Automatic Home Nursing Activity Recommendation

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Abstract
The rapid deployment of Web-based, consumer-centric electronic medical records (CEMRs) is an important trend in healthcare. In this paper, we incorporate nursing knowledge into CEMR so that it can automatically recommend home nursing activities (HNAs). Those more complex HNAs are made clickable for users to find detailed implementation procedures. We demonstrate the effectiveness of our techniques using USMLE medical exam cases.

1. Introduction

Web-based, consumer-centric electronic medical records (CEMRs) are currently undergoing widespread deployment by a few major Internet companies, including Google, Microsoft, and Revolution Health[9]. This is an important trend in healthcare, as ordinary consumers can actively manage their medical records and thus health through a Web interface.

Existing CEMRs have limited intelligence and can fulfill only a small portion of users' healthcare needs. In this paper, we study how to incorporate nursing knowledge into CEMR so that it can become an intelligent CEMR (iCEMR)[9] and support the function of automatically recommending home nursing activities (HNAs). Patients and caregivers can perform these recommended HNAs at home or in the community. Each nontrivial HNA is made clickable for users to find various, detailed implementation procedures for it on the Web. We achieve this through introducing and extending expert system and Web search technology into the CEMR domain. The expert system uses nursing knowledge and information in the CEMR to automatically form keyword queries, and then the search system uses these keyword queries to discover related healthcare information from the Web.

For a given care context, there are often hundreds of related HNAs covering a wide range of daily activities[1, 2, 5]. Consumers usually cannot obtain complete information on these HNAs from physicians and nurses in the limited amount of interaction time. Thus, it is desirable for iCEMR to provide consumers with detailed, comprehensive information on HNAs. This is especially true for chronic conditions, where care is ongoing for extended intervals.

We implemented our techniques in a prototype iCEMR system and evaluated its effectiveness using USMLE medical exam cases[8]. Our experiments show that iCEMR significantly outperforms both a popular medical Web site[12] and a major medical Web search engine[3] in providing HNA information.

In related work, GuidedMed[4] and iMed[6, 7] are two consumer-centric medical search engines using expert system technology. Both systems focus on *disease diagnosis*, by using diagnosis knowledge to help users find disease information related to their medical conditions. The application in this work is recommending HNAs, and differs radically from disease diagnosis.

The rest of the paper is organized as follows. Section 2 briefly reviews some basic nursing knowledge. Section 3 describes iCEMR's HNA recommendation function. Section 4 evaluates our techniques. We conclude in Section 5.

2. Background on Standardized Nursing Languages

Through continuous efforts of thousands of nurses over two decades, the nursing informatics community has systematically organized nursing knowledge into several standardized nursing languages[5], among which we incorporate North American Nursing Diagnosis Association International (NANDA-I) nursing diagnoses and Nursing Interventions Classification (NIC) nursing interventions into iCEMR's knowledge base. We choose these two standardized nursing languages because of the comprehensiveness of their scopes and their close relevancy to people's daily activities.

NANDA-I nursing diagnoses and NIC nursing interventions cover the full range of the nursing domain, including all settings (from hospital to home and community), both general practice and specialties, all time spans (from short-term to long-term), all ages of patients, and various kinds of actions that nurses, patients, and caregivers can take on illness treatment (e.g., disease management), illness prevention (e.g., fall prevention), and health promotion (e.g., exercise promotion).

The 188 *NANDA-I nursing diagnoses* are clinical judgments about individual, family, or community responses to actual or potential health problems[10]. Using Maslow's hierarchy of human needs, these nursing diagnoses are assigned five levels of

priorities[1]. In descending order of priority, these five priority levels are: (1) physiological needs, (2) safety and security needs, (3) love and belonging needs, (4) self-esteem needs, and (5) self-actualization needs. Each medical situation links to one or more nursing diagnoses[1]. (We use the term "medical situation" to refer to a broader concept than medical condition. It includes diseases, symptoms, health conditions (e.g., surgery), and life situations.) For example, for the medical situation of Alzheimer's disease, the linked nursing diagnoses include *impaired environmental interpretation syndrome*, *risk for trauma*, and *imbalanced nutrition*. A nursing diagnosis always has the same priority regardless of which medical situation links to it.

