A Work Domain Ontology for Modeling Emergency Department Workflow

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Abstract Emergency Department clinicians perform life-critical tasks that require acquisition, processing, transmission, distribution, integration, search, and archiving of significant amount of data in a distributed team environment in a timely manner. In order to better reveal the complexity of emergency care and reflect such a complexity in information system design, we need an abstract description of the clinical and cognitive work performed by clinicians, independent of how the clinical setting is implemented with specific technology, artifacts, and environmental variables. For this purpose, we developed a work domain ontology for the ED (ED-WDO). We evaluated the semantics of the ED-WDO with domain experts and its application and usage using an emergency nurse assessment use case. From the evaluation results, we can conclude that the lexical and semantic definitions of the classes, the hierarchical structure, as well as the semantic relation definitions in the ED-WDO are well defined and can faithfully represent the ED work domain.

Introduction

Emergency Department (ED) clinicians perform life-critical tasks that require acquisition, processing, transmission, distribution, integration, search, and archiving of significant amount of data in a distributed team environment in a timely manner. ED clinicians monitor their constantly changing information environment, respond to unpredictably occurring issues, collaborate and communicate with other people in the system as issues arise, and prioritize and solve multiple issues as they occur. Managing information needs and supporting clinical decision making in ED is of great importance for patient safety and healthcare quality [2]. Rather than focusing on a single task at a time, ED clinicians are forced to switch between multiple tasks and usually multiple patients. Many of these switching decisions are based on unplanned, unorganized, and unpredictable environmental factors. This high level of complexity in the ED is one major factor that contributes to potentially preventable adverse events [3]. Recent studies show that the complexity of critical care can be addressed in a systematical way from a cognitive perspective [2, 4]. One fundamental step towards reducing the complexity of the ED is to recognize what information is needed and processed by clinicians, the activities they perform with these information and decisions they make regarding these information items and activities. In order to better reveal system complexity and reflect such a complexity in information

system design, we need an abstract description of the clinical and cognitive work performed by clinicians, independent of how the clinical setting is implemented with specific technology, artifacts, and environmental variables. The work domain ontology (WDO) is a framework for this purpose [5]. In this paper, we introduce our effort on developing a work domain ontology for the emergency department (ED-WDO).
The ED-WDO is represented in the Web Ontology Language (OWL) [6]. OWL is a standard ontology language that allows data and knowledge to be represented in a machine-understandable way (an ontology), which enables automatic intelligent queries and semantic reasoning for the data. Successfully representing the ED work domain in OWL will provide a standard and explicit ontological model for (ii) ED clinical & information management processes, hospital business rules & resources planning; and (ii) triage and decision support in the ED.

ED Work Domain Ontology (ED-WDO)

A Work Domain Ontology (WDO) outlines the basic structure of the work that the system together with its human users will perform [7-9]. It is an explicit, abstract, implementation-independent description of that work. It describes the essential requirements independent of any technology systems, strategies, or work procedures. It tells us the inherent complexity of work; it separates work context (physical, organizational, computational,

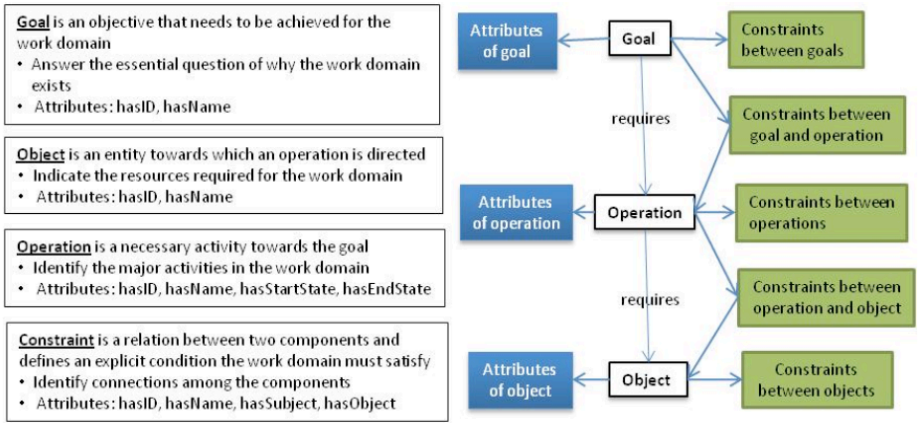

Figure 1: Overview of the Work Domain Ontology [1]

etc.) from the nature or functions of the work itself. A WDO is composed of goals, operations (or actions), objects, and the constraints that capture the functions of work. Figure 1 shows the four fundamental components (goal, object, operation, and constraint) of WDO and their definition, scopes, attributes, and relations. The WDO is represented in OWL for a standard and formal representation, where Goal, Object, and Operation are defined as OWL classes, constraints among them are defined as object properties, and attributes are defined as data properties.

