Expert Systems with Applications 39 (2012) 10311–10323

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Multi-agent ontology-based Web 2.0 platform for medical rehabilitation

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ARTICLE INFO

Keywords:
Rehabilitation medicine
Web 2.0
Ontology
Evidence-based medicine
Knowledge-based system
Agent technology

ABSTRACT

Information technologies have played key roles in a wide range of medical settings such as hospital wards, operating rooms, emergency departments, and rehabilitation centers, rendering biomedical knowledge and data more accessible for human comprehension, comparison, analysis and communication. In this context, ontology has been recognized in the bioinformatics literature as a suitable technique for advancing knowledge and data representations in biomedicine. With the enhancement of automated reasoning and graphical visualizations, ontology-technology can assist human comprehensibility as well as mitigating the complexity inherent to this domain.

Rehabilitation medicine has become an important part field in medicine, as distinct from preventive medicine, health care medicine and clinical medicine. In this article, we aim to address the ontological and epistemological issues of information services through the example of OntoRis, an ontology-based rehabilitation service OntoRis is designed to assist patients in acquiring actionable knowledge about his/her prescribed rehabilitation, and to expedite recovering through providing suggestions and advice drawn from evidence-based medicine. Moreover, OntoRis can also serve as an interactive learning platform for people who are interested in rehabilitation medicine.

1. Introduction

In recent years, rehabilitation medicine has developed rapidly and assumed an important role in modern medicine, alongside preventive medicine and therapeutic medicine. In rehabilitation therapy, most patients just follow a physiatrist's instructions with little knowledge of the reasons for of consequences of those instructions. It is nevertheless crucial for the patient to understand the rationales, procedures, and potential side effects of his rehabilitation. Doing so not only provides the patient with a better understanding of his disability, but also provides basic knowledge of the rehabilitation process related to different aspects of the patient's living situation.

The Internet offers access to vast information resources in nearly every possible domain, but the data are published in a completely "unstructured" and "uncontrolled" way. In addition, its human-oriented representation and its size make any kind of centralized computer-based processing difficult and time-consuming (Śanchez & Moreno, 2006). The task of structuring relevant information and then extracting knowledge from that information is currently performed manually with tremendous effort. A formal representation for structuring knowledge is needed to allow for the automation of knowledge extraction from web resources.

Ontologies comprised of classes, sub-classes, instances, and non-taxonomic relations are an emerging approach to knowledge representation (Smith, Welty, & McGuinness, 2004). Gruber (1995) indicated that *an ontology is the explicit specification of a conceptualization* enabling the sharing and reuse of knowledge. An ontology defines the entities and their relationships with each other, comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary. In essence, an ontology provides shared understanding within a community of people by providing a declarative specification of entities and their relationships with each other and by defining constraints and rules that permit reasoning within the ontology. The behaviors of the entities can be associated with stated or inferred facts that are derived from a reasoner to satisfy a pre-defined goal. Through developing an ontology for rehabilitation, knowledge can be formally modeled by a set of concepts and the relationships between those concepts within rehabilitation medicine.

This paper develops a base ontology for rehabilitation (RO), which serves as a knowledge base to develop an ontology-based knowledge support system. This system, called OntoRis, is a comprehensive domain knowledge resource for a specific rehabilitation therapy equipped with a Web 2.0-enabled discussion forum for the exchange and sharing of experiences among patients and therapists.

The exchange and sharing of experiences can inspire and promote new ideas or useful information for the rehabilitation process. Equipped with these ideas and information, OntoRis can make

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0957-4174/$ - see front matter © 2011 Published by Elsevier Ltd.
doi:10.1016/j.eswa.2011.09.089

provide patients and therapists with more rehabilitation-related knowledge. However, to ensure that patients do not receive erroneous or potentially harmful information, the user's experience in the forum will be filtered by evidence-based medicine (EBM) prior to integrating it into OntoRis. In other words, the information has to be certified.

The main objective of this paper is to develop an ontology-based rehabilitation information service, OntoRis, and to use Agent technology to explore external ontologies for integration with the OntoRis foundation. These external ontologies will enhance the base ontology and subsequently enrich our rehabilitation knowledge base. OntoRis is designed to assist patients in acquiring comprehensive information about their prescribed rehabilitation, and provide advice derived from evidence-based medicine to expedite recovery. Moreover, OntoRis can also serve as an interactive learning platform for people who are interested in rehabilitation medicine.

Section 2 describes the work related to ontology, mobile agents, and evidence-based medicine. Section 3 presents the OntoRis system design and architecture three, while usage scenarios and implementation are illustrated in Section 4. Finally, Section 5 provides conclusions and suggestions for future work.

2. Related work

2.1. Ontology

Although there is some disagreement in regards to how ontology should be defined (Borst, 1997; Gruber, 1995; Neches et al., 1991), generally an ontology is considered to be a formal, explicit specification of a shared conceptualization (Studer, Benjamins, & Fensel, 1998). An ontology describes the important concepts and relationships of a particular domain, providing a vocabulary for that domain as well as a computerized specification of the meaning of terms used in the vocabulary. An ontology consists of classes, properties, and individuals. A class defines a concept. Instances are elements of classes and are linked to classes via properties. Properties can be used to state relationships between individuals, or between individuals and data values. Ontologies aim to formalize domain knowledge in a generic way and provide a common understanding of a domain. This understanding may then be used and shared by applications and groups. Ontology helps realize reasoning and can be used in data integration (Chang, Sahin, & Terpenny, 2008). Many businesses and scientific communities have adopted ontology as a way to share, reuse and process domain knowledge. Ontologies are now central to many applications such as scientific knowledge portals, information management and integration systems, electronic commerce, and semantic web services (Horridge et al., 2007). Furthermore, ontologies play a key role in information retrieval from nomadic objects, the Internet and heterogeneous data sources.