The 542 *NIC nursing interventions* are treatments that can be performed to enhance patient/client outcomes[2]. Each nursing intervention includes a list of (usually 10 to 30) *nursing activities* that are used to implement it and listed in descending order of priority[2]. For example, the nursing intervention of fall prevention includes:

(1) **Nursing activity 1**: Use partially-filled water mattress on bed to limit mobility, as appropriate;
(2) **Nursing activity 2**: Use a bed alarm to alert caretaker that individual is getting out of bed, as appropriate; and
(3) **Nursing activity 3**: Provide visible handrails and grab bars.

The same nursing activity can have various priorities when it is used in different nursing interventions.

Every nursing diagnosis links to a list of (often more than 10) nursing interventions[2, 5]. Each nursing intervention belongs to one of the following three priority levels according to its importance and applicability: (1) priority interventions for the majority of patients, (2) suggested interventions addressing only selected characteristics, and (3) additional optional interventions applying only to some patients. For example, for the nursing diagnosis of impaired environmental interpretation syndrome, the linked nursing interventions include *fall prevention*, *environmental management*, and *anxiety reduction*. The same nursing intervention can have various priorities when it links to different nursing diagnoses.

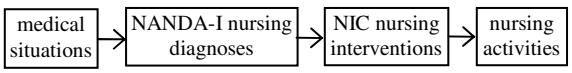

Figure 1. Linking medical situations to nursing activities.

Using nursing diagnoses and nursing interventions as intermediate steps, we can link each medical situation to multiple nursing activities, as shown in Figure 1. These nursing activities represent the actions that nurses, patients, and caregivers can take to achieve desirable outcomes for this medical situation. For example, using the nursing diagnosis of impaired environmental interpretation syndrome and the nursing intervention of fall prevention as intermediate steps, the medical situation of Alzheimer's disease links to Nursing activities 1, 2, and 3.

3. Home Nursing Activity Recommendation

3.1 Weight Assignment for Priorities

When recommending HNAs, iCEMR considers the priorities of various nursing diagnoses, nursing interventions, and nursing activities by assigning them different weights. Each medical situation M links to a set S_M of nursing diagnoses. Each nursing diagnosis $D \in S_M$ has both a weight w_D reflecting its priority and a normalized weight $n\_w_D = w_D / \sum_{E \in S_M} w_E$. There are five priority levels for all nursing diagnoses. The default value of the weight for the i-th ($1 \le i \le 5$) priority level is $1/i$.

Each nursing diagnosis $D \in S_M$ links to a set S_D of nursing interventions. Each nursing intervention $I \in S_D$ has both a weight w_I reflecting its priority and a normalized weight $n\_w_I = w_I / \sum_{J \in S_D} w_J$. There are three priority levels for all nursing interventions. The default value of the weight for the i-th ($1 \le i \le 3$) priority level is $1/i$.

Each nursing intervention $I \in S_D$ includes a set S_I of nursing activities sorted in descending order of priority. Each nursing activity $A \in S_I$ has both a weight w_A reflecting its priority and a normalized weight $n\_w_A = w_A / \sum_{B \in S_I} w_B$. Suppose S_I contains h nursing activities. The default value of the weight for the i-th ($1 \le i \le h$) nursing activity is $1/i$. According to her preference and inputs, the user can adjust the default weight values for the nursing diagnosis priority levels, the nursing intervention priority levels, and the nursing activities.

Some nursing activities are performed only by nurses (mainly in the hospital), whereas the others are *home nursing activities* (HNAs) that patients and caregivers can perform at home or in the community (occasionally also in the hospital). This paper focuses on HNAs because of iCEMR's consumer-centric view.

Next, we present iCEMR's HNA recommendation function. For medical situations that a user cares about, this function finds all the relevant HNAs and displays them as a prioritized hierarchy. This function also helps the user understand HNAs and find various, detailed implementation procedures for nontrivial HNAs.

3.2 Input Interface

iCEMR provides its intelligent functionalities to users through a Web interface described in our previous work[9]. The right side of iCEMR's main Web page has a button entitled "Recommend home care activities," by clicking which the user is led to the input interface Web page of the HNA recommendation function. This Web page collects a set of medical situations that the user currently cares about.

As shown in Figure 2, iCEMR automatically extracts from CEMR the user's current medical situations and displays them on the input interface Web page. The user can select the ones that she cares about. She can also add other medical situations by choosing from an extensive list of medical situations stored in iCEMR's knowledge base. All the medical situations that the user cares about form a list L_m. For each medical situation $M \in L_m$, the user can indicate whether M is highly important to her.

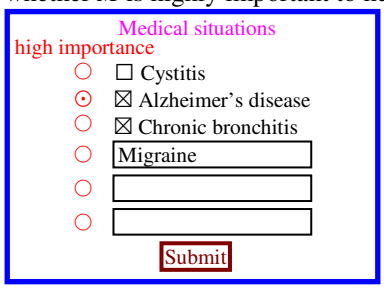

Figure 2. The input interface Web page of iCEMR's HNA recommendation function.

3.3 Search Algorithm

The HNAs for a disease d include the HNAs for d's symptoms. Hence, for each disease $d \in L_m$, iCEMR removes its symptoms from L_m to avoid generating redundant information. Each medical situation $M \in L_m$ is a topic that has a weight w_M reflecting its importance. If the user specifies in the input interface that M is highly important, $w_M = w_H > 1$. Otherwise, $w_M = 1$. w_H is a predetermined constant whose default value is 2.

For each medical situation $M \in L_m$, the set S_M of linked nursing diagnoses is found. For each nursing diagnosis $D \in S_M$, the set S_D of linked nursing interventions is found. All these nursing interventions are merged into a single set $V = \bigcup_{M \in L_m, D \in S_M} S_D$. Then they are displayed to the user in descending order of their overall weights reflecting their global priorities. For each nursing intervention $I \in V$, its global priority depends on its own priority, the priority of its linked nursing diagnosis D, and the importance of the medical situation M linked to D. Consequently, its overall weight o_w_I is defined as the product of its normalized weight n_w_I, D's normalized weight n_w_D, and M's weight w_M. That is, $o\_w_I = n\_w_I \cdot n\_w_D \cdot w_M$, where $I \in S_D$, $D \in S_M$, and $M \in L_m$. I has several overall weights if either I links to multiple nursing diagnoses or I's only related nursing diagnosis links to multiple medical situations. In this case, all those overall weights are summed into a single number. For ordinary users without much medical background, nursing diagnoses can be difficult to understand. Moreover, nursing diagnoses are used only as an intermediate step rather than the final result. Thus, they are not displayed to the user.

For example, in the case that Alzheimer's disease is the only medical situation in the list L_m, the top 12 displayed nursing interventions are: (1) environmental management, (2) energy management, (3) dementia management, (4) self-care assistance, (5) self-care assistance: instrumental activities of daily living, (6) medication management, (7) pain management, (8) surveillance: safety, (9) teaching: individual, (10) discharge planning, (11) anxiety reduction, and (12) exercise promotion.

For ordinary users without much nursing knowledge, iCEMR helps them understand nursing interventions and HNAs. Each nursing intervention is accompanied by its definition in layman terms[2]. The user can click a nursing intervention to see its HNAs displayed on a Web page. Some of these HNAs are straightforward to understand whereas the others are nontrivial, e.g., the HNA "Coach in breathing/relaxation techniques" included in the nursing intervention of asthma management. The user needs detailed implementation procedures to properly carry out nontrivial HNAs, but she may not always realize this due to lack of nursing knowledge. iCEMR makes nontrivial HNAs clickable to explicitly hint the user that she should check their detailed implementation procedures.

In general, a nontrivial HNA can have multiple aspects. For instance, if it mentions several medical products, then each medical product can be one aspect. For each aspect of a nontrivial HNA, iCEMR's knowledge base stores a pre-compiled phrase as its so-called *search guide information*[9]. A link is added into the Web page for this aspect. If the user clicks this link, that phrase is submitted as a query to a large-scale medical Web search engine (e.g., Google Health[3]) and the search results are returned to the user. This helps the user find various, detailed implementation procedures for this aspect.

A nontrivial HNA usually can be implemented in several different ways. The corresponding implementation procedures often have long descriptions scattered in multiple Web sites. Moreover, new implementation procedures keep being developed as medical knowledge and technology improve. Thus, a large-scale medical Web search engine is needed to find the latest information that is on these implementation

procedures and scattered in numerous Web sites. For example, for the breathing aspect of the HNA "Coach in breathing/relaxation techniques" for asthma management, the top results retrieved by the corresponding phrase "asthma breathing techniques" include: (1) the Buteyko method for breathing (www.correctbreathing.com), (2) two new breathing exercises for asthma (www.sciencedaily.com/releases/2008/05/080528095853.htm), and (3) the book "Free Your Breath, Free Your Life" teaching breathing techniques (www.authentic-breathing.com/asthma.htm). As another example, the nursing intervention of "self-care assistance: transfer" includes the HNA "Instruct individual in use of ambulatory aids (e.g., crutches, wheelchairs, walkers, trapeze bars, cane)." For this HNA's crutch aspect, the top three Web pages retrieved by the corresponding phrase "use crutches" are: (1) orthoinfo.aaos.org/topic.cfm?topic=A00181, (2) sportsmedicine.about.com/od/surgeryrehab/a/crutches_use.htm, and (3) www.ehow.com/how_13092_crutches.html. They describe multiple ways of using crutches safely and comfortably. We encourage readers to browse these Web pages to get some concrete feeling.

In general, the total number of HNA implementation procedures is large. The user wants to see both HNAs and their detailed implementation procedures. Also, due to the large scale of the used medical Web search engine and the limitations of existing Web search technology, many irrelevant Web pages will be retrieved for at least some pre-compiled search guide information. At present, no known method can reliably detect and remove these irrelevant Web pages. If the Web pages retrieved for all the nontrivial HNAs are merged together and displayed as a sequential list, the user can be overwhelmed, because that list may begin with many irrelevant Web pages retrieved by some search guide information. Also, it is difficult to properly merge trivial HNAs, nontrivial HNAs, and their detailed implementation procedures into a single list. Hence, iCEMR's HNA recommendation function uses no sequential output interface.

3.4 Alternative Output Interface

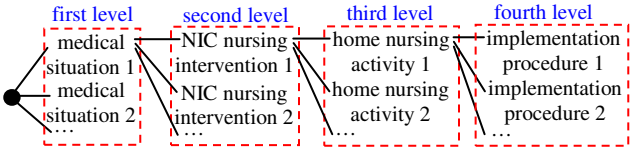

Figure 3. The four-level hierarchical output interface of iCEMR's HNA recommendation function.

The above description uses a three-level hierarchical output interface[7]: the first level for nursing interventions, the second level for HNAs, and the third level for HNA implementation procedures. We can also use a four-level hierarchical output interface by adding a level of medical situations so that the user can easily find the information for a specific medical situation, as shown in Figure 3. The details of this four-level hierarchy are similar to those of the three-level hierarchy and omitted.

4. Experimental Results

We implemented a prototype iCEMR system supporting the function of automatically recommending HNAs. We conducted experiments under a wide range of medical scenarios to demonstrate the effectiveness of our techniques.

4.1 Experimental Setup

We used United States Medical Licensing Examination (USMLE) Step 2 Clinical Skills (CS) medical exam cases[8]. Physicians have to pass the USMLE exam to obtain their licenses for practicing medicine. The exam cases used in USMLE Step 2 CS cover the typical cases encountered in daily medical practice. Each exam case has a sample medical record including a few most likely candidate diagnoses, and a summary including a several-page-long, detailed description of the patient's situation. In our experiments, we treated the first candidate diagnosis as the correct diagnosis and ignored the other candidate diagnoses.

We randomly selected 30 USMLE medical exam cases as our test cases. Since USMLE covers almost every aspect of medical practice, our random samples have a broad coverage of medical topics. Ten people, six females and four males, served as users. Their median age is 38. None of them has formal medical training. All of them are regular Internet users and have received college education or above.

WebMD[12] is one of the most popular medical Web sites and provides much information on HNAs. Google Health[3] is a major medical Web search engine. In our experiments on recommending HNAs, we compared iCEMR with WebMD and Google Health. For a medical case, each user randomly selected one of iCEMR, WebMD, and Google Health with equal probability and had up to 45 minutes to perform search. The search session was terminated when either the user had found enough desired information on HNAs or time ran out, whichever came first. We allow users to search for a relatively long time, because users care about their health and often spend much time on searching medical information.

Similar to the TREC interactive track[11], we use two sets of measures as the performance metrics: one set is objective whereas the other set is subjective. The objective performance measures include the number of search result Web pages viewed and the time spent on the search process. The subjective performance measures include the amount of desired information

found on HNAs, ease of using the system, usefulness of the search results, and overall satisfaction with the system. All the subjective performance measures are on a 7-point scale, with 1=low and 7=high[11]. (For the amount of desired information found on HNAs, 1=small and 7=large.) All the subjective performance measures were obtained from a brief questionnaire that users filled out after using the systems. For each objective or subjective performance measure, we average it over all the 30 medical cases and all the users, and report both its mean and its standard deviation when appropriate. We used ANOVA as the significance test. Our experiments were performed on a computer with two 3GHz processors, 2GB memory, and one 111GB disk.

4.2 Overall Results

iCEMR is efficient at searching HNA information. For all the 30 medical cases, the average time taken by iCEMR to generate the first result page is less than one second. The objective performance measures in Table 1 show that due to the high quality of iCEMR's search results, an iCEMR user views more search results and spends more time on reading the results than a WedMD or Google Health user does. Both differences are statistically significant.

Table 1. Objective performance measures (* means significant at <0.05 level compared to iCEMR).

mean (standard deviation)	iCEMR	WebMD	Google Health
number of search result pages viewed	28 (7.1)	5* (2.2)	20* (6.2)
time (minutes)	31 (11)	7* (3)	22* (9)

Table 2. Subjective performance measures (* means significant at <0.05 level compared to iCEMR).

mean (standard deviation)	iCEMR	WebMD	Google Health
amount of desired information found on HNAs	5.5 (1.0)	2.3* (0.6)	4.2* (0.9)
ease of use	5.6 (1.1)	4.8* (1.0)	4.8* (1.0)
usefulness	5.4 (1.0)	3.3* (0.7)	4.4* (0.9)
satisfaction	5.4 (0.9)	2.9* (0.7)	4.2* (1.0)

Table 2 shows the subjective performance measures, which clearly indicates the advantages of iCEMR in all aspects. iCEMR's input interface automatically extracts from CEMR the user's current medical situations. Moreover, iCEMR's output interface has explicitly marked medical meanings and systematically organizes HNAs so that users can easily find them. Consequently, users consider that iCEMR is easier to use than traditional Web search engines. iCEMR's advantage is statistically significant.

The search processes in Google Health and WebMD are tedious, because the user needs to manually construct multiple queries, first for finding HNAs related to his medical situations and then for finding detailed implementation procedures of the HNAs. Moreover, due to limited medical vocabulary and lack of nursing knowledge, the user often encounters difficulties in constructing effective queries. Frequently the manually constructed queries are incomplete and fully cover neither the user's important medical situations nor the related HNAs. In contrast, iCEMR has comprehensive built-in nursing knowledge and lists in a single pass a complete set of HNAs related to the user's important medical situations. For a nontrivial HNA, iCEMR automatically forms one or more high-quality queries facilitating the user to find its detailed implementation procedures. Consequently, users find that compared to WebMD and Google Health, iCEMR retrieves a larger amount of desired information on HNAs, produces search results that are more useful, and is more satisfactory. All these differences are statistically significant. Moreover, Google Health significantly outperforms WebMD in these three performance measures, because Google Health has a much broader coverage of HNA information than WebMD does.

5. Conclusions

This paper incorporates nursing knowledge into iCEMR to automatically recommend home nursing activities. Our experiments show that WebMD provides limited information on HNAs although it is a popular Web portal for healthcare. Google Health can find more information on HNAs, whereas iCEMR provides the most complete and useful information on HNAs thanks to its built-in nursing knowledge. An interesting area for future work is to investigate efficient ways of compiling more complete, higher-quality search guide information.

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