User-centric Ontology for Smart Holistic Health Information Systems

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ABSTRACT: This paper describes the first steps in the development of a user ontology for a Smart Health Information Portal (SHIP) to provide collaborative health terms in holistic medicine. Recent trends in the increasing dissatisfaction with conventional medicine and towards embracing holistic model of health for improving quality of life is being witnessed worldwide, more importantly in the technologically advanced countries. Today, advancements in Internet technology and the vast as well as growing source of information available in World Wide Web have the vision to achieve patient education and empowerment of their own health conditions and well-being. Hence, holistic medicine with the theory that each individual has an immense potential for self-healing could be mobilised by harnessing information technology intelligently. To achieve this, it becomes imperative to provide health information specific to each patient's needs in a personalised way due to the diversity in the patient circumstances and the availability of vast and varied information in the Web. A Smart Health Information Portal (SHIP) could provide quality information that is most relevant to patients pursuing holistic treatments. In this paper, we describe the initial development of a user ontology for holistic medical information that integrates conventional medical terms related to cardiac conditions along with Homeopathy and Ayurvedic terms towards providing meaningful complementary heart health information within an existing SHIP.

KEYWORDS: Health Information Systems, Holistic Health, User-centric Ontology

1. INTRODUCTION

Tele-medicine is increasingly being considered as a key for healthcare reform by providing a platform for patient empowerment [1]. Internet provides users with a wide range of health information. However, these are predominantly disjointed and even misleading with confusing terms of the subject domain. For users to make queries about a subject domain effectively with relevant information, domain conceptualisation is important. Since the domain conceptualisation facilitates in naming and describing the

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entities of the domain and their interrelationships, it could provide the representations for user vocabulary and for communicating the domain knowledge. Such a formal conceptualisation of a subject domain and its explicit specifications is called an ontology. Ontologies play a pivotal role in the development of knowledge-base systems, and in particular are useful for interoperating heterogeneous systems to share common interpretations of vocabulary while communicating with each other. Biomedical ontologies have been developed in the subject domain of health and related topics with specific purposes. For example, while software to represent clinical information such as GALEN was developed to support the reuse of information to integrate medical records, decision support and other clinical systems, the purpose of UMLS was mainly to link biomedical vocabulary among disparate sources of terms and terminologies. However, the major concerns to be addressed together are, ambiguity of information available in Internet resources [2-3], sensitivity of search techniques on vocabulary [4] and lack of personalisation [5]. Though ontologies are being developed to alleviate some of these problems [6-7], there is scarcity of an user-centric ontology that could facilitate in providing personalised health information and advice [8]. Due to the nature of health information that varies considerably due to user circumstances including biological and environmental factors, developing an user ontology that caters to individualistic needs plays a major role for the provision of relevant and meaningful health information. The paper aims to take a modest step in this direction.

In this paper, we propose a hierarchical method for developing the user-centric ontology to provide quality and personalised information about heart health with a holistic approach. We classify the terms commonly used for retrieving quality content pertaining to heart health into hierarchical levels in order to cater to the needs of different types of users for the development of a smart health information portal (SHIP) that integrates complementary medicine towards the advancement of holistic medicine. Though online resources as information portals are being developed and available for doctors and healthcare professionals, only recently, there are some initiatives towards including naturopaths and other allied medicines for supporting mainstream medicine. However, the majority of information seekers are patients who are increasingly turning to alternative support medicines that suits their personal lifestyle and circumstances. In order to address their growing health information needs and to promote patient empowerment for a healthy living, comprehensive online health information access has become an integral part of health strategy in most countries. With this view, the information seeker or user of SHIP is developed to be predominantly patients and may even involve patient's family and friends.

Heart health portal users could be normal people seeking information for preventive health purpose, or could be potential patients who would like to explore alternative

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medicines before resorting to conventional procedures, or could even be cardiac patients who have undergone conventional procedures and wish to adopt holistic medicine as part of their future lifestyle. Holistic medicine encompasses all forms of medicine that users could resort to for their well-being with a focus on the person and user interactions with the environment as a whole instead of dealing with solely on a specific illness or a certain part of the body. In other words, with a "person centered" philosophy, it could involve various forms of diagnosis and treatment to include allopathy and alternative medicines [9-10] and modalities such as aromatherapy, acupuncture, herbal medicines, Homeopathy, Traditional Chinese Medicine (TCM), Ayurvedic Medicine (AM) [11-13]. National Center for Complementary & Alternative Medicine [14] reports increasing trend from an earlier statistic of 38% effective use of CAM use in America [15]. In Australia, over 70% of the people in New South Wales have increasingly visited holistic medicine practitioners and have used at least one of 14 forms of complementary therapies [16-18]. This would increase further with the introduction of electronic health records (EHR), which could be extended to include CAM health events to form a complete and holistic health record for enhanced healthcare provision of the empowered patients [19-20].