2.2. OWL

Ontologies are used to capture knowledge about some domain of interest, and different ontology languages provide different facilities. The most recent development in standard ontology languages is OWL (Web Ontology Language) from the World Wide Web Consortium [w3c]. OWL is based on DAML+OIL and an extension of the RDF Schema (Corcho, Fernández-López, & Gómez-Pérez, 2003). OWL can be used to explicitly represent the meaning of terms in vocabularies and the relationships between those terms. This representation of terms and their interrelationships is called an ontology. OWL provides three progressively expressive sublanguages designed for use by specific communities of implementers and users: OWL Lite, OWL DL and OWL Full (McGuinness & Harmele, 2010).

2.3. Mobile agent

The word *agent* was derived from the notion of *software agents* in the area of artificial intelligence (AI). It has been in use since the mid-1970s, with most authors referring to Hewitt's (Hewitt, 1997) use of the term. An agent is a software entity that continuously and autonomously performs tasks as instructed by a user within a particular restricted environment. It is their autonomy which distinguishes agents from general software programs. Autonomy in agents implies that the software agent is able to perform its assigned tasks without direct control (fully autonomous) or with minimal supervision (semi-autonomous). A mobile agent is not bound by the system where it begins execution, but has the unique ability to transport itself from one system to another within a network. Thus, a mobile agent can move to a system containing objects useful to the agent (Bellavista, Corradi, & Stefanelli, 2001; Chiang, 2008). Mobile agent have drawn attention from various fields including software engineering and knowledge engineering (Okada, Eun-Seok, & Shiratori, 1996), as well as the Internet (Magedanz, Rothermel, & Krause, 1996). In their studies of the development of mobile agent programs in the Internet, Etzioni and Weld (1995) suggested that the ability of mobile agent programs to move in the Internet could, in the future, lead to the use of mobile agents to find data or service requests in high-speed data networks. Domel's (1996) studies of the actions of Mobile Tele-script Agents on the Web suggested that providing mobile agents with more intelligence would give them more applicable value in action on the Web. Additionally, in their study of the structure management of distributed application systems, Berghoff, Drobnik, Lingnau, and Monch (1996) used a mobile agent to find the correct addresses for data transmission within the network, so as to reduce network traffic flow. Thus, the use of mobile agents can enhance the performance of distributed application systems.

2.4. Evidence-based medicine and systematic reviews

Evidence-based medicine (EBM) is the integration of best research evidence with clinical expertise and patient values. It aims to apply the best available evidence, gained from the scientific method, to medical decision-making and to assess the quality of evidence available for treatment risks and benefits (Timmermans & Mauck, 2005). Systematic reviews are a keystone of evidence-based medicine. Systematic reviews of randomized controlled trials constitute the top level of evidence for the effectiveness of healthcare interventions because they are more likely to provide valid (i.e., less-biased) evidence of the effectiveness of the trial interventions.

Starting from a clearly defined research question, such reviews use systematic, predefined and explicit methods to identify, select and critically appraise all relevant research, collect and analyze data from eligible studies, and present results and draw conclusions. Where statistical techniques are used to combine the results of the included studies, systematic reviews are often called meta-analyses (Handoll, Gillespie, Gillespie, & Madhok, 2008).

Cochrane collaboration is one of the best-known and respected examples of systematic reviews. Like other collections of systematic reviews, it requires authors to provide a detailed and repeatable plan of their literature search and evaluations of their evidence. Once all the best evidence is assessed, treatment is categorized as "likely to be beneficial", "likely to be harmful", or "evidence did not support benefit or harm".

3. Methodology

3.1. OntoRis platform design

The main objective of this paper is to establish an ontology-based application, OntoRis, to provide a rehabilitation information service and use agent technology to explore and integrate external resources into the application. One of the main characteristics of ontology is reusability. The Rehabilitation Ontology (RO) that we built in this work can not be expected to cover a full spectrum of related knowledge. A comprehensive ontology requires collaborative effort the collection of information from many distributed sources across the Web. Distributed information can be easily aggregated and combined due to the characteristics of the RDF model. The integrated information can be understood if all information providers have used the same ontology to markup their data. In this paper, we therefore assume that interested parties and contributors will use our ontology for data markup. Otherwise, the ontology found can only be used as a reference through a URL link.

As illustrated in Fig. 1, the OntoRis platform consists of three main components: an agent environment, a Knowledge Engine, and a User Interface. Implemented in JADE (http://jade.tilab.com/), the agent environment comprises several agents that will follow a user's instructions to enhance and extend rehabilitation information in the OntoRis platform by discovering related information resources on the Web. Based on the proposed RO, the Knowledge Engine serves as a knowledge base for OntoRis while the Inference Engine provides required knowledge when users execute queries via the Query Engine. The OntoRis components are illustrated in detail in the following sections.

3.2. Agent environment in OntoRis

An agent environment is composed of multiple agent containers that contain more than one agent. This environment is not only where stationary agents reside but also where mobile agents are created. In general, stationary agents stay within an execution environment, i.e., an agent container, for the provision of resources and functionality to mobile agents. While stationary agents remain "static" in an agent container, mobile agents migrate among agent networks, taking advantage of the locality and its resources to satisfy their goals.

The JADE-implemented agent environment in OntoRis consists of hosts running the agent containers and supporting services: Ontosearch2 and RSS service (see Fig. 2). Agent containers can be dynamically added to and removed from an agent environment which allows for large-scale, and even network-wide, installations.

3.2.1. Agent containers

In JADE, each running host in the OntoRis agent environment is called a *Container*, as it can contain several agents. The set of active containers is called a *Platform*. A single special *main container* must always be active and, upon initiation, all other containers register with the main container. As specified by JADE, the main container is an essential component which manages all of the containers and agents in OntoRis. The other containers, called *non-main containers*, are designed for different purposes such as providing relevant external services and connecting with the client side. Among the non-main containers in OntoRis, containers that connect with the Rehabilitation Ontology Knowledge Engine are called *data containers*. The other non-main containers, called *client containers,* connect with the client side and are responsible for delivering OntoRis applications to users. *Client containers* are also equipped with mobile agents responsible for exchanging data with data containers as illustrated in Fig. 3.

The OntoRis agent environment has four primary agent types, differentiated according to architectural features: User Agent, Discovery Agent, Update Agent and Resource Agent.

