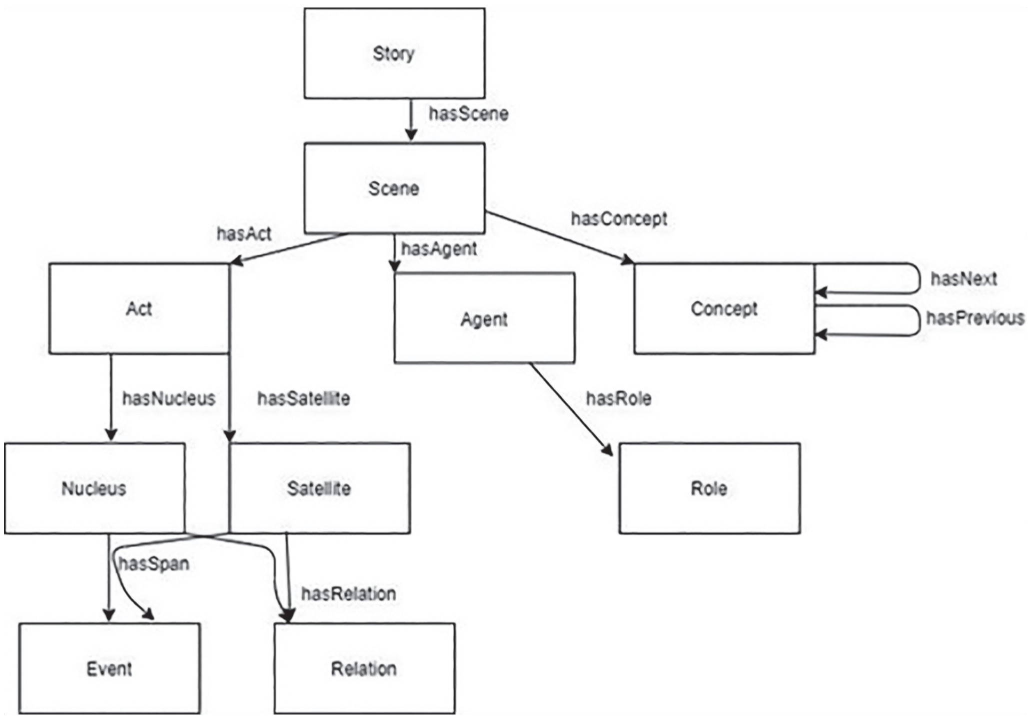

Figure 1. Diagrammatic representation of the domain independent framework for narration by Nakasone and Ishizuka (2006)

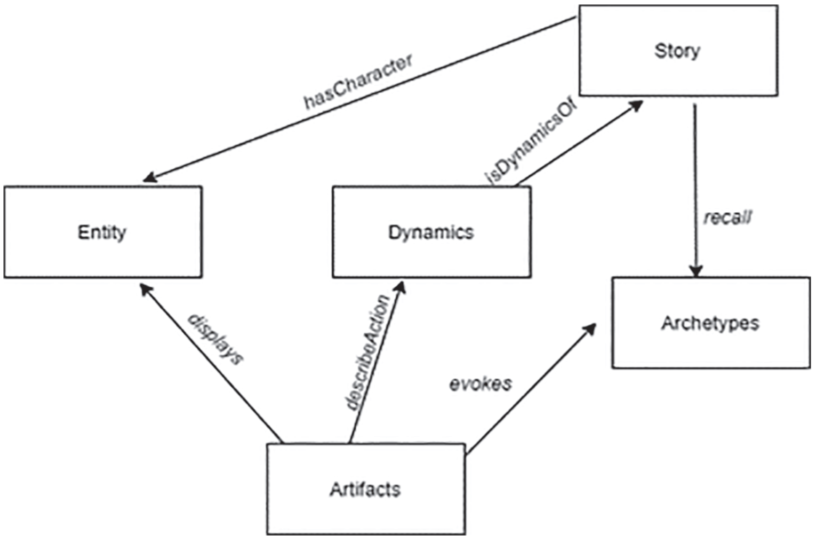

Figure 2: Top-level classes of Archetype Ontology

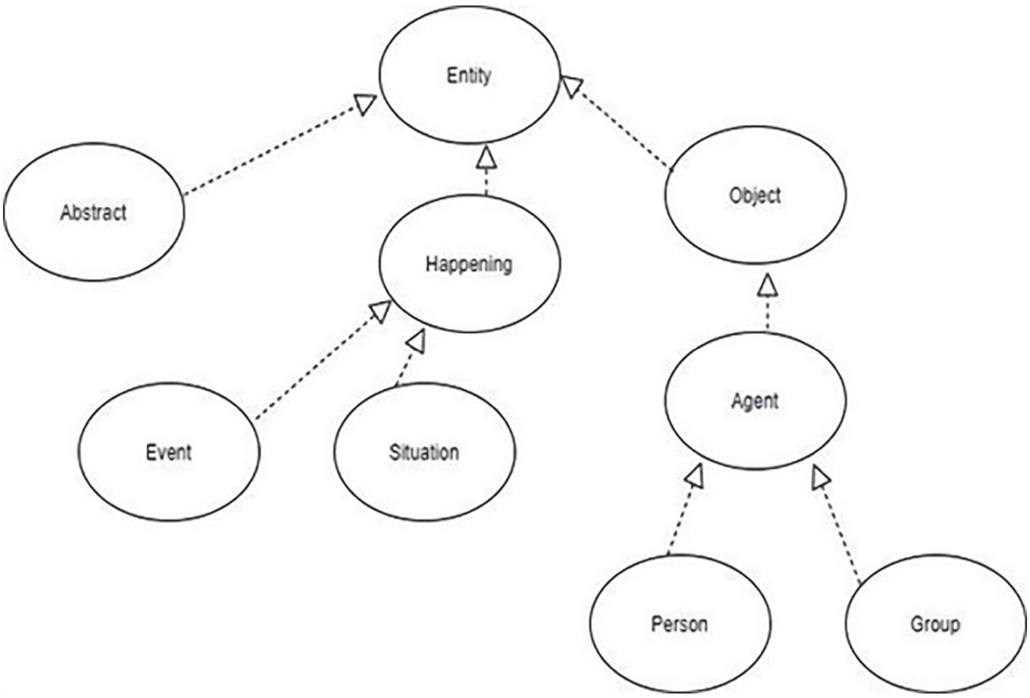

Figure 3. ODY Onto top-level classes

top-level categories of dramatic entities are (1) DramaEntity, (2) DataStructure, (3) DescriptionTemplate, and (4) ExternalReference. These entities represent the things that are exclusive to drama, guidelines for representing drama and connection between theatre, linguistic and resources ideas found in outside sources (Damiano et al. 2019).

Observing the study, it is possible to see that certain elements are common across the domain, acting as the skeletal layer for any narrative information capture. These elements are story, which captures the whole story; scene, which captures the events that make up the stories; acts, which are the actions happening in an event; agents, who carry out the actions; cause and effect of these actions.

