

Graph Based Model to Support Nurses' Work

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Abstract. Health care is a knowledge-based community that critically depends on knowledge management activities in order to ensure quality. Nurses are primary stakeholders and need to ensure that their information and knowledge needs are being met in such ways that enable them, to improve the quality and efficiency of health care service delivery for all subjects of health care. This paper describes a system to help nurses to create nursing care plan. It supports focusing nurse's attention on those resources/solutions that are likely to be most relevant to their particular situation/problem in nursing domain. System is based on multi-relational property graph representing a flexible modeling construct. Graph allows modeling a nursing domain (ontology) and the indices that partition domain into an efficient, searchable space where the solution to a problem is seen as abstractly defined traversals through its vertices and edges.

Keywords. Organization, ontology, nursing, nursing process, recommendation system, electronic health record, e-documentation

Introduction

Due to the complexity of healthcare and the decreasing boundaries among health care professionals, the ability to communicate effectively about patient care among multiple professional groups is more important than ever [1]. Nurses are primary stakeholders and need to ensure that their information and knowledge needs are being met in such ways that enable them, to improve the quality and efficiency of health care service delivery for all subjects of health care. Nurses deliver healthcare service to subjects of health care through nursing process as a structured, problem-solving approach that provides a framework for process-oriented nursing documentation using care plans [1, 2]. Nursing documentation should provide patient's health status information through nursing anamnesis, nursing diagnosis, nursing goals, nursing interventions and other health related elements. Implementation of nursing care plans in patient's health records has been slow due to the lack of a uniform and unambiguous system [1]. Therefore, a detailed representational model of the nursing care plan is a key factor for data quality and documentation consistency.

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The purpose of a recommendation system is to help fulfill source requirements of the individual enacting the service [3]. Recommendation systems serve as an information filtering tool that reduces the search space to a more easily manageable subset [4]. Within this subset, the individual is able to better identify required resources. The most important aspect of recommendation is ability to understand the user requirements in a given context. Nurses within the nursing process are facing a variety of contexts each with different resource requirements [5]. For example, nurses identify patients' symptoms and signs; based on patients health characteristics they identify nursing diagnosis; set nursing goals; set nursing interventions and evaluate patient health progress through changes in patient's health status over time in accordance with preset nursing goals.

This article presents a recommendation system approach to support the nursing process. Recommendation system maintains a resource-rich, property graph-based model of the nursing domain that includes various domain concepts and relationships among them. System utilizes the model to execute recommendation algorithms - problem-solving strategies in all phases of nursing process.

1. Nursing Ontology Representation

The foundation of the nursing recommendation system is a rich model of nursing domains in the form of semantic network as a multi-relational property graph structure [6]. Graph is a set of vertices and edges between couples of vertices. Edges, used in our model, are directed and labeled. Properties in our property graph, to which we assign values, can be assigned to either vertices or edges.

Ontology allows us knowledge modeling in the nursing domain. To assure clear meaning of the elements in the semantic network, it must have clear rules on how to build the network. It defines a set of abstract classes that represent domain concepts in nursing and define vertex types in our graph representation. Further it defines possible inter-conceptual relationships that limit which abstract classes can be connected and what labels can be used to name the connections. On this basis ontology defines inference rules for deriving implicit relationships [7]. As such it defines the knowledge needed to make recommendations in the process of building a nursing care plan [8].

The proposed recommendation system's abstract data model is presented as four-layer ontology. Each layer presents a different level of abstraction. At the lowest layer, the meta-meta-model concepts allow the modeling language to be represented by the Graph Defining Schema Model (GDSM). It is defined by a graph database management system that we used - Neo4j. The second layer named GDSM contains rules for defining domain concepts in form of required and optional properties. Third layer limits the types of concepts and possible relationships among them. It must be broad enough to support complexity of ontology in nursing. The highest level presents nursing concepts.

Ontology language is the basis for exposing nursing domain graph to traversals algorithms to enable recommendation functionalities. The next section discusses basic types of the graph traversal algorithms and its application to problem-solving situations. Property graph allows modeling a nursing ontology and the indices that partition domain into an efficient, searchable space where the solution to a problem is seen as abstractly defined traversals through its vertices and edges.