3.2.2. User Agent

A User Agent is a type of stationary agent that serves as a user's intelligent gateway to the platform by providing a bridge between the user and the Discovery Agent. The User Agent interprets communications between the user and heterogeneous agents. Upon receiving a user request, the User Agent starts to drive the platform's internal services. Therefore, the User Agent holds the mechanism of access-control and authenticates the user before starting the Discovery Agent. The User Agent is also responsible for presenting the Discovery Agent's result to the user.

In OntoRis, the User Agent is used by the administrator to collect user requests through a Graphical User Interface (GUI),

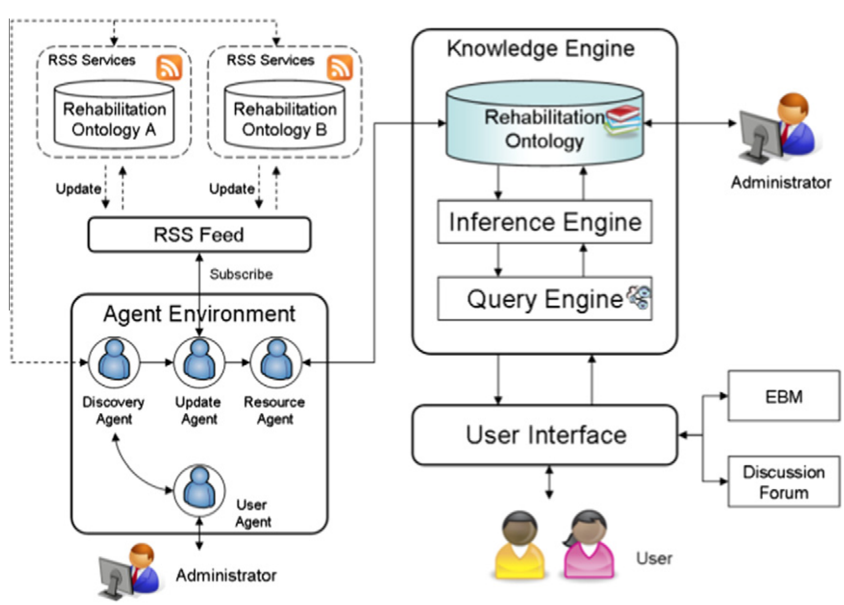

Fig. 1. OntoRis platform architecture.

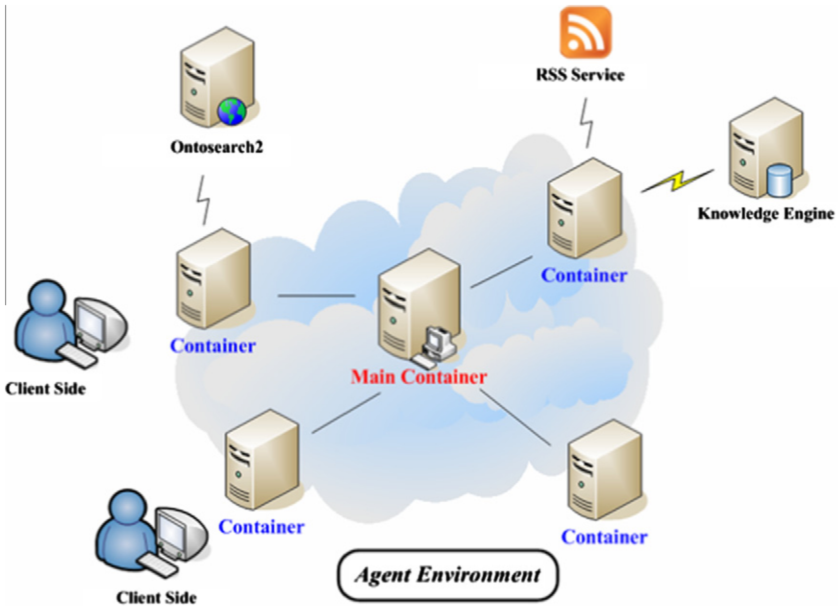

Fig. 2. Agent environment.

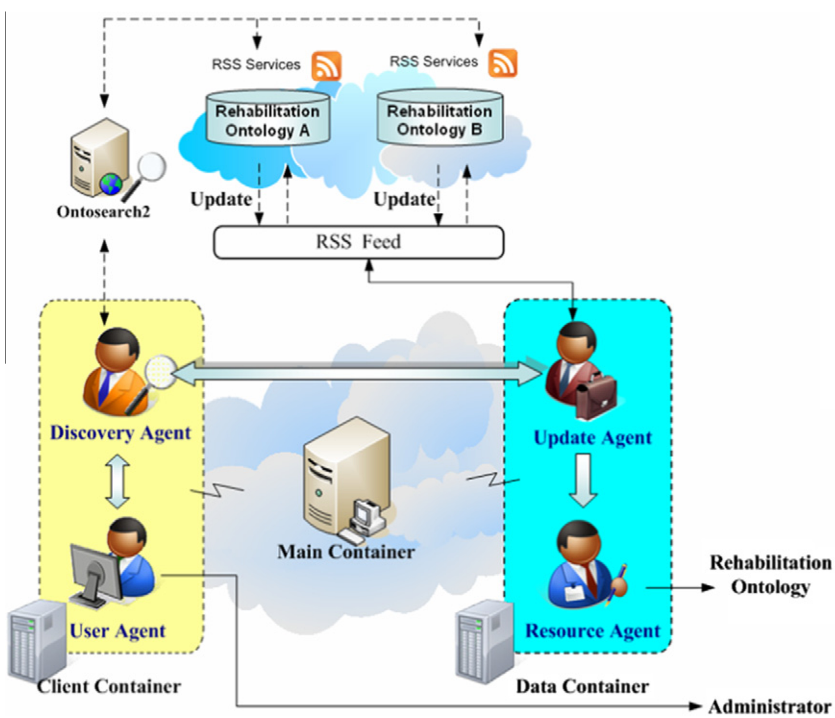

Fig. 3. Multi-agents in the agent environment.

submitting them to the Discovery Agent, and finally presenting to the administrator the results (ontologies) discovered by the Discovery Agent. The administrator will then determine the suitability of the discovered ontologies and remove the unrelated ones. The filtered result will subsequently be sent back to the Discovery Agent which then delivers the result along with RSS (Really Simple Syndication) to the Update Agent. Finally, the result will be transmitted to the Resource Agent to enhance the Knowledge Engine.