We carried out literature review of narrative capture in the health and medical domain aiming to develop an ontology for the patient-doctor narration. A biomedical model (Jing et al. 2007) was developed for cystic fibrosis to be used as a plugin in any EHR related to cystic fibrosis. The model

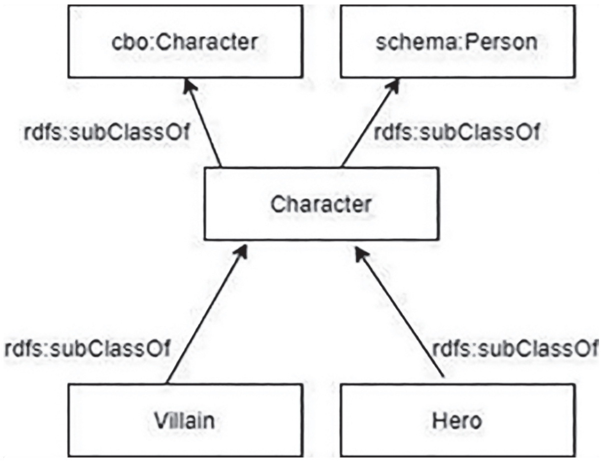

Figure 4. A glimpse of the Transmedia Ontology

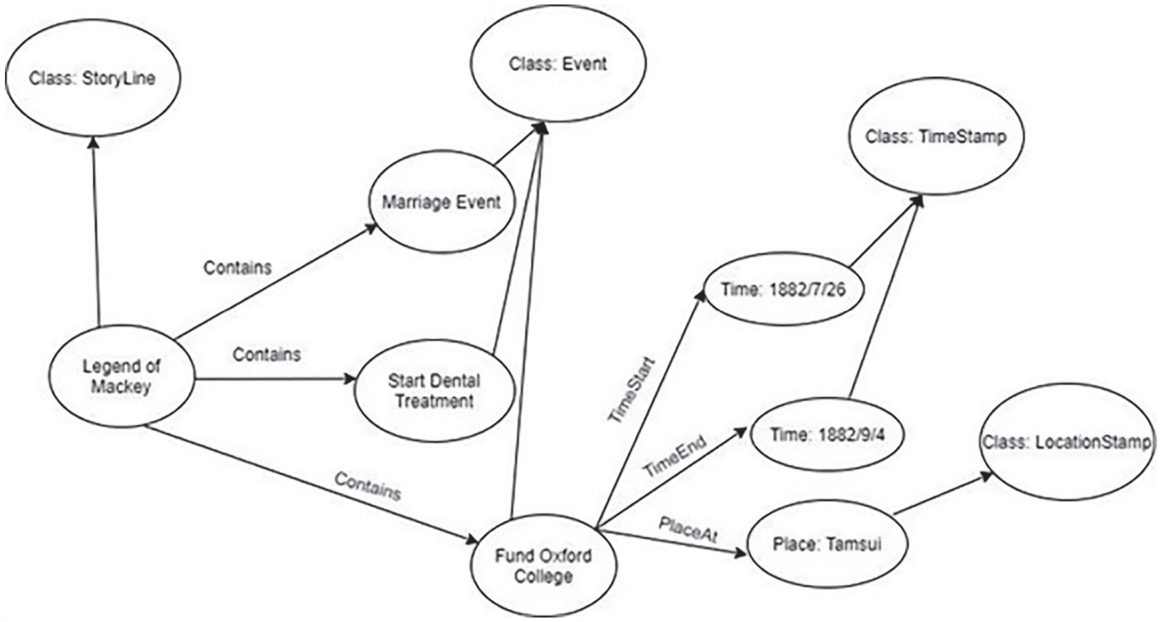

Figure 5. A glimpse of the BK onto:

takes on a modular approach and contains the various areas of gene mutation, cystic gene mutations, amino acid change, etc. The work (Ogbuji 2011) describes a CPR Ontology. With the example of a real-world use case, the author constructs an ontology for the capture of the computer-based patient record. The classes, associated relations and properties are illustrated in Figure 6.

El-Atawy and Khalefa (2016) present a solution for EHR in which ontology supports the management of concepts such as space, time data, credentials, digital photos, and fiscal dealings. For a domain that depends on collaborative decision-making, there is a need to integrate the data present in silos. Yehia et al. (2019) developed an Ontology-Based Clinical Information Extraction System (OB-CIE) to extract clinical notions from free-text transcripts and convert the unstructured datatypes to structured information.

According to Ehrlinger and Wöß (2016), a knowledge graph acquires and integrates information into an ontology and applies a reasoner to derive new knowledge. The current work extends a knowledge graph created by Varadarajan and Dutta (2021) for narrative information in medicine.

Despite literature pieces of evidence of the significance of narration in medicine, few structures aid in capturing this narration. This is despite the existence of a framework for the capture of narratives across various domains. It is also with clarity that ontologies and semantic web technologies are used in the medical domain. Hence, this work aims to develop the framework for capturing narrative information in a medical setting.

3. Methodology

The methodology section describes the approach adopted to develop the ontology. Works from Uschold and King (1995), Gruninger and Fox (1995), Sure et al. (2004), Noy and McGuinness (2001), Suárez-Figueroa et al. (2015), Dutta et al. (2015) and Varadarajan et al. (2023) are some methodologies for ontology development. In the present work, to tackle the segmented nature of the concepts, the approach toward the ontology construction was carried out in two phases. Phase I involves the steps for the creation of a narrative framework. Identification, extraction, and formulation of elements of narration are the focus of this framework. Phase II presents steps towards ontology construction. This phase brings together the elements modeled in Phase I with the data available for holistic ontology model development. The steps are detailed below. Figure 7 illustrates the workflow for the ontology construction. This methodology is adopted from the work of Varadarajan and Dutta (2021).

Phase I: Narrative Framework Construction

Phase one of the methodology involves the development of the narrative framework. This was accomplished by identifying the elements of narration from the theoretical models from the language and literature studies domain. The literature review methodology of Kitchenham and Charters (2007) was followed to identify the models. The steps for Phase I are as follows.