On top of the WDO, detailed ontologies can be defined for specific work domains. Each detailed WDO outlines the basic structure of the work that a system for that work domain together with its human users required for the work. It provides an explicit, abstract, implementation-independent description of the specific domain of work. In the next section, we introduce our implementation of a work domain ontology for the ED work domain.

The ED work domain ontology (ED-WDO) includes classes that define operations and objects, as well as the goal for each operation. The ED-WDO is built on top of the WDO and it adopts all the concepts, properties, and constraints defined in the WDO. The ED-WDO was built with the additions of the essential classes and their constraints specifically for the ED work domain. Following the American College of Emergency Physician Definition, the practice of emergency medicine includes "the initial evaluation, diagnosis, treatment, and disposition of any patient requiring expeditious medical, surgical, or psychiatric care." [10]

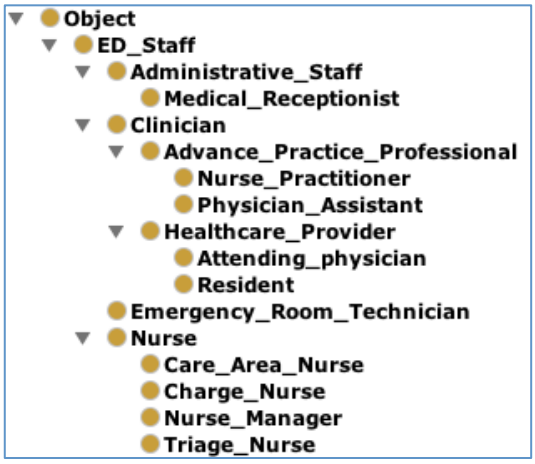

Figure 2: ED staff objects defined in ED-WDO

Define the Emergency Department Staff Objects: We first defined the ED staff object classes in the ED-WDO. *Figure 2* shows these classes and their hierarchical information in the protégé ontology editor. As Figure 2 shows, *ED_Staff* is an OWL class which is a subclass of the *Object* class defined in WDO. We further classified ED staff into four categories: Administrative Staff, Clinicians, Emergency Room Technicians, and Nurses, each of which is defined as an OWL class. Under each of these category classes, further classes can be defined. For example, a provider can be an attending physician, resident, or an Advance Practice Professional (nurse practitioner, physician assistant). For each class, a textual definition can be defined. Acronyms and alternative labels of each object class can also be defined if applicable. For example, "Advance Practice Professional" can also be called as "APP" or "limited license provider". These can be defined as alternative labels of the class.

Define the Emergency Department Operations: We then defined the operation components for a typical ED patient from arrival to departure. Column 1 in **Error! Reference source not found.** shows the meta-level operations in the ED-WDO. Each operation is defined as an OWL class (also a subclass of the general *Operation* class in WDO). Each operation can be further classified into different subclasses. For example, we can further define different disposition types such as Admit, AMA (Against Medical Advice), LWBS (Leave Without Being Seen), Transfer, and Home/Self-care according to the American

College of Emergency Physicians Emergency - Department Medical Record Elements [11].

Define Goals: We also defined major (intermediate) goals for ED visit. Column 3 in **Error! Reference source not found.** shows the details. Each goal is defined as an OWL class and a subclass of the Goal class defined in the WDO.

Table 1: High level ER-WDO components

Operation	Required Object	Goal
Arrival	Medical Receptionist	Check in
Triage	Triage Nurse	Determine Emergency Severity Index Category
Nurse Assessment	Care Area Nurse	Collect initial encounter data
MSE	Clinician	Determine whether an emergency medical condition (EMC) exists
Administration	Admin Staff	Billing
Provider Assessment	Clinician or Nurse	Diagnosis for treatment
Test	Ordered by clinician or nurse	Obtain Information for Assessment and diagnosis
Treatment	Clinician or Nurse	Provide initial treatment/stabilize the patient
Disposition	Clinician	Sign to discharge the patient
Departure	Care area nurse	Instruct the patient for departure