3.2.3. Discovery Agent

The Discovery Agent is a mobile agent migrating between a client container and the Resource Agent's data container. The Discovery Agent acts on an administrator request to search information available on the Internet, submits the search result to the User Agent, and delivers the filtered results to the Update Agent.

For Internet-based ontology search, we adopted the Ontosearch2 (Pan, Thomas, & Sleeman, 2006) and used an agent to execute the search task. The Discovery Agent is also responsible for transmitting the administrator-approved information (ontologies and RSS) to the Update Agent.

3.2.4. Update Agent

The Update Agent is a stationary agent which is responsible for transmitting the URL of external ontologies from the Discovery

Agent to the Resource Agent, and updating the content of the rehabilitation ontology via RSS to enhance the Knowledge Engine. According to the ontologies and RSS provided by the Discovery Agent, the Update-Agent subscribes the RSS service, and transmits the URL of the ontologies to the Resource Agent. Through RSS, the Update Agent can then incrementally update the approved ontologies.

3.2.5. Resource Agent

The Resource Agent is encapsulated in a data container and connected to the RO of the Knowledge Engine. The Resource Agent is a stationary agent and operates at a higher level of trust, mediating access to data resources for other agents to the RO. The Resource Agent usually resides in a data container, integrating compatible information or exporting the URL of external ontologies into the RO of the Knowledge Engine.

3.3. Ontology-based Knowledge Engine

An ontology-based Knowledge Engine is a knowledge base which can provide users with comprehensive knowledge. An ontology-based Knowledge Engine offers the following advantages over traditional databases:

- Greater efficiency and flexibility in capturing knowledge about concepts within the domain and relationships between these concepts.
- Ability to maintain and extend a knowledge corpus and track the effects of changes to a section of the knowledge base.
- Ability to infer further knowledge that might be associated with the user query.

The Knowledge Engine in OntoRis comprises (1) a Rehabilitation Ontology, (2) an Inference Engine, and (3) a Query Engine. The Knowledge Engine provides users with the required rehabilitation knowledge according to the user's query and tries to infer further knowledge that might be associated with the query. Accomplishing this requires the development of an ontology to model knowledge associated with rehabilitation medicine.

3.3.1. Rehabilitation Ontology

Referring to the medical ontologies of the OBO Foundry (e.g., Disease Ontology (http://www.obofoundry.org/)) and medical information in MedicineNet.com (http://www.medicinenet.com/~.asp/), we develop the RO to serve as a knowledge base for the OntoRis Knowledge Engine. The OntoRis RO defines basic terms and relations comprising a vocabulary for Rehabilitation Medicine as well as the rules for combining terms and relations for the definition of extensions to the vocabulary. The partial Rehabilitation Ontology developed with TBC (TopQuadrant, 2010) is illustrated in Fig. 4.

3.3.2. Inference Engine and Query Engine

The Rehabilitation Ontology used the OWL DL as an ontology language. The OWL DL contains a rich set of knowledge representation constructs that can be used to formally specify medical-domain knowledge that, in turn, can be exploited by description logic reasoners for the purposes of inference.

The RO has four classes: **Electrotherapy, Rehabilitation Practice, Tools,** and **ElectrotherapyEquipment** with a property "**need Tool"**. The relationship among these classes is illustrated in Fig. 5. Suppose an instance belonging to the **Electrotherapy** class must (1) be a rehabilitation practice and (2) use electrotherapy equipment as a tool. The resulting class axiom would be "Rehabilitation Practices **and** (need Tool **some** ElectrotherapyEquipment)". Through the class axiom, the instance will be inserted into the class **Electrotherapy** which conforms to conditions (1) and (2).

3.3.3. Query engine

The Query engine is based on SPARQL, which is a proposed standard for querying RDFS/OWL data. For example, if we want to search all Electrotherapy and the required equipments, the SPARQL statement would be:

SELECT ?practice ?tool
WHERE {?practice a R1:Exercisetherpy.
? practice need_Tool ?tool}

In the statement, *SELECT* is the query command. *WHERE* describe the conditions for the command, that is, the triples satisfying the conditions will be the returned results. Through the SPARQL, all rehabilitation that need tools for rehabilitation practice can be acquired as shown in Table 1

3.3.4. Web 2.0-enabled discussion forum for collective intelligence

The concept of "Web 2.0" represents a new level of technological interactivity between web sites, services and social phenomena derived from new types of online communities and social networks. A Web 2.0 platform is a knowledge-oriented environment where human interactions generate content that are published, managed and used through network applications in a service-oriented architecture. In this research, a Web 2.0-enabled rehabilitation discussion forum is attached to OntoRis as a module for collective intelligence. The module is used for the creation, exchange, and sharing of experience and knowledge among patients and therapists.

This exchange and sharing of experience and knowledge can inspire and generate new ideas or useful advice for those in rehabilitation or those providing rehabilitation services. For example, a patient may have experienced that "therapeutic Yoga was especially well-suited to the rehabilitation of his/her knee injuries". However, this new idea must be approved before it can be added to the platform. The experience might be useful for patients recovering from knee injuries, but its validity and applicability must be first supported by evidence gained from the scientific method.

Evidence-based medicine (EBM) integrates clinical expertise with the best available research evidence and patient values. It seeks to assess the quality of evidence for treatment risks and benefits (including lack of treatment). The objective of EBM is to apply the best available evidence gained from the scientific method to medical decision-making (Timmermans & Mauck, 2005).