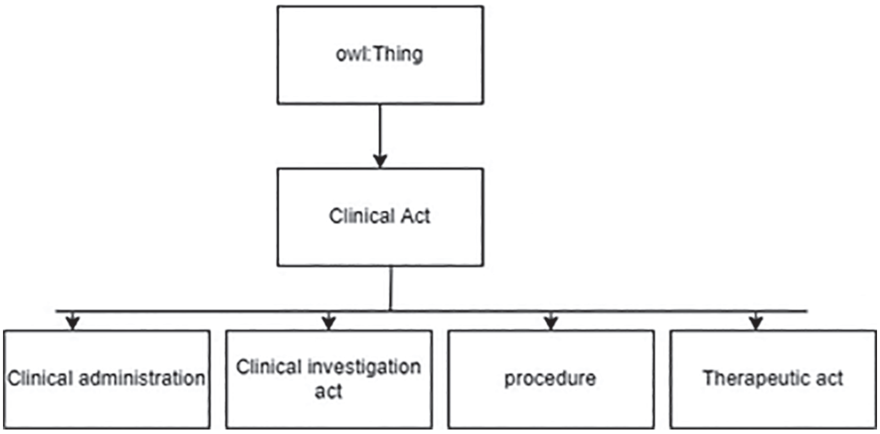

Figure 6. Clinical Act Taxonomy of CPR Ontology

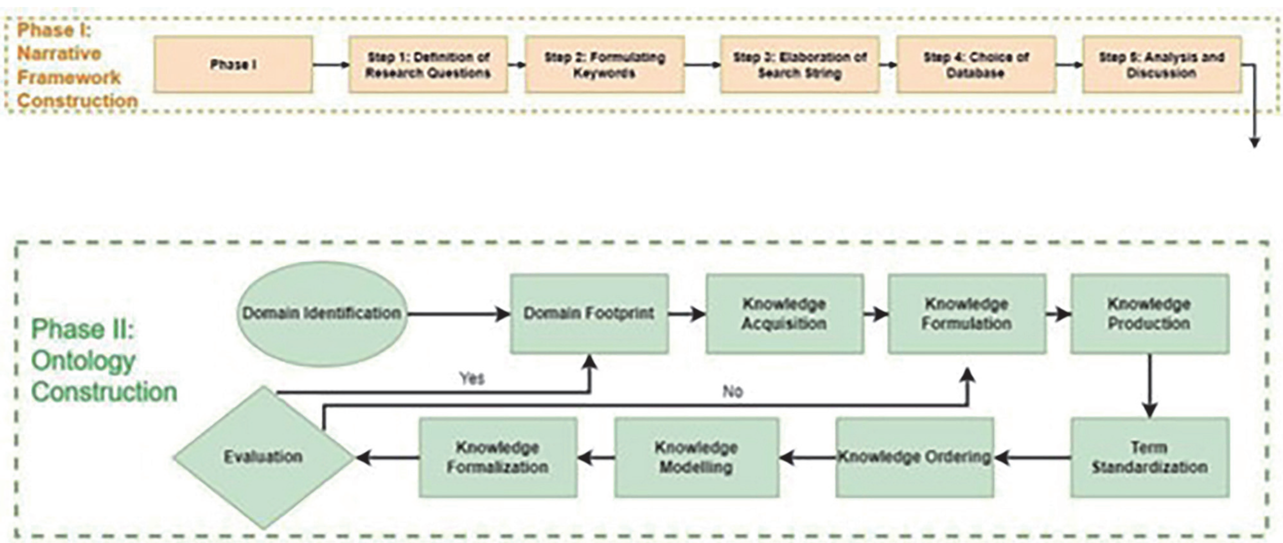

Figure 7. Workflow of ontology construction

Step 1: Research question development
Based on the aims, this stage generates the pertinent research questions. The research questions for the current work are listed from RQ1 to RQ4.

RQ1 What are the elements of narration?
RQ2 What constitutes the story?
RQ3 What are the components used in the story?
RQ4 What are the models for narrative information?

Step 2: Keyword formulation
Keywords were generated from the questions identified in the previous step. These generated keywords will assist in the search and retrieval of relevant literature. The keywords identified from the research questions are mentioned below and numbered K1 – K5.

K1 narrative models
K2 elements for narration
K3 models in narration
K4 aspects of narration
K5 fundamentals of a story

Step 3: Expansion of search string
Once the keywords are produced, the following step is to expand the keywords into search strings. This step means to transform the keywords by adding logic such as AND, adding quotes to retrieve the exact match, and including terms closely associated to retrieve relevant literature. Various combinations of the search strings are listed below.

String1 "narrative models"
String2 "narrative terms"
String3 "narrative information" AND "elements"
String4 "narrative" AND "terms"
String5 "model" AND "narration"
String6 "parts of narrative"
String7 "model for storytelling"
String8 "parts of the story"

Step 4: Choosing of repositories
Scholarly repositories were chosen by cherry-picking the features such as accessibility (or subscription-based), repute and topic covered. Databases examined are Google Scholar (*https://scholar.google.com/*), Scopus (*https://www.scopus.com/home.uri*), Web of Science (*https://clarivate.com/webofsciencegroup/solutions/web-of-science/*), IEEE/IET Electronic Library (IEEE IEL Online) (https://ieeexplore.ieee.org/Xplore/home.jsp), ScienceDirect (https://www.sciencedirect.com/), Gale Literature (*https://www.gale.com/intl/databases/gale-literature*), The Science Fiction and Fantasy Research Database (*https://sffrd.library.tamu.edu/site/*).

Step 5: Study and Discussion
Examination of several resources returned the works pertinent to the study. The initial model was that of Aristotle's elements – exposition (preliminary situation in a narrative), crisis (disturbances in the preliminary situation), and denouement (resolve catastrophe leading to new exposition) (Klarer 2013).

Another linguistic framework for conversational narrative is the one of Labov and Waletsky (1967). The work is significant because, out of the existing models for narration, it is this model that finds a place in the literature that discusses storytelling in medicine.

The actantial model from Greimas includes six actants. They occur as units of two. The six actants are "subject, object, sender, receiver, helper, opponent" (Greimas 1973). The tasks such as search, aim, desire, communicate, support or hinder are performed by the actants (Herbert 2019; Barry 2009). The Freytag's Pyramid (Gustav 1900) is a narrative theory that describes the plot structure of a tale. The Pyramid's components are given in Figure 8.

Following this, another commonly referred work is the one for the fairy tale representation by Propp (2009) for functions and roles. The author asserts that there is an initial condition (the hero's introduction), which is followed by another circumstance that causes the hero to defy orders. The anti-hero has the chance to influence and harm the

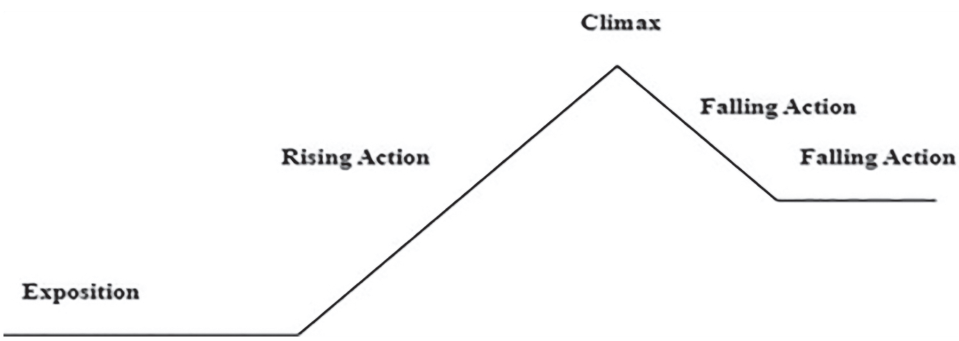

Figure 8. Freytag's Pyramid

hero or the things the hero values, which prompts the hero to make some decisions. The hero succeeds and is acknowledged. The anti-hero is overcome and penalised (Propp 2009). Traditional concepts of narrative include plot, characters, situation and setting. The plot directs to what happens. The characters are people present in the plot. The narrative situation encompasses the speaker and audience. Setting indicates the space and time of a plot (Klarer 2013; Barry 2009). "Stories have shapes which can be drawn on graph paper, and the shape of a given society's stories is at least as interesting as the shape of its pots or spearheads" (Case Western Reserve University 2016). The shape or the emotional arcs corresponds to the fall and the rise of the protagonist's journey. The arcs can be plotted on the x-axis y-axis. The start and end of the story are depicted in the x-axis and named 'Beginning-End' (BE axis). The y-axis plots the 'Ill Fortune-Great Fortune' (GI axis). All narrations occur in amongst these axes (Case Western Reserve University 2016). A summary is provided in Table 1. From the ancient to the contemporary, these ideas have divided the tale into many aspects. The present study grasps the narratological theories pertinent to modeling a narrative ontology.