Developing an information portal for the wide spectrum of holistic medicine would be an Herculean venture. While catering to the information needs of users, studies have always considered two means, namely specificity (user focus on a narrow topic) and exhaustivity (wider scope of user interest). In this paper, we take advantage of ontologies using specificity to provide personalised information related to heart health with the novelty of integrating holistic medical information with an existing SHIP, the Smart Health Information Portal. In addition, the study uniquely investigates the inclusion of mental health within the heart health information personalisation.

2. RELATED WORK

This section presents a literature review of popular user-centric ontology techniques and recent developments in personalised health information approach.

2.1 User-centric Ontology Techniques

Ontology is a formal conceptualisation of domains that describes the abstract and concrete meaning of domain aspects by means of concepts and their interrelations [21]. They are content theories about the sorts of objects, properties of objects, and relations between objects that are possible in a specified domain of knowledge. Ontology differs from knowledgebase mainly in that ontology provides a set of concepts and terms for
describing some domain, while a knowledgebase uses those terms to represent what is true about some real or hypothetical world. An ontology is also a concept of warrant providing fundamental principles that guide the process of selecting and expressing terminology [22]. Hence, ontologies provide an abstract view of an application domain for facilitating communication among distinct groups using different vocabularies with the aim to create common vocabularies. In a user-centric ontology, the user warrant relies primarily on the language of people who are expected to use the system, which include people both people who construct the system and people who use the controlled vocabulary [22].

The main advantage of ontologies is that they can outperform in semantics when compared to traditional information retrieval and knowledgebase systems for domain specific natural language learning tasks [23, 2]. Automatic ontology learning approaches with the design of simple classes for atomic concepts and assembling them into compound classes depicting complex concepts were studied [24]. However, user-centric approaches for improving retrieval effectiveness became important for personalisation of information content. While some studies use ontology references to categorise online portals for personalised web search and browsing [25, 5, 7], others focus on user profiles for personalisation [26, 24]. Unfortunately, most of previous work on ontology-based approaches did not capture user circumstances well and were focused on a single domain knowledge, thereby lacking relevance/specificity for integrating knowledge from many related domains to cater to the user needs in health domains. In this paper, such user-centric perspectives are considered as contemporary steps in developing an ontology of multi-level hierarchical structure to combine information from mainstream medicine domain as well as complementary medicine domains within SHIP, contributing towards the advancement of holistic medicine.

2.2 Personalised Health Information

Personalisation has become a key feature in any user oriented information system. The Internet provides a plethora of information and majority of them are not customisable and hence information acquisition is likely to be irrelevant and even misleading to the users. Many studies have been undertaken to improve the quality information provided, in particular the accuracy and effectiveness to suit individual user information needs. In the context of health information, the quality of information and customised content is crucial for patient health and well-being. Users find more utility in complementary and alternative medicine (CAM) than in conventional medicine as CAM therapies are characterised by personalised diagnosis and interactive treatments, providing a greater value of their
holistic well-being. Hence, personalisation becomes even more a necessary user warrant in this study to have a meaningful integration of the information content from conventional medicine and CAM domains. User ontologies have been developed to capture users' interests or user profile in target domain for personalisation [26, 24, 5, 7]. However, these methods focus on capturing user behaviour in browsing the Web and are not capable of integrating concepts and semantic relations pertaining to health information from multiple domains. The main challenge here is to discover and characterise user intent based on their circumstance. One popular approach is based on quantification such as determining relevance weight of a pattern [26]. However, previous works predominantly use such techniques for document-based ranking.

In the context of health information, the relevance measure poses considerable variations both individually and circumstantially. For instance, individual factors such as gender, age, marital status, ethnic background, occupation, and even the stage of patient illness could influence their medical conditions and thus providing the information most suitable to a patient/user is a major challenge [27]. While it is difficult to address all possibilities and combinations of such circumstances, it is possible to provide a significant degree of personalisation to predominant user situations. In order to address this concern, a smart health information portal (SHIP) has been developed with a substantial level of personalised access to quality assessed health information and advice. We propose a user-centric ontology with a hierarchical level of concept and heart-related terms from multiple domains including mainstream conventional medicine and homeopathic medicine for a holistic medical approach in SHIP. We cater to the information relevance in SHIP by providing the health information to be congregated at multiple levels of granularity. SHIP ensures that the health information is not only from medical advice viewpoint, but a range of perspectives from different parties involved/affected by the condition, including practitioners, researchers, patients and families of patients as article authors. A novel ontology-based approach is introduced in SHIP to provide personalised information pertaining to heart and mental health for the users.