In relation to EBM, evidence-based practice (EBP) is a method of treatment which promotes the collection, interpretation, and integration of valid, important and applicable patient-reported, clinician-observed, and research-derived evidence. Dependent on patient circumstances and preferences, the best available evidence is applied to improve the quality of clinical judgments and facilitate cost-effective care. EBP offers treatment prescriptions through adopts evidence of statistically-significant effectiveness for treatments of specific problems provided by systematic empirical research.

Experiences or advice posted in the forum might be based on a loose body of knowledge. Some knowledge could simply folk remedies with little if any scientific justification. To avoid providing unhelpful or potentially-harmful information, user posts to the forum are filtered by EBM prior to being integrating into the OntoRis knowledge base. In other words, the information will be certified.

3.3.5. User Interface

The OntoRis User Interface allows users to execute queries via the Query Engine to acquire the rehabilitation information from the Knowledge Engine. The User Interface may also be linked to the Web 2.0-based forum and EBM described in the previous section.

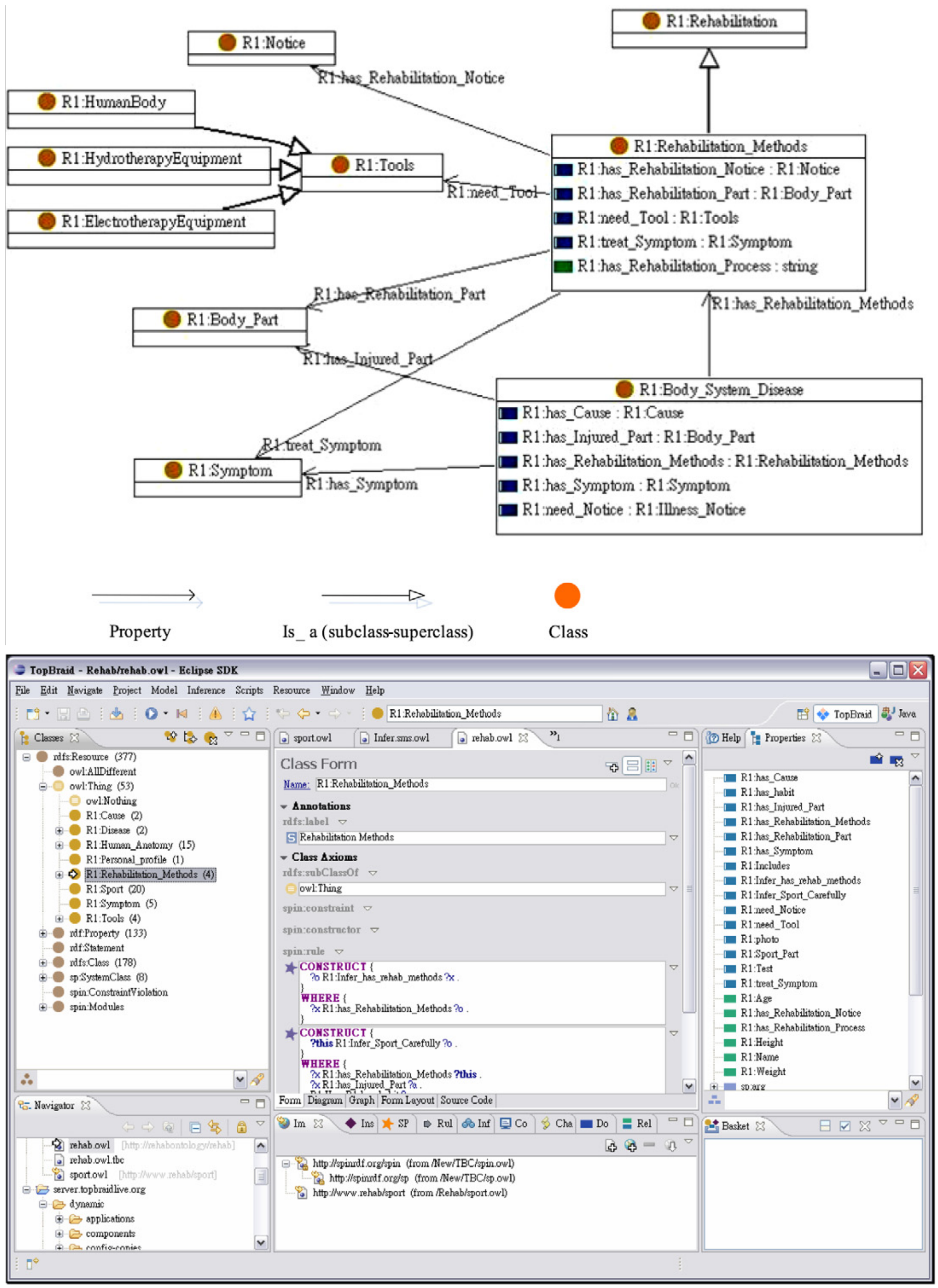

Fig. 4. Partial Rehabilitation Ontology developed with TBC.

The discussion forum provides a Web 2.0-based platform in which users may create, share, and discuss rehabilitation information with each other. Interesting tips and novel ideas about rehabilitation can be published and discussed in the forum. However, these tips and ideas need to be certified by evidence-based medicine prior to becoming a part of the knowledge base. Users may link to an EBM web page such as the Cochrane Library to search for supporting references for the information they want to publish in the forum. If the information is supported by EBM, the administrator of OntoRis can then integrate it into the Rehabilitation Ontology and turn it into a knowledge instance in the OntoRis.

4. Implementation

A system prototype for OntoRis was developed to demonstrate the feasibility of the thesis. The prototype embodies the study's generalized and functional design concepts for ontology-based application and agent technology. Two scenarios are used to demonstrate OntoRis's capabilities in accomplishing the research objectives listed in Section 1: (1) providing comprehensive information about a user's prescribed rehabilitation with supporting advice from evidence-based medical and (2) serving as an interactive learning platform for people interested in rehabilitation medicine.