Observations from the literature study and the model analyzed above lead to certain conclusions. Firstly, a basic framework for narration can be extracted from the study. Most of the models reviewed contain either one of the following elements. These common elements are in presented in Table 2.

With these common elements as a guide, a domain-specific narrative framework can be developed. The concepts specific to the domain can be added, reformed and revised to suit the narrative across domains. From studying the literature there is a scope for developing a narrative framework for medicine. This facet has been least explored despite the literature pointing to the importance of narration in medicine. The limitations of the use of semantic web technologies, especially that of ontologies, are the difficulties in modeling the textual description with terms such as 'especially,' 'very common,' etc. in the OWL. The methodology now will proceed towards the development of the ontology.

Phase II: Ontology Construction

For the construction of any artifact, there are methodologies. Likewise, for the development of a semantic artifact

Model Name	Domain	Elements of the model
Model of personal narratives (Labov and Walestsky, 1967)	Domain independent	Abstract | Orientation | Complicating Actions | Evaluation | Resolution | Coda
The Actantial model (Greimas, 1973)	Fiction	tasks such as search, aim, desire, communication, support or hindrance | subject/object | sender/receiver | helper/opponent |
Freytag's Pyramid (Gustav, 1900)	Domain independent	Exposition | Rising action | Climax | Falling action | Catastrophe
Morphology of the Tale (Propp, 2009)	Folklore	an initial situation | absence of the family members | instructed not to engage in activities | hero disobeys | villain manipulates | family hurt | hero acts | hero victorious | villain overpowered and punished
Aristotle's Analysis (Klarer, 2013)	Epics	exposition | crisis | denouement
Shapes of Stories (Case Western Reserve University, 2016)	Domain independent	BE axis depicting beginning and end. The GI axis, "Ill Fortune-Great Fortune" denoted the arcs of the story.

Table 1. Models for narration

Sl. no	Element	Definition
1	Story or storyline	that discusses the complete story
2	Actors/characters/agents	a person or organisation involved in the story
3	Events	Happening of something in space and time
4	Spatial factors	spatial or scene where an event occurs
5	Temporal factors	the time the event occurs
6	Theme	the overarching idea in a story
7	Relations or attributes	association between entities in a story

Table 2. Common elements for narration

(ontologies, controlled vocabularies, subject headings, thesauri, etc.), there are multiple development methodologies. Ontology development methodologies are activities associated with the process of developing ontologies, their life cycle, the procedures, apparatuses, and languages for building ontologies (Gómez-Pérez et al. 2004).

The most commonly cited and used methodologies include the ENTERPRISE methodology, which details the informal and formal stages in ontology development (Uschold and King 1995). TOVE (Gruninger and Fox 1995), highlights post-development stages of ontology development (evaluation and maintenance). METHONTOLOGY is another ontology development process (Férnández et al. 1997) with six phases - Specification, Conceptualization, Formalization, Integration, Implementation, and Maintenance of ontology development. Ontology Development 101 (Noy and McGuinness 2001) is the bible for ontology development. The On-To-Knowledge Methodology (OTKM) (Sure et al. 2004) covers ontology engineering, knowledge management, and knowledge processes. Pinto et al. (2004) developed DILIGENT (Distributed, Loosely-Controlled and Evolving Engineering of Ontologies) for a dispersed semantic web environment. For large scale building of ontologies, NeON methodology (Suárez-Figueroa et al. 2015) and Yet Another Methodology for Ontology or YAMO (Dutta et al. 2015) are two methodologies. YAMO is based on the analytico-synthesis approach, a combination of top-down and bottom-up approaches, and guided principles. This enables the complex concepts to be fragmented into their central concepts, studied and grouped by their characteristics, and a connection between concepts. This makes it flexible and accommodative during conflict. This motivates the use of YAMO for ontology construction. The step-by-step instructions for the ontology construction are detailed below.

Step 0: Domain Identification – As the first step in the development of ontology, it is a crucial step to identify the domain or field of study. The domain in which the artefact is developed is chosen keeping in mind the question or the user requirement (Dutta et al. 2015). The domain chosen for the modeling has to be computable, i.e., the domain can be divided into its last basic unit. The broader domain identified for the current work is medicine.

Step 1: Domain Footprint – There is a need to narrow from the broader domain identified in the previous step. Identifying the reason, purpose, and ideology behind the framework development can help in narrowing down the scope. With the literature studied, the purpose was identified, which was to capture, manage and infer the patient-doctor narration. The framework will gather data through subject interactions, observations, video data, audio tape, or note-keeping that is of major medical significance. A fictitious real-world situation is provided below to serve as an incentive (see "ad Step 1" below).

Generating competency questions (CQ) is a standard practice followed for ontology development (Noy and McGuinness 2001). From this used case scenario, competency questions were generated to evaluate the ontology and are given in the evaluation step of the methodology.

Step 2: Knowledge Acquisition – The artifact takes shape with the help of the concepts acquired from the domain. Knowledge can be acquired from multiple resources. Many use cases, literature, interviews, and other media can be sources for concept collection. The more specific the sources are to the domain the more standardized concepts are extracted. The concepts for the patient-doctor framework were collected from the literature, stories, and anonymized patient records. A few concepts gathered are as follows (see "ad Step 2" below).

Case 1: A lady goes to the doctor with a cough and a cold. She is given cold and cough medications as part of her therapy. The issue persists even after the course of medications has been completed. A follow-up appointment alarms the doctor. They enquire about the lifestyle. The patient describes everyday activities. They observe a shift in the ambience of her workplace as a result of this. The only difference in her workstation was the addition of a new 3D printer. Doubtful, the doctor urges her to relocate the printer to another area. The minute particles generated from the machine when working were the true cause of the cough and cold. The patient recovered when the alteration was made.

ad Step 1

lady, patient, micro particles, visit, cough, cold, treatment, prescribe, medicine, ulcer, mouth, no effect, complain, doctor, distressed, facial features, course, follow up, alert, enquire, lifestyle, change, office, cause, recover, not reduce

ad Step 1

Health Problem		
	Disease	
		Cold
		MouthUlcer
	Symptom	
		Cough
		CoarseFacialFeature

Table 3. Knowledge production of the concept of illness

Step 3: Knowledge Formulation – In this step, we analyze the concepts collected. The analysis involves grouping or splitting them based on the similarities or differences in meaning, and characteristics. From the terms collected in the previous step, for example, *cough, cold, mouth ulcer,* and *coarse facial features* were grouped as a chief complaint. The reason for this grouping is that these are the reasons for the visit to the health care centre. A similar process was conducted for other terms as well.