2. Recommendation Approach

Recommendation systems are designed to help with information overload by filtering elements that don't pertain to the person [3]. There is a standard dichotomy in recommendation research in regard to content (recommending resources that share characteristics) or collaboration (similarity of resources based upon the similarity of the taste of the users modeled within the system). These two seemingly different approaches are conveniently solved using a property graph together with its serialization into database and two simple traversal techniques. Figure 1 presents a simple nursing ontology subset. Theory is described by vertices with dark text (circles) that consist of nursing problems (NP), health characteristics (Ch) and features (F) that are used to describe health characteristics when a certain patient is described. For the purpose of our examples the figure also shows a part of nursing documentation for two patients (P) with certain signs/symptoms (S) and nursing diagnoses (ND).

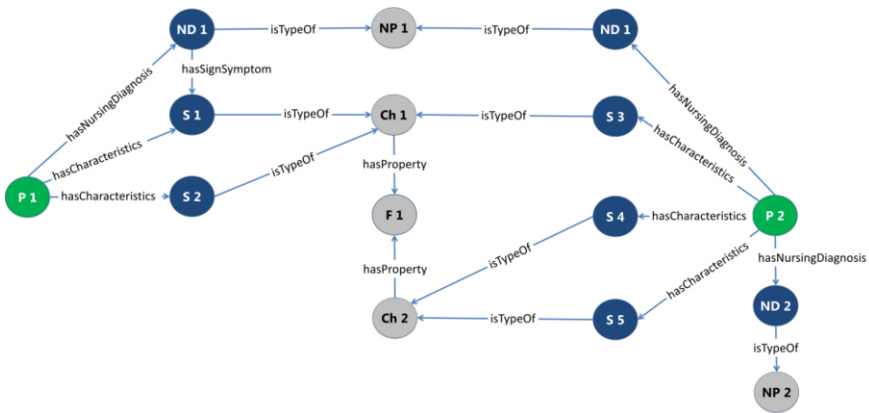


Figure 1. Simplified example of nursing ontology graph.

2.1. Content-Based Recommendation

In order to identify resources that are similar in features to a resource we need to traverse to all resources that share the same features. This is accomplished with the following function:

$$f(i) = (\varepsilon_i \circ v_{in} \circ \varepsilon_{hasProperty} \circ e_{out} \circ v_{in} \circ \varepsilon_{isTypeOf} \circ e_{out} \circ v_{in} \circ \varepsilon_{hasCharacteristic} \circ e_{out})(i)$$

Assuming $i = P1$ (patient P1), recommendation function $f(i)$ states as shown in Figure 1, traverse to the outgoing edges of patient P1, only allow “hasCharacteristics” edges, and then traverse to the incoming vertices of those edges. At this point, the recommendation traverser is located at S2 vertex. Next, traverse to the outgoing edges of the vertex, only allow “isTypeOf” edges, and then traverse to the ingoing vertices of these edges. At this point, the traverser is at Ch1. We proceed by going to outgoing edges “hasProperty” and then to ingoing “hasProperty” edges. After completion of these steps we are presented by health characteristic domain concept Ch2 that is similar in feature F1 to health characteristic domain concept of Ch1 that patient P1 has. Thus,

given the simple ontology data graph set, domain concept Ch1 is similar to concept Ch2 in content by feature named F1. We presented an example of the use of graph traversals to do naive content-based recommendation. By composing different predefined paths into a longer compositions traversals different complexity of recommendation can be achieved. Along with speed of execution, this is one of the benefits of using a functional, flow-based model for graph traversals [3]. Moreover, each component has a high-level meaning (e.g. the health characteristics that a patient has) and as such, the verbosity of longer compositions can be minimal.

In practice this means that for a given patient with a set of characteristics we try to suggest nursing diagnoses that are related to the same characteristics. This part of knowledge base can be derived from theory, for example school books.

2.2. Collaborative Filtering-Based Recommendation

Collaborative filtering technique try to identify a set of resources that have a high probability of being present at a patient based upon identifying other patients that have similar characteristics. For example, if patients P1 and P2 share a nursing diagnosis ND1, then the remaining nursing diagnoses of P2 may be recommended to P1.