3. METHODOLOGY

3.1 Proposed Ontology-Based Ship

We describe the development of an user-centric ontology with the provision of smart technology and techniques to enhance the core capabilities of health content delivery, management, and collaboration for an existing Heart Health Online portal as part of the
SHIP. The core of SHIP consists of a constrained vocabulary of popular user terms, encompassing both medical and general categories that are relevant to the domain of heart and mental health. It is developed and maintained by domain experts based on a formal medical vocabulary such as the Medical Subject Headings vocabulary [28]. The ontology supplements the vocabulary further with synonyms that could be coming from complementary medicine terms for facilitating information provision towards holistic medicine. Each information resource is linked to the vocabulary as well as synonyms and related terms within the ontology by defining relationships linking the set of terms.

The main aim of SHIP is to incorporate computational intelligence features for health information acquisition, assess its quality and enable personalised information delivery to the users of the portal [27]. In this paper, the focus is on the ontology approach for content management as it imposes the conceptual basis for integrating holistic medicine within the design and development of the portal in terms of the information acquisition, quality assessment and maintenance process. An iterative lifecycle method is adopted for the ontology development and content management in SHIP that suits the dynamic nature of health information and quality content maintenance.

An overview of the stages involved in the ontology construction for user query and content management is provided in Figure 1, which are: Ontology Capture, Personalise, Integrate and Evaluate. The diagram also depicts the main tasks involved in the construction of the ontology from one stage to the other.

**Ontology Capture** – This is the first stage of each cycle of the ontology construction for acquiring new domain knowledge and content (i.e., the descriptions of the vocabulary...
terms) to be represented. It involves identifying the different types of intended users and their requirements for using the ontology so that the domain experts are able to identify the relevant terms, phrases, synonyms and any other resource identifiers for the knowledge acquisition and content creation in a hierarchical structure. For the ontology construction of SHIP, some of the knowledge gathering questions for the complementary medicine experts are:

1. What are the popular terms used in complementary medicine that relate to cardiac patients?
2. Which of these relate to mental health?
3. Is there a dictionary of terms containing the definitions?
4. What are the synonyms of these terms?
5. For each term, what are the related terms and the type of relationship (child or parent)?
6. Do these terms have reliable sources of information, and what are they?

The domain experts verify the reliability of the sources of information when they query search engines, online libraries, academic journals and other portals. This is ensured by measuring the credibility of the author and the publishing body that provides the information pertaining to the heart health or target user sub-groups. E.g. credible publishers of information such as symptoms or remedies that is relevant to both adults and children with the same heart condition. Table 1 provides some of the terms based on user queries that include chest pain and similar terms.

<table>
<thead>
<tr>
<th>Popular Terms &amp; Synonyms: Heart condition/symptom, remedy, etc</th>
<th>Equivalent Terms: Complementary Medicine (Ayurveda, Homeopathy, etc)</th>
<th>Related Terms &amp; Relationships (Parent, Child, etc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest pain, Pressing Heaviness</td>
<td>Angina Pectoris: Heart condition - Allopathy, Homeopathy, Ayurveda</td>
<td>Lycopodium (Child), Symptom (Parent)</td>
</tr>
</tbody>
</table>

The identified key concepts and relationships and their definitions are captured as the first stage of the ontology creation and these are refined and extended with add-ons in the

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hierarchy through feedback and evaluation for subsequent iterations. Domain terms are identified as concepts, instances, verbs, synonyms, relations or properties and represented within the hierarchy (“Is-A” relation in the knowledge backbone).