Step 4: Knowledge Production – The grouped terms are synthesized in this step. Hierarchy is created for the concepts collected. The categorization can be performed based on any number of factors. The synthesis for categorization for the current work was by identifying what these terms mean. For example, the synthesis of the terms cold (a disease involving the nose and respiratory passages) and mouth ulcer (a health problem on the surface of the skin or mucous surface of the mouth) from the previous example aligned them as diseases. This categorization is represented in Table 3 above. This table also shows another example. Cough (a symptom involving sudden expulsion of air from lungs) and coarse facial features (symptoms related to the face) were identified as symptoms. This differentiation of the health problem helps in the facet identification of the concepts and helps in the following steps of ordering and standardization.

Step 5: Term Standardization and Ordering – The natural language contains synonyms, and every concept can be in multiples. This step is to bring a standardized representation of the terms. When concepts are expressed in multiple terms, there is a need to choose one particular term that will fit the purpose of why the ontology is constructed. This is in alignment with the current best practices of reusing the existing vocabulary. Medical vocabularies, and thesauri such as the Unified Medical Language System (UMLS) (https://www.nlm.nih.gov/research/umls/index.html), SNOMEDCT (https://www.snomed.org/), etc. can be used. Besides these, there are vocabularies such as schema.org and Wikidata (https://www.wikidata.org/wiki/Wikidata:Main_Page) that were consulted for standardizing. For the concepts expressed in the previous step, i.e., cold, mouth ulcer, coarse facial feature and cough, there are multiple terms used for expressing them. These terms were replaced with common cold, oral ulcer and coughing following the UMLS. The coarse facial feature is already a standardized term. Similarly, for a person affected by some illness or disease, the terms are patient, sufferer, sick person, or even client in certain cases.

The term patient was chosen over the other terms because it is the term relevant within the domain as well as with the purpose of modeling, sticking with the Canon of Currency (Ranganathan 1937). Canon of Currency directs the users to use the term that is currently in use, the implication of which is that the terms that are 'in use' at the time of development will be added to the model. During the knowledge acquisition step, the terms were already collected from domain-specific literature (anonymized patient records and use cases). This eased the standardization since the terms were mostly domain specific and already standardized.

To have regularity in the ontology, we order the terms following some criteria. The ordering can be purpose-based, alphabetical, or chronological (Ranganathan 1937). The logic of the ordering disease followed by symptom was purpose-based. The idea was that the body gets affected by a disease first and then the symptoms show up. Figure 9 illustrates a sample of the standardized terms with the examples mentioned in this step. The ordering of the concepts of symptom and disease shows that both these concepts represent some health problem.

Step 6: Knowledge Modelling and Formalization - This step reorganizes the knowledge produced in the previous step into entities, entity relationships, and their attributes and expresses them in a machine-processable format. Figure 10 shows the UML representation of the overall framework of ontology.

For formalizing and expressing the knowledge in a machine-processable format, we use OWL DL (Web Ontology Language Description logic) (Smith 2004). OWL is the language for describing and defining ontologies. OWL DL is a species of OWL that aids the users for maximum expressiv-

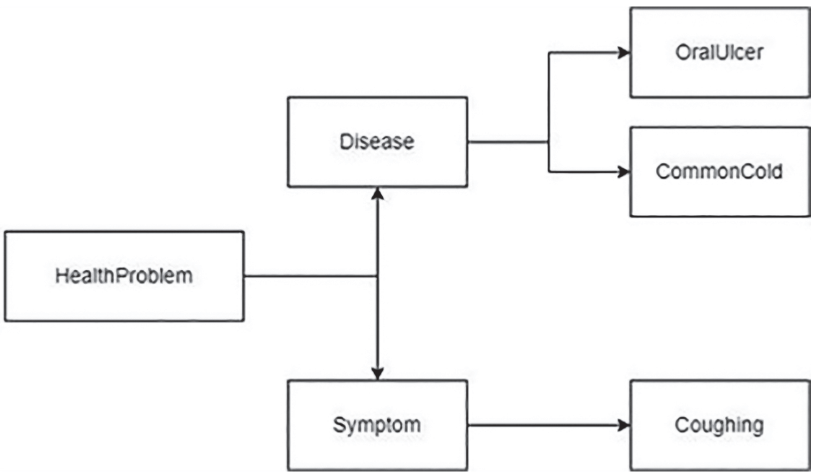

Figure 9. Standardization and Ordering of the concepts

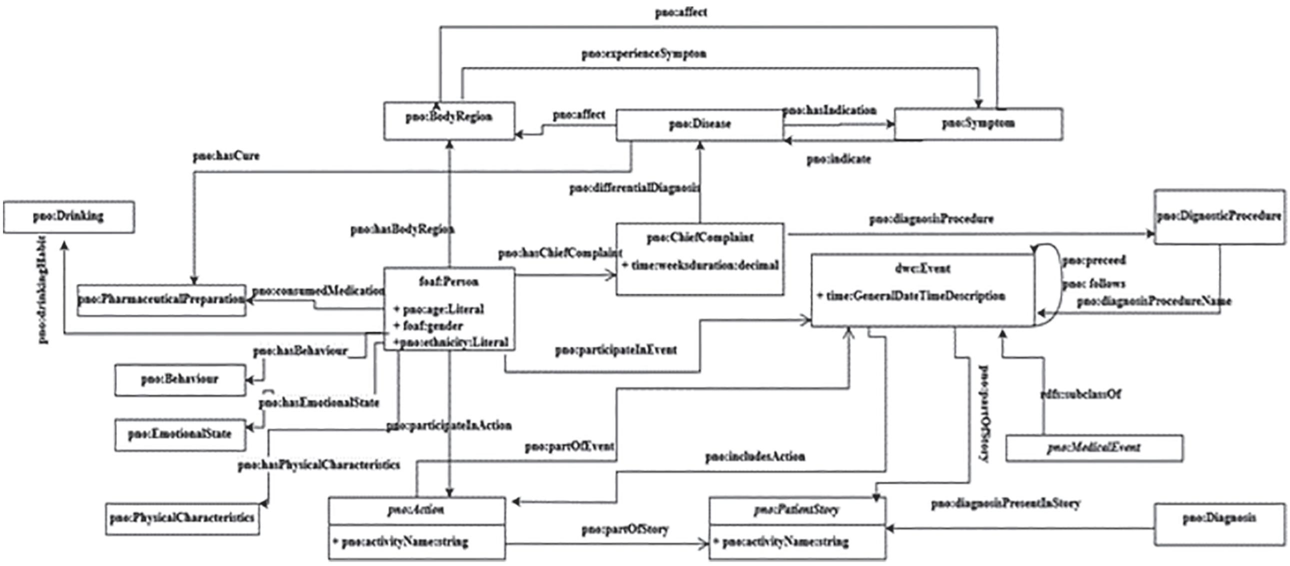

Figure 10. UMLS of the ontology

ity. We use Protégé ontology editor for the knowledge modeling and development of the ontology.