Define the Required Objects and Goals: **Error! Reference source not found.** shows the details. We have defined 10 meta-level operations, their required objects (medical professionals), and the major goal for these operations. For example, the hospital must provide an appropriate medical screening examination to determine if an emergency medical condition exists [10]. Therefore for the operation MSE (Medical Screening Exam), the required object is Clinician since an MSE can only be done by a health care provider or an advanced practice professional. We use an OWL restriction to define this condition:

MSE *requireObject* some Clinician

where *requireObject* is an OWL object property defined in the WDO for specifying any required object for a given operation; some represents owl:someValuesFrom axiom which formally defines that MSE requires at least one Clinician to be its object. Please note that in some clinical settings, MSE can be performed by nurses. This constraint can be adjusted to allow nurses to be associated with the requirements for this object.

We also defined relationships between operations and goals using the *requiresOperation* property defined in WDO. For example, the goal "Determine whether an emergency medical condition (EMC) exists" in ED requires operation MSE. We can use an OWL restriction to define this condition:

"Determine whether an emergency medical condition (EMC) exists"

requiresOperation some MSE

where *requiresOperation* is an OWL object property in the WDO for specifying any required operation for a given goal; some represents the owl:someValuesFrom axiom which defines that the goal requires at least one MSE to be its operation in the ED workflow.

ED-WDO Expert Evaluation

We followed the ontology evaluation criteria introduced by Brank et al [12] to evaluate the WDO-ED meta ontology. The ontology evaluation criteria cover several levels: syntactic, lexical, hierarchical, semantic relations, and context and application. The OWL ontology has been validated using HermiT reasoner v1.3.8 embedded in Protégé 4.3 (http://protege.stanford.edu/) for syntactic and consistency checking. For lexical, hierarchical, and semantic relations defined in the ontology, we interviewed four ED clinicians from two different hospital systems for manual evaluations of the ontology. The members of the review panel are not involved in the development of the ontology. We refined the ED-WDO according to the review panel's feedback until the experts agreed that the ontology reasonably represents the ED work domain. For context and application evaluation, we evaluated the ontology on an emergency nurse assessment use case, which we will discuss in the next section.

ED-WDO Use Case Evaluation

The ED-WDO models the basic backbone structure of the ED work domain which is independent of any artifacts, healthcare settings, or implementations. It also provides the flexibility to be extended for any specific settings, requirements, or focus. The Emergency Nurses Association (ENA), for example, provides a guideline for the workflow of nurse assessment and documentation for different patients [13]. Here we use it as a use case to evaluate and illustrate how the ED-WDO can be applied and extended to model the specific work domain for nurse assessment.

Initial assessment:

For the initial assessment, patients with different emergency severity levels need to follow different workflows. We first need to model patients with different levels of emergency severity as different object classes (subclasses of the Object class in WDO) in the extended ED-WDO for nurse assessment. Figure 4 shows the patient classification using the Emergency Severity Index (ESI) per ENA. As specified in the ED-WDO, the Emergency Severity category for each patient is decided on the triage stage. Only patients classified as levels 3-5 needs to complete a full nurse assessment. Patients classified as levels 1-2, on the other hand, require immediate medical interventions and will not be delayed in order to complete a full nurse assessment. In this case, we can add a new constraint to the "Nurse Assessment" Operation,

"Nurse Assessment" *requireObject* only (Patient_Level3 or Patient_Level4 or Patient_Level5)

which indicates that this operation only requires patients classified as level 3, 4, or 5.

- Level 1: conditions that are threats to life or limb (or imminent risk of deterioration) requiring immediate aggressive interventions.
- Level 2: conditions that are a potential threat to life, limb, or function requiring rapid medical intervention or delegated tasks.
- Level 3: conditions that could potentially progress to a serious problem requiring emergency intervention.
- Level 4: conditions related to patient age, distress, or potential for deterioration or complications would benefit from intervention or reassurance within one to two hours.
- Level 5: conditions that may be acute but non-urgent as well as conditions, which may be part of a chronic problem with or without evidence of deterioration.

Figure 4 Patient Category using the Emergency Severity Index (ESI)

- Level 1 = Critical: Every 5-15 minutes as needed and no less frequently than every hour for the first four hours, then every 2 hours if clinically stable.
- Level II = Emergent - vital signs no less frequently than every hour for the first four hours, then every 2 hours if clinically stable.
- Level III = Acute – vital signs no less frequently than every two hours for the first four hours, then every four hours if clinically stable.
- Level IV = Urgent – vital signs per acuity and clinical assessment, but no less than every four hours.
- Level V = Minor - vital signs per acuity and clinical assessment, but no less than every four hours.