Table 2: Example hierarchical categories of terms

<table>
<thead>
<tr>
<th>Hierarchical Level 1 Category of Terms</th>
<th>Level 2 Category of Terms</th>
<th>Level 3 Category of Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptoms</td>
<td>Heart Failure</td>
<td>Angina, Aortitis</td>
</tr>
<tr>
<td></td>
<td>Types</td>
<td></td>
</tr>
<tr>
<td>Diagnosis</td>
<td>Screening &amp; Testing</td>
<td>Angiogram Results</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment / Remedy</td>
<td>Surgery</td>
<td>Stent</td>
</tr>
<tr>
<td></td>
<td>CAM Therapy</td>
<td>Lycopodium</td>
</tr>
<tr>
<td>Side Effects</td>
<td>Contraindications</td>
<td>Allergy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day-to-Day Matters</td>
<td>Psychological Exercise</td>
<td>Stress Treadmill</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Medical</td>
<td>Financial Support</td>
<td>Medicare</td>
</tr>
</tbody>
</table>

Table 2 provides an example hierarchy categories of terms resulting from the ontology capture for heart health relating conventional and homeopathy medicine domains. The next stage of the ontology construction involves personalisation of the content.

Personalise – This stage of the ontology construction involves refining the acquired content to personalise the information for users. We introduce meta-tags to cater for information relevance and usefulness for the different types of users. For instance, the information should aid towards the benefit of the users’ mental or physical condition based on their circumstances. It also involves managing search results, ascertaining meaningful resources and compiling content summaries that are reliable. In addition to quality metrics such as relevance, usefulness and reliability, we introduce the measure of timeliness. For instance, comparison of the time of article publication with recent developments in the specific area of heart health would help to determine if the provided information is current or obsolete. Figure 2 shows the different combinations of options provided for users in SHIP for a personalised keyword search related to breast cancer.
The existing SHIP was developed as Breast Cancer Knowledge Online (www.bckonline.monash.edu.au/search/personalised.do/). For heart health, the search is customised to suit user needs based on their circumstances including mental health and interests in complementary medicine. This work is driven by a previous study [29] that identified mental health information needs of people with cardio vascular disease (CVD), with and without comorbid depression. Subsequent study [19] has also established the need for health information resources to relate heart disease along with psycho-education and strategies for dealing with psychological symptoms such as depression, anxiety and stress that are often associated with coronary diseases. Such studies have prompted the
ontology of the heart health portal to cater to the breadth of information with a focus to include mental health in delivering personalised content for the users. Achieving this is important for integrating domain knowledge of other CAM therapies with the existing SHIP for meaningful advancement towards holistic medicine.

Integrate – The third stage in the ontology development involves arriving at a common interpretation of the vocabulary used in different knowledge domains of heart health and their communications and unifying the interoperations of heterogeneous systems. Stranieri and Vaughan [30] identify four main types of relationships between conventional medicine and CAM, namely, embedded coexistence, independent coexistence, allopathic dominance, and integrated medicine. They argue that among these scenario types, coexistence of diverse medical systems is potentially more beneficial for patients, governments and health care professionals. Since coexistence enables patients to have more personal choice, it could gain more acceptance and the ontology of SHIP adopts this view. However, due the availability of several forms of complementary medicine, the integration process requires defining the scope for holistic medicine within the context of mental health and related heart conditions, and redefining in each iteration of ontology development becomes essential [31]. For instance, mental health status of patients are more closely linked to the theories of homeopathy or Ayurveda than in aromatherapy or chromotherapy. Hence, unifying heterogeneous information from diverse health related knowledge domains with automated metadata specifications iteratively would lead to the ontology refinement and evolution for SHIP. The integration process at each iteration considers side-effects, contraindications, adverse reactions or interactions, if any, with each CAM therapy that would be included for rendering quality advice to patients opting for holistic medicine information from SHIP. Overall, integrating ontologies in health portals can serve as references for consensus reached by professional community from allopathy and CAM domains, and common vocabulary used in their interactions could facilitate in the advancement of holistic medicine.

Evaluate – The evaluation of the ontology is required as part of continuous quality improvement process of the SHIP. This stage of the ontology lifecycle involves a check for meeting the purpose, user requirements and semantic consistencies within the knowledge domains. Here, the domain experts review the adherence to the four quality metrics, namely, reliability, relevance, usefulness, and timeliness of the ontology information resources using the portal metadata elements for updating the content repository. In addition, their role is crucial in verifying that each form of holistic medicine is defined within the scope and personalisation required for the information delivery of SHIP. User feedback and critical review serve as useful inputs for the next iteration of the ontology life cycle in order to identify and acquire new domain knowledge that are
required to follow through the ontology enhancement stages as depicted in Figure 1.