Figure 11 depicts a glimpse of class (a class is a group of individuals that belong together) and class hierarchies from ontology. MedicalStructure, details the medical aspect of the patient narration; StoryEntity details the elements of narration; DrammaticStrucure and DescriptionTemplate classes assist StoryEntity class in describing the narration. MedicalStructure has subclasses ChiefComplaint, HealthProblem and PharmaceuticalPreparation. HealthProblem has subclasses of Disease and Symptom which have instances, of oral ulcer and cough, respectively.

Entity relationship is the relationship between entities. Figure 12a is a screen grab of the object properties. Object property is the property that relates two individuals. For example, the property hasIndication links the Disease and Symptom. Similarly, the property performedBy connects the Action or Event class to the Agent (one who performs the action or event). Figure 12b shows the data properties. A data property connects individuals and the datatypes. For example, the properties duration(xsd:dateTimeStamp) and severity(xsd:literal) are attributes used for HealthProblem.

The current ontology consists of 52 classes, 42 object properties, and 18 data properties. Figure 13 provides a snap

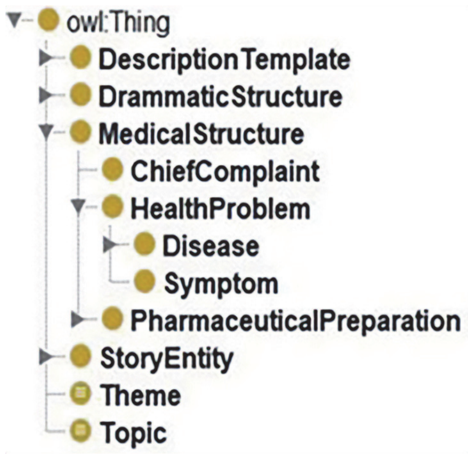

Figure 11. The class hierarchy in the ontology

Figure 12a. Object property hierarchy

Figure 12b. Data property hierarchy

```
<?xml version="1.0"?>
<Ontology xmlns="http://www.w3.org/2002/07/owl#"
     xml:base="http://www.isibang.ac.in/ns/OntoPaN"
     xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
     xmlns:xml="http://www.w3.org/XML/1998/namespace"
     xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     ontologyIRI="http://www.isibang.ac.in/ns/OntoPaN">

<Declaration>
        <Class IRI="#Agent"/>
    </Declaration>
<Declaration>
        <Class IRI="#ChiefComplaint"/>
    </Declaration>
<Declaration>
        <ObjectProperty IRI="#hasChiefComplaint"/>
    </Declaration>
<Declaration>
        <ObjectProperty IRI="#hasIndication"/>
    </Declaration>
<Declaration>
        <DataProperty IRI="#duration"/>
    </Declaration>
<Declaration>
        <DataProperty IRI="#frequency"/>
    </Declaration>
<Declaration>
        <NamedIndividual IRI="#Bilateral_knee_pain"/>
    </Declaration>
<SubClassOf>
        <Class IRI="#Agent"/>
        <Class IRI="#StoryEntity"/>
    </SubClassOf>
<SubClassOf>
        <Class IRI="#ChiefComplaint"/>
        <Class IRI="#MedicalStructure"/>
    </SubClassOf>
```

Figure 13. A Snippet of the OWL code

shot of the ontology. The complete OWL file is available from https://www.isibang.ac.in/ns/ontopan/index.html.

Step 7: Evaluation – This step involves the evaluation of ontology. The purpose of the evaluation is to determine the quality of the developed ontology. The quality can be determined by verifying the constructed ontology for its logical consistency, its ability to retrieve answers to the query and its capability to support the knowledge representation of the domain. These types of evaluations were performed for the current ontology. This is detailed below.

Evaluation 1

To check for modelling errors, one can use ontology pitfall scanners such as OOPS! (Poveda-Villalón, et al 2014). The pitfalls identified and corrected are given in the figures below (Figure 14a and 14b respectively). The critical pitfall was the use of multiple domains and ranges for an individual property. This was rectified. The important pitfalls were missing disjoints, no license declaration missing domain and range for the properties, and wrong declaration of equivalent classes. The domain and range for the properties were added. The equivalent classes declaration was corrected. Other pitfalls, such as missing disjoints and no license will be corrected in the final version of the ontology. This is because, with more data for the ontology, the modelling can be perfected. Minor pitfalls were synonyms as classes, missing annotations, inverse relations, and inconsistent naming conventions in the ontology, which did not affect the overall concept of the ontology. These pitfalls highlight the best practices in the ontology development domain. Attempts were made to rectify these pitfalls as well. The scanner also produced some suggestions for declaring the transitive and symmetric properties. Also, the scanner erroneously suggests making the classes Event and Effect equivalent. These were ignored during the evaluation.

Evaluation 2

In addition, to evaluate the support for knowledge representation of an ontology, different use cases can be employed. The use case for the evaluation is given below.

Case 2: A patient is 24 years old, an African American male with a history of sickle cell reports to the ED with the chief complaint of bilateral knee pain with a history of 2 days. The pain began on Thursday at 4.00 am when the patient was working the night shift in the department store. The pain continued to increase from aching to 8/10. The pain didn't re-