Figure 3: Reassessment Guidelines for Patients with Different Levels of Emergency Severity

Reassessment:

The ENA also specified guidelines for reassess patients according to their Emergency Severity category.

In order to represent different temporal factors for reassessment for patients in different categories, we adopted the time representation from the clinical narrative temporal relation ontology (CNTRO) [14]. CNTRO specifies how to represent different kinds of temporal relations and expressions including repeated events with frequencies. Figure 5 shows an example of how to represent the reassessment operation for level 2 patients. There are two stages involved in this operation: Reassessment Critical Stage 1 and Reassessment Critical Stage 2. These stages can also be represented in OWL. For example, we represented "Reassessment Critical Stage 1" as follow:

"Reassessment Critical Stage 1" *frequency* *some*
(Frequency and (hasUnitOfMeasure value hour)
and (hasValue some int[< 1]))

"Reassessment Critical Stage 1" *duration* *some*
(Duration and (hasUnitOfMeasure value hour)
and (hasValue value 4))

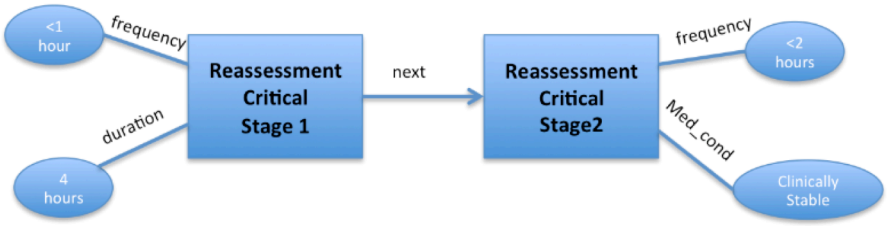

Figure 5: Example of representing reassessment temporal pattern

Assessment for patients with different ages:
Additional assessments may be required for patients with different ages. For example, patients under 18 months of age will have a head circumference measured. We also need to be able to represent this kind of constraints for operations. For this example, we first need to represent the objects that satisfy the constraint "under 18 months of age". We use an object property *hasAge* to represent a patent's age. We then define the constraint has-Value some int[<18] with unit of measures as month to represent "under 18 months". The relation between the operation and the object can be specified as:

"Head Circumference Measure" *requireObject*
(Patient and hasAge some
(Age and (hasUnitOfMeasure value month)
and (hasValue some int[< 18]))

Conclusion and Future Direction

In this paper, we introduce our preliminary effort to create an ontology for the Emergency Department work domain (ED-WDO). The ED-WDO includes necessary ED operations and objects, as well as the goal for each operation. It outlines the basic structure of the ED work that the system together with its human users will perform. It is an explicit, abstract, implementation-independent description of the ED work.

The primary purpose of ED-WDO is to serve as an abstract ED model for understanding, measuring, and designing cognitive work to increase care quality and patient safety. By identifying the ED-WDO, we will know the work that has to be done. All other factors, including how the work is implemented, how it is performed procedurally by users and machines, and how different designs affect user performance, can then be examined. In other words, with ED-WDO, we can explore how decisions are made, care given, and information sought in EDs that vary in the degree to which they have adopted electronic health records, use health information technology, or vary according to implementation specific idiosyncrasies. In our project, we are currently using the WDO-ED to design am information visualization system with multiple levels of details to support opportunistic decision making by clinicians.

We evaluated the semantics of the ED-WDO with domain experts. From the evaluation results, we can conclude that the lexical and semantic definitions of the classes, the hierar-

chical structure, as well as the semantic relation definitions in the ED-WDO are well defined and can faithfully represent the ED work domain. For the context and application criterion, we evaluated the usage of the classes and properties, on an emergency nurse assessment use case. The results also indicated that the ED-WDO can be used to represent the use case.

Several future directions we would like to pursue to extend and improve the ED-WDO. First, the WDO focuses on operations and goals. It declares constraints such as required objects for an operation, or required operations for a goal. We would like to provide more flexibility on defining the constraints in ED-WDO, e.g., to be able to model required operations or required goals (of operations) for different categories of patients. We then need to propose new properties to define this kind of relations. Second, an ontology development process is usually iterative. We plan to evaluate the ED-WDO using more use cases and data. Based on the results, further improvement can be done to the ontology itself.

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