4. FINDINGS

Several studies conducted in different countries demonstrate reasons for an overall increasing trend in the usage of some form of CAM therapies, such as huge waiting time for allopathic specialists / treatments, dissatisfied hospital treatments and after-care, reduced side-effects, increased health awareness, patient empowerment and self-control of one's health, etc. [12-13, 15, 32]. However, findings in previous work [33] highlight the idiosyncratic nature of the information seeking process. To address this concern, this work makes use of user-centric ontology development to enable an existing smart health information portal (SHIP) cater to the growing trend in holistic medicine information seekers with personalised information delivery related to heart health.

Our first finding is that our iterative lifecycle development of the ontology (Figure 1) suits well in incrementally augmenting the several forms of holistic medicine catering to adaptability, extensibility, and maintainability. Since the ontology depicts the reality of the world constructed from the domain analysis, it requires domain experts to provide continuous feedback and enhancements iteratively based on the recent developments taking place in the domain knowledge. Though the ontology built by this iterative approach may not have reached a comprehensive or formal structure, it is appropriate for including different forms of holistic medicine as they evolve, thereby catering to future scenarios of user requirements and personalisation. In this way we achieve the goal of creating learning ontologies that get evolved based on the dynamically changing environment.

Our second finding is that personalised user queries of heart health predominantly involve mental conditions and more and more requirements for in-depth information with relevant treatment options including medications, surgery, CAM therapies, modalities, herbs, and dietary supplements. Though developing ontologies are more complex in such cases due to the availability of different forms of CAM therapies, these domains share the same common terms related to heart and mental health. However, some terms could be more prevalent in specific domains. For instance, terms such as 'vital force' and 'potency' are more used in the context of homeopathy. Capturing such differences in terms, synonyms, their definitions as well as inter-relations would facilitate in a better customisation of the information catering to the user circumstances. For instance the homeopathic remedy Kalmia treats bradycardia accompanied by rheumatism or gout, and hence would benefit patients with such health conditions.

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The third main finding is that even though most of the CAM therapies claim to have no side effects, there could be drug interactions and contraindications when combined with more than one form. While debates on the safety of CAM procedures continue in academic circles, many patients perceive herbal medicines to be safer than allopathic medicines that could have adverse side effects in the long term [34-35]. CAM practitioners also promote their theory that unlike scientific tests conducted in other fields, a patient should be treated as a whole individual with a history of doctor-patient interactions rather than a mere medical case for experimental testing [36]. It is well known that homoeopathic remedies have no measurable physical substance in them for most of their commonly used potencies indicating no chemical interactions that might occur even with herbs or other dietary supplements. However, some of their remedies may have side effects if not prescribed in the correct way with right potency. They may also interact with other forms of CAM or allopathic medications. For instance, there is evidence that the effects of Warfarin, one of the blood thinning allopathic medicines prescribed for heart treatments are altered by many combined therapies in holistic medicine such as dietary supplements (Coenzyme Q10, fish oil supplements), homeopathic remedy (Crataegus Oxyacantha) and Chinese herbs (Green tea). In addition, with new products and drugs being introduced as a combination, it is important that patients are well-informed on the positive as well as negative interactions with other treatments based on the drug’s components and strength before they could safely undertake such holistic approaches.

5. CONCLUSIONS

With the growing popularity of holistic medicine, the need for developing holistic health information portals has emerged. However, several challenges are to be addressed for an information portal to be meaningful and effective in meeting the diverse requirements of individual users considering holistic medicine. In this paper, we have proposed a systematic ontology development methodology as a viable solution for these challenges. The main distinctive characteristics of our proposal are:

1) The information acquisition for holistic medicine portal is based on ontological semantics theory with an iterative ontology lifecycle approach for combining different knowledge domains (Allopathy, Homeopathy, Ayurveda, Naturopathy, etc) in an incremental manner;

2) The quality of the content is evaluated with measures such as reliability, relevance, usefulness and timeliness, taking into account both common elicitations as well as specific to certain forms of holistic medicine;

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3) The hierarchical structure of the ontology enables ease in adaptations and extensions of the ontology population;

4) The personalisation feature considers user circumstances including mental health and user preferences in providing customised health information and advice;

5) The inclusion of inter-related information through data analytics such as between diabetes and CVD [37] as well as with combined therapies of CAM, based on symptoms, side effects or even nutrition depletion by drugs, contraindications and adverse reactions would lead towards the advancement of holistic medicine and an integrated healthcare.

The current ontology being developed with allopathy and homeopathy information pertaining to heart and mental health would also include Ayurveda, traditional Chinese medicine, naturopathy and other holistic medicine domains. Future work is envisaged in developing and evaluating the portal using feedback from users of different types including clinicians, practitioners, education bodies, apart from patients and their support network.

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