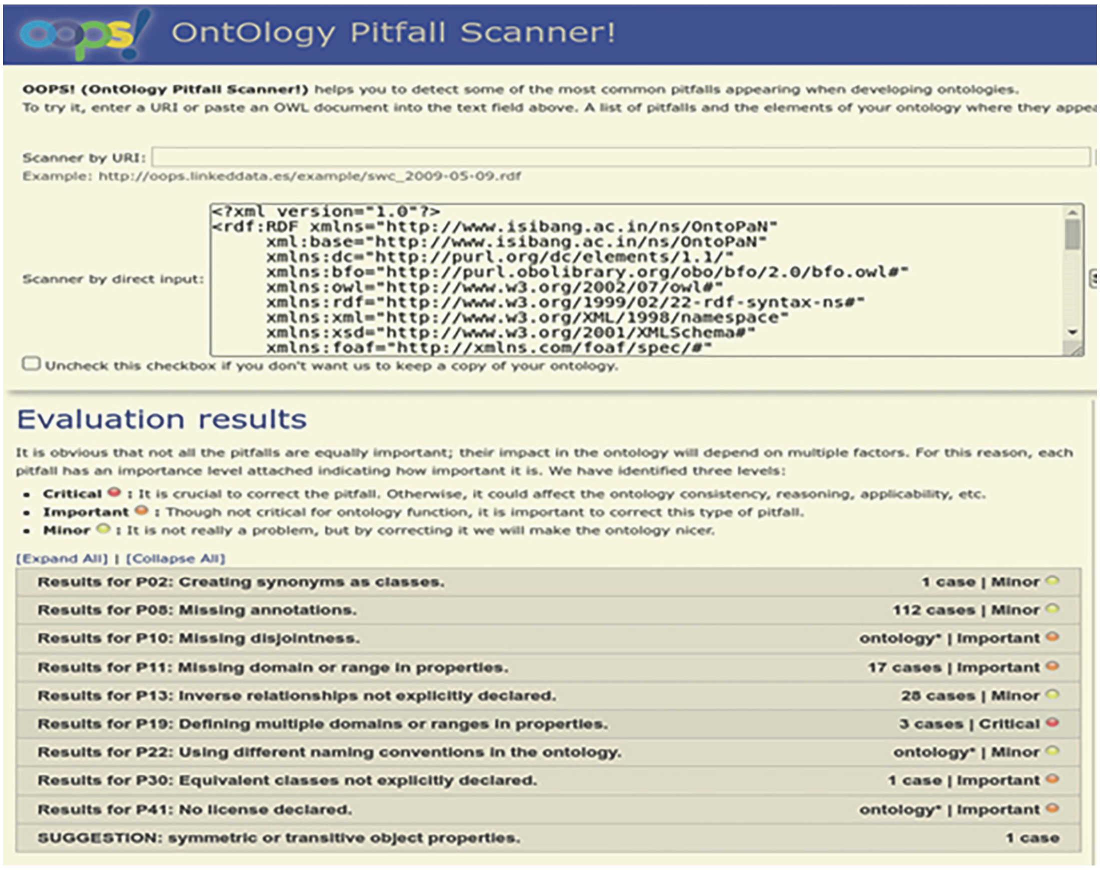

Figure 14a. OOPS!Pitfall scanner result

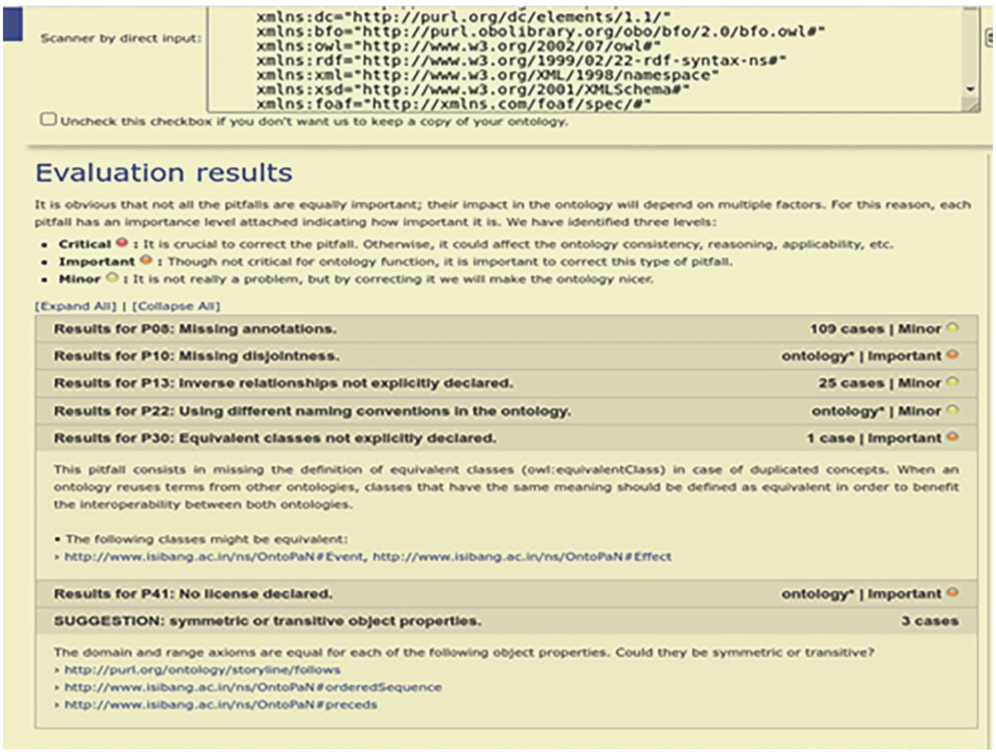

Figure 14b. OOPS!Pitfall scanner result after rectification

duce with Percocet. The patient also experienced some chills and mild SOB. The pain was localized to the right knee.

Case 3: A 27-year-old male went to the dermatology clinic complaining of a rash on his back, arms, and hands that had appeared a week before. He had a history of obesity, ate a high-fat diet, and drank heavily. Physical examination revealed scattered pink-yellow papules on the upper back, extensor surfaces of the upper arms, and hand dorsa. The cause of the eruptive xanthomas was determined to be severe hypertriglyceridemia. Molluscum contagiosum, sebaceous hyperplasia, and widespread eruptive histiocytoma are among the possible diagnoses. However, eruptive xanthomas should be recognized in individuals with risk factors. The skin lesions disappeared after one month of fenofibrate therapy, which included abstaining from drinking, exercising, and eating a low-fat diet.

The data added via the use case helps in the creation of the knowledge base. The knowledge base consists of TBox (Terminological Box) (which consists of the concepts and their defining properties) and ABox (Assertional Box) (which contains the individuals and their property values) (Gruber 1993). From the use cases, the individuals were identified and fed into the framework. The framework was able to capture the details for cases 2 and 3. The screenshot in Figure 15 shows the modeling of use case 2. From the figure, you can observe that the Agent is described with the object properties that connect the agent to the symptom, chief complaint, the events performed, and Medication consumed. The depiction of use cases validates the ontology's expressivity.

Evaluation 3

Another method of evaluating the ontology is to perform a set of SPARQL queries. We use case scenarios (Cases 2 and 3) to perform the SPARQL query. Competency Questions (CQ) are generated from the use cases. Some CQs are: What was the primary reason for visiting the hospital? What were the symptoms of the case presented?

CQ derived from both the use cases (cases 2 and 3) is listed in column 'Competency Questions' of Table 4. The CQ has to be translated into machine-understandable language. Here

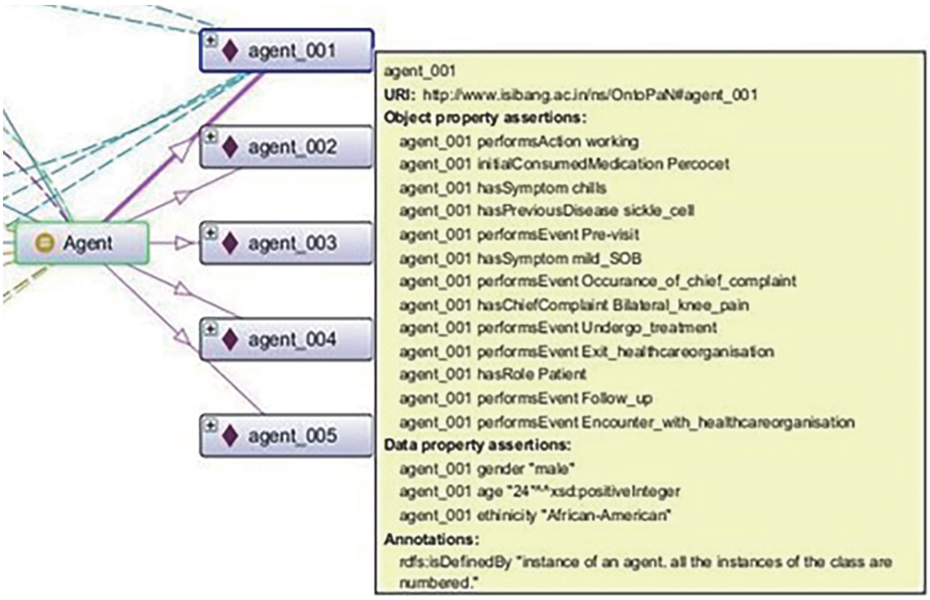

Figure 15. The screenshot of the use case 2

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX rdfs: http://www.w3.org/2000/01/rdf-schema#