We can accomplish this by traversal that is broken into components $f(i)$ and $g(i)$, where $f: P(V) \rightarrow P(V)$ and $g: P(V) \rightarrow P(V)$. Function $f(i)$ is defined as:

$$f(i) = (\varepsilon_i \circ v_{out} \circ \varepsilon_{hasNursingDiagnosis} \circ e_{in} \circ v_{out} \circ \varepsilon_{isTypeOf} \circ e_{in} \circ v_{in} \circ \varepsilon_{isTypeOf} \circ e_{out} \circ v_{in} \circ \varepsilon_{hasNursingDiagnosis} \circ e_{out})(i)$$

Function $f(i)$ traverses to all those patients vertices that have the same nursing diagnose concept (theory based) as patient vertex i and who themselves are not vertex i . The more nursing diagnoses (ND) that other patients share in common with patient i , the more traversers will be located at that patient's vertex. In other words, if patient i and patient j share 10 ND in common, then function $f(i)$ will return patient j 10 times.

Function $g(i)$ is defined as:

$$g(i) = (v_{in} \circ \varepsilon_{isTypeOf} \circ e_{out} \circ v_{in} \circ \varepsilon_{hasNursingDiagnosis} \circ e_{out})(i)$$

Function $g(i)$ traverses to all the nursing diagnosis (ND) that patient j vertex has. In composition, $(g \circ f)(i)$ determines all those ND that are present in those patients that have similar health problems to patient i . Figure 1 diagrams a function path starting from vertex P1 ($i = P1$). Only one legal path is presented for clarity.

By using multi-relational property graph and graph traversal pattern, there exists a single graph data structure that can be traversed in different ways to expose different types of recommendations. Being able to mix and match the types of traversals executed, this alters the semantics of the final rankings and conveniently allows for hybrid recommendation algorithms to emerge. Ways in which vertices relate to each other determine which graph traversals are most efficient to execute and which problems can be solved by a proposed graph structure. Graph databases and the graph traversal pattern do not require a global analysis of data. For many problems, only local subsets of the graph need to be traversed to yield a solution. By structuring the graph in such a way as to minimize traversal steps, limit the use of external indices, and reduce

the number of set-based operations, modelers gain great efficiency that is difficult to accomplish with other data management solutions.

By mixing content based and collaborative based recommendation techniques we were able to identify different recommendation contexts. System can identify patient's health characteristics that should be assessed based on the set of present characteristics. They can remind the nurse of further assessment. At the same time system is able to recommend a set of nursing diagnoses based on current patient's health characteristics. For a selected nursing diagnosis a set of nursing goals can be recommended. Further on, a nursing goal can trigger a recommendation of nursing interventions.

3. Results

We have applied our ontology modeling approach and recommendation system with multi-relational graphing to model a nursing ontology for the Nephrology Department of the University Clinical Centre Maribor in Slovenia. Nephrology nursing is a specialized area of nursing that concerns individuals with kidney failure and their families. Care is provided over a long period of time, usually several years. The spectrum of nephrology nursing practice for patients with acute and chronic renal failure includes hemodialysis, peritoneal dialysis, and transplantation [9]. Methodological approach consisted of three stages: the feasibility stage (specification and conceptualization), development stage (formalization and implementation), and evaluation stage allowed us to first model nursing ontology domain consisting of 207 domain data concepts for nursing assessments, problems, goals and interventions.

After population process of ontology instances we were able to evaluate our proposed recommendation context by using Gremlin query language, which is specialized for querying data stored in graph database using property graph structure.

The use of domain modeling with the multi-relational property graph structure was a feasible approach to enable recommendation support in process of care plan construction. Based on the results of first phase of a larger study aimed at developing a prototype recommendation nursing system it was observed that time for care plan construction was reduced and nurses are more willing to use computerized care plan system. Nurses on the first evaluation phased also stated that for optimal work process, ten most likely recommendation elements (nursing diagnosis, goals, intervention, health characteristics) are sufficient to provide high recommendation level help in the process of care plan creation.

With an integrated recommendation engine and the capability of allowing domain users to model concepts via a friendly graphical user interface. Investigating the terms and the information structures of a domain are essential first steps towards clarifying any ambiguity in the representations of the domain contents. Actively involving domain experts in the development and maintenance of the system improves the accuracy of the data representation and the reusability of the data.

4. Conclusion

The purpose of the study described in this paper was to develop and validate an unambiguous nursing ontology and recommendation system as a multi-relational property graph. We used a four-layer representation model and a three-stage

methodological approach, to ensure flexibility in the modeling process. The use of the multi-relational property graph structure allowed us to model a nursing ontology and the indices that partition the domain into an efficient, searchable space, where the solutions to a nursing problem are abstractly defined recommendation traversals through its domain concepts, instances, and relationships. We have found a proposed model efficient in saving documenting time in practice. The model will have to be further tested in practice.

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