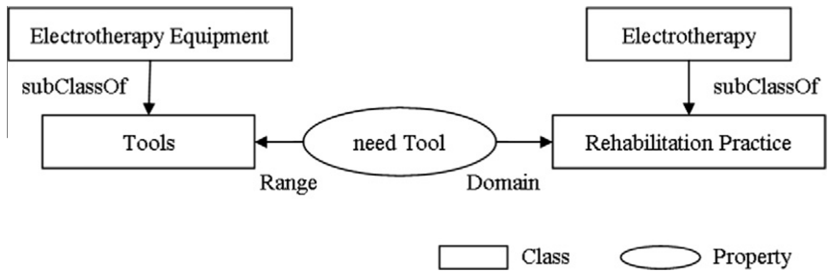

Fig. 5. Relationship between Electrotherapy, Rehabilitation Practice, Tools, ElectrotherapyEquipment and need Tool.

Table 1
Query results.

Rehabilitation practice	Tool
Electrical simulation	BioStim PigTail electrodes
Biofeedback	MyoTrac Infiniti
Stick exercise	Stick

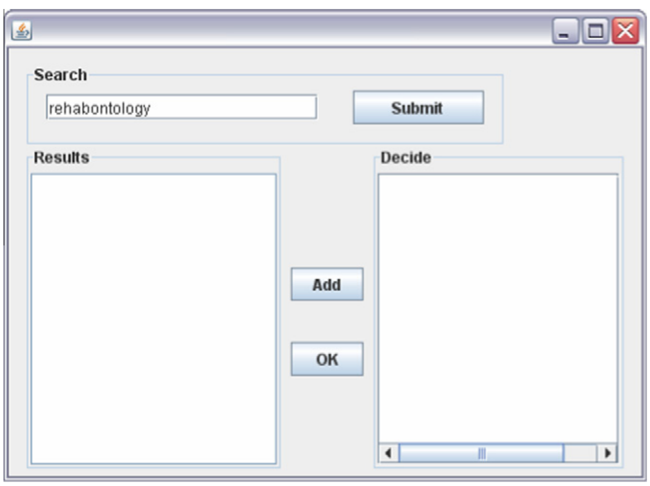

Fig. 6. Search interface.

4.1. Hardware and software configuration

Given the ubiquity of the Microsoft™ Windows operating system (OS), we implemented the OntoRis platform in Windows XP. Deriving new knowledge from existing rehabilitation knowledge requires an inference engine which takes an "asserted" model as its input and creates an "inferred" model as output in an ontological context. A wide selection of inference engines is available, including OWL DL tableaux reasoners like Pellet, Flora-2 implemented F-OWL, RacerPro, FacT++, Minerva, and Rule engines such as Jena (http://jena.sourceforge.net/index.html). In many cases, several inference engines need to be integrated together. For instance, SPARQL or Jena have no built-in knowledge of OWL DL, and would need to be implemented on top of an OWL-compliant reasoning service such as Pellet. In consideration of future expansion to the proposed system, we adopted TopBraid™ Composer (TBC) (http://www.topquadrant.com/~html/) as our development-platform. Based on Eclipse, TBC is not only a visual ontology editor but also a knowledge-base framework which can integrate inference engines through hybrid inference-chaining.

The OntoRis Agent Environment is implemented in JADE, running on the Java 2 Run-time Environment (JRE). However, installing the full Java 2 Source Development Kit (J2SDK) is preferable to handle the development and compilation of our own agents in JADE.

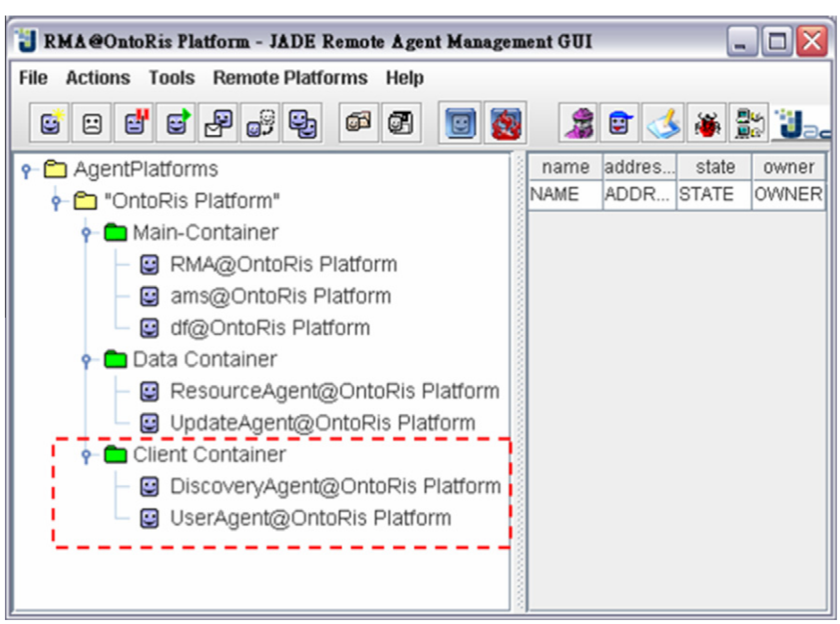

Fig. 7. Initial state of initiator container in JADE GUI.

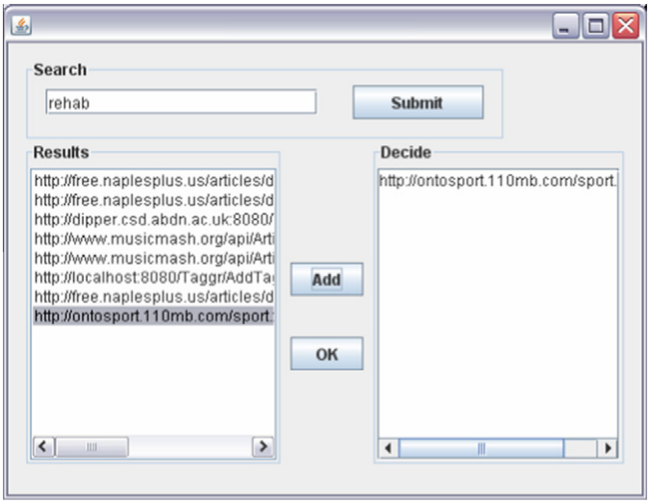

Fig. 8. Search results in search interface.

4.2. Usage Scenario and Demonstration 1: Using agents to enhance OntoRis – An administrator's perspective

The OntoRis RO described in this paper can not be expected to cover the full spectrum of related knowledge. A comprehensive ontology requires extensive collaboration and relies on collecting information from distributed sources on the web. Agent technology is used to search related ontologies on the internet and integrate them with our ontology in OntoRis, thus creating a more comprehensive ontological knowledge base. The system administrator is responsible for incorporating, maintaining, and managing ontologies to provide users with a comprehensive rehabilitation knowledge base.

Fig. 10. Successful RSS message.

Fig. 11. Update message.

First, as illustrated in Fig. 6, the administrator opens the search interface and submits the request to search the Internet for existing ontologies by Ontosearch2. In Fig. 7 we can see that the data container with the Update Agent and Resource Agent has been started and registered with Main-Container, and the Update Agent and Resource Agent are displayed in the GUI. In addition, the client container with the User Agent and Discovery Agent is signed into OntoRis and are ready to work.

The Discovery Agent passes the search results to the User Agent's GUI, where the administrator can review the results and determine the suitability of discovered ontologies, removing those found to be unrelated (as shown in Figs. 8 and 9). In this case, the administrator decided to integrate the external ontology: http://ontosport.110mb.com/sport.xml (Sport Ontology) into the RO. The contents of Sport Ontology are shown in Fig. 9.

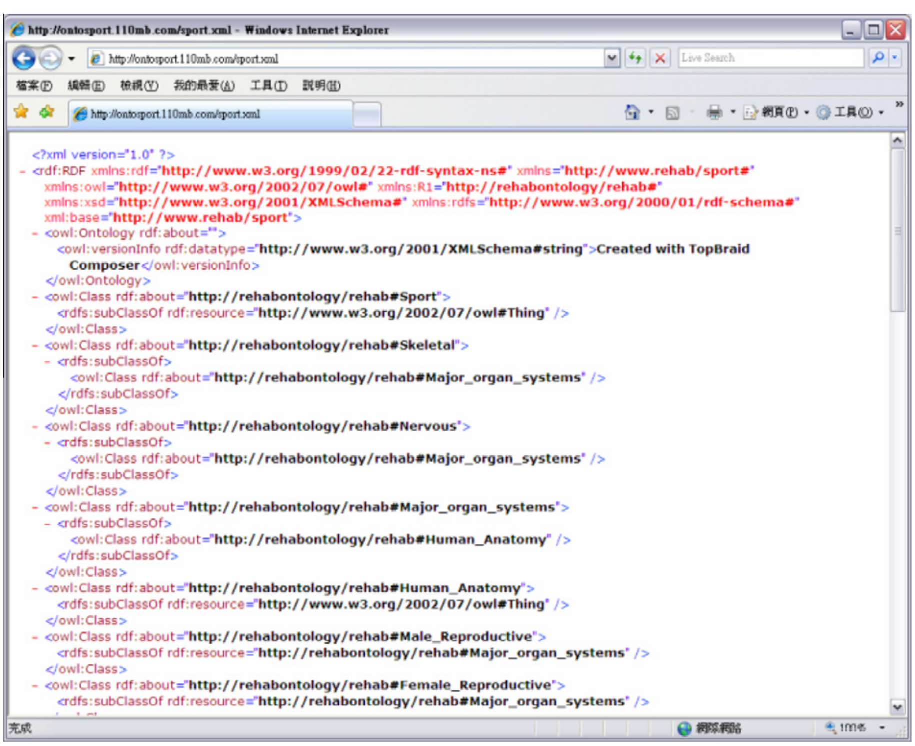

Fig. 9. Content of external ontology.

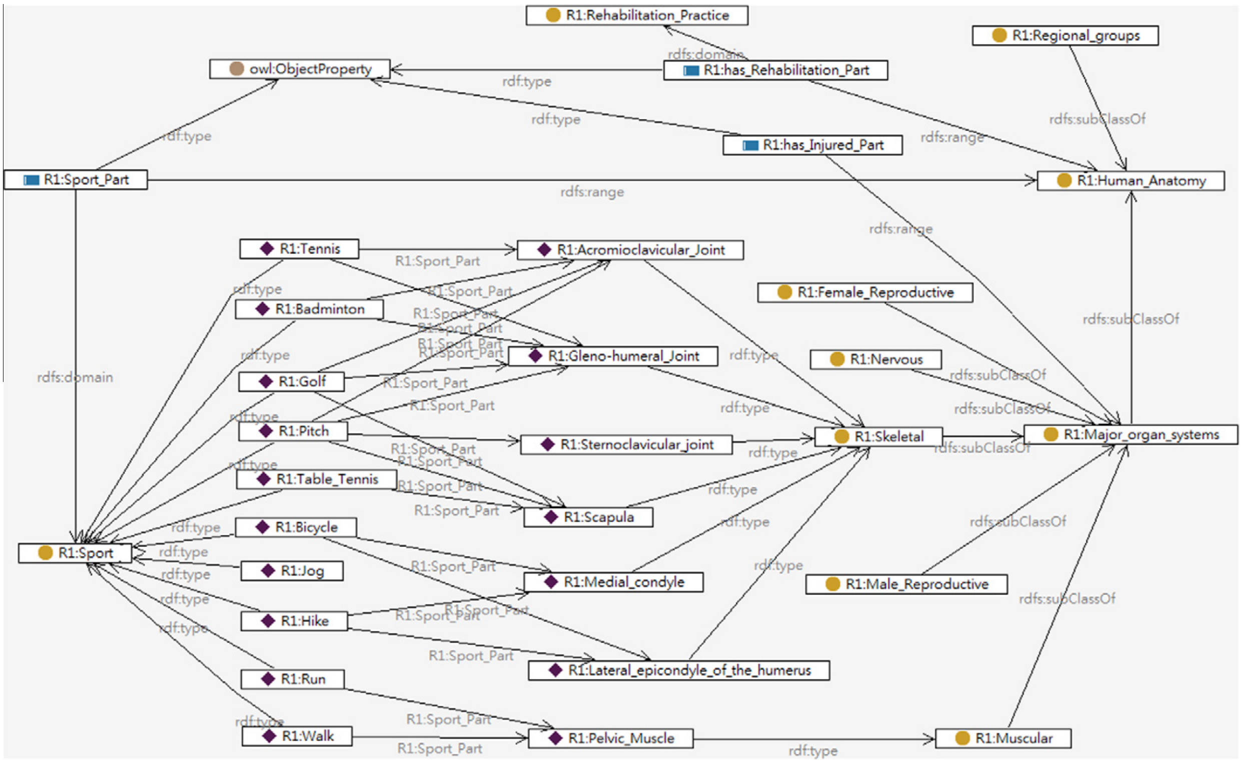

Fig. 12. Partial RO model (integration with Sport Ontology).

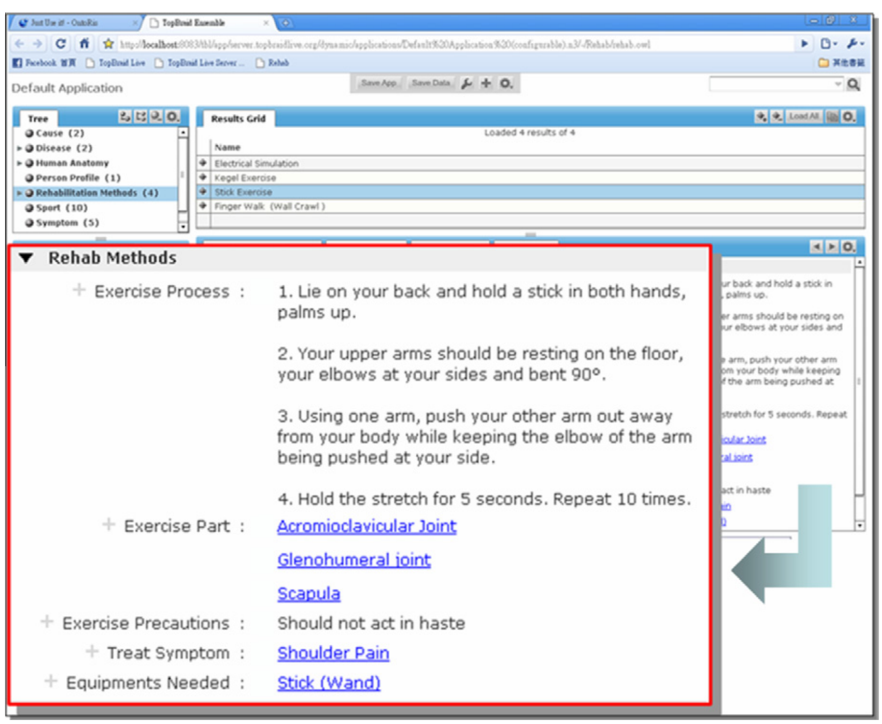

Fig. 13. Knowledge Engine.

Subsequently, the Update Agent will subscribe to the RSS service according to the administrator's decision (Sport Ontology) and transmit the URL of the Sport Ontology: http://ontosport.110mb.com/sport.xml to the Resource Agent. If the ontology's web location does not provide RSS, we would adopt Page2RSS (http://page2rss.com/) to generate RSS for the web site containing the targeted ontology. Page2RSS is a service for monitoring web sites that do not publish feeds, regularly checking the page for updates and delivering those updates to RSS readers. Once the Update Agent successfully subscribes to the RSS service, a message will appear as shown in Fig. 10. Through RSS updates to the external ontology will be automatically detected by the Update Agent, which incrementally updates the ontologies as shown in Fig. 11.

Fig. 14. Ethan Hunt's profile.

Table 2
The exercise part of sport.

Sport	Main exercise part	Sport	Main exercise part
Tennis	Acromioclavicular Joint Gleno-humeral Joint	Running	Calf muscle Thigh muscle Pelvic muscle
Table tennis	Acromioclavicular Joint Gleno-humeral Joint Scapula	Hiking	Calf muscle Pelvic muscle

Fig. 15. Sport (inference).

After obtaining the URL of the Sport Ontology from the Update Agent, the Resource Agent exports the URL: http://ontosport.110mb.com/sport.xml to the Knowledge Engine RO. Through this type of integration, OntoRis's Rehabilitation Ontology will gradually grow to cover a full spectrum of related knowledge. Fig. 12 illustrates the partial RO model for the integration of Sport Ontology.

4.3. Usage Scenario and Demonstration 2: Acquiring rehabilitation-related knowledge – The user's perspective

Ethan Hunt is a businessman suffering from chronic shoulder pain. His physician diagnoses the condition as adhesive capsulitis of the shoulder (also known as "Frozen Shoulder"). The condition is commonly characterized by pain and stiffness, or loss of motion in the shoulder. The physician recommends a type of rehabilitation therapy - "Stick Exercise" - for shoulder pain relief.

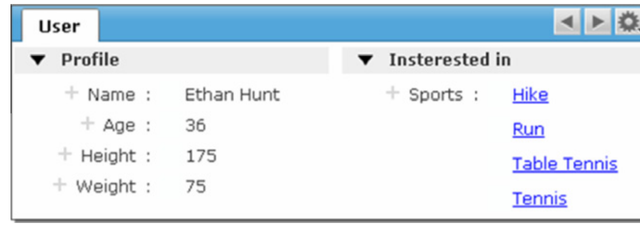

Fig. 16. Ethan Hunt's profile (update).

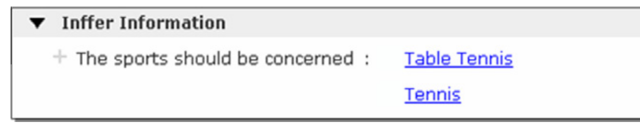

Fig. 17. Sport (inference).

When Mr. Hunt returns home, he accesses OntoRis to search for "Stick Exercise", learning more about his recommended rehabilitation program. As shown in Fig. 13, through the OntoRis Knowledge Engine he can find information related to Stick Exercise, including