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX pno: <http://www.isibang.ac.in/ns/PNO #>
```

Table 4. Prefixes of SPARQL Query

we use SPARQL (Prud'hommeaux and Seaborne 2008). The column 'SPARQL Query' in Table 5 is the corresponding translation of CQ. The SPARQL Query results are listed in Table 5 under the column 'SPARQL Query Result.' Every SPARQL Query starts with the following prefixes. These prefixes contain the internal (such as *http://www.w3.org/1999/02/22-rdf-syntax-ns, http://www.w3.org/2002/07/owl*) and external URLs (*http://www.isibang.ac.in/ns/PNO*) which abbreviate the URLs.

For example, CQ '*What was the primary reason for visiting the hospital?*' is used to identify the reason for visiting the hospital. In the ontology, the object property hasChiefComplaint shows the relation between the Agent and the reason for visiting the hospital. We use the SELECT query form for extracting the values and WHERE clause for matching the graph pattern to the data graph i.e., triples (?Agent and ?ChiefComplaint) to the object property (hasChiefComplaint). The results appear in tabular format. For convenience of representing them, we have the result of the triples queried {?Agent, ?ChiefComplaint} represented as {agent_001,bilateral_knee_pain} and {agent_002,shortness_of_breath} in Table 5.

Screenshots of the queries (Figures 16 and 17) are listed below.

Sl No.	Competency Questions	SPARQL Query	SPARQL Query Result
1	*What was the primary reason for visiting the hospital?*	SELECT ?Agent ?ChiefComplaint WHERE { ?Agent a:hasChiefComplaint ?ChiefComplaint }	{agent_001,Bilateral_knee_pain} {agent_002,Shortness_of_breath} {agent_007,Rash}
2	*What events does the agent perform?*	SELECT ?Agent ?Event WHERE { ?Agent a:participateInEvent ?Event }	{agent_001,Exit_healthcareorganisation} {agent_001,Encounter_with_healthcareorganisation} {agent_001,Follow_up} {agent_001,Pre-visit} {agent_004,Exit_healthcareorganisation} {agent_004,Encounter_with_healthcareorganisation} {agent_001,Visit_healthcareorganisation} {agent_001,Pre-visit} {agent_007,Pre-visit} {agent_007,Occurence_of_chief_complaint} {agent_007,Encounter_with_healthcareorganisation} {agent_007,Undergo_treatment} {agent_007,Exit_healthcareorganisation}
3	*What were the activities that the patient was involved in during the occurrence of the chief complaint?*	SELECT ?Agent ?Action ?ActionType WHERE { {?Action a:actionType ?ActionType} UNION {?Agent a:performsAction ?Action} }	{agent_001,working,Action_during_chief_complaint} {agent_004,sleeping,Action_during_chief_complaint}
4	*What are the events and the associated actions in the story of the patient?*	SELECT ?Story ?Event ?Action WHERE { {?Story a:hasEvent ?Event} UNION {?Event a:partOfEvent ?Action}	{patientstory1,action009,Encounter_with_healthcareorganisation}

Table 5. The natural language and SPARQL queries for the ontology evaluation

Figure 16. Screenshots of CQ1 executed via SPARQL

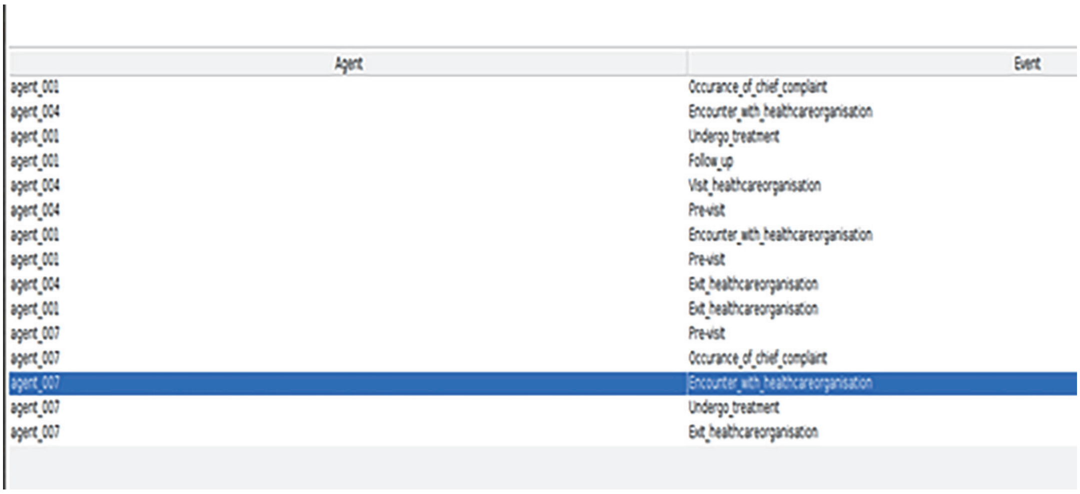

Figure 17. Screenshots of CQ2 executed via SPARQL

4. Discussion and Conclusion

The patient's narrative provides medically relevant information. This information is preserved in the EHRs' notes area but is otherwise misapplied. Despite the significance of narration in medicine, few narrative ontology models for medicine have been identified. The objective of this study was to create an ontology for patient narratives. The ontology aids in the capture of patient narration data. The framework development process contributed to identifying the common elements of narrative for modeling narrative information. These elements act as a framework for modeling narrative across various domains. They can act as the skeletal structures for capturing narrative across domains. The model is significant because it is: (i) helpful in finding the relationships between the causes of the diseases and the associated environmental factors; and (ii) is utilized as a training resource for novice healthcare professionals.

The current framework includes the class StoryEntity which details the narrative features. This class is connected to the MedicalStructure class to record medically significant data for inclusion in the clinical narration. Agents were associated with each Event (like doctors, caretakers, patients, etc.). This complex modeling was simplified by constructing Event instances such as “Encounter with healthcare-organization,” “Visit healthcare-organization,” etc. DescriptionTemplate, DrammaticStructure, StoryEntity, and MedicalStructure are now the model's top-level classes. These top-level classes are modules that encapsulate the narrative in a medical setting with a narrative-like description.

The future of the work is envisioned to automate the data population and capture. The terms from the narrative records will be extracted and populated in the model using the widely available technologies of NLP, annotations and data integration. Further study on the model will include expert feedback on its usability and feasibility in the real world. This will be done by interviewing experts in the medical domain. Further, in the future, the framework will be published as a knowledge graph for community use to record the narrations.

Endnotes

1. See Damiano and Lieto 2013; Winer 2014; Bartalesi et al 2016; Khan et al. 2016; Adel et al. 2019; Karami and Rahimi 2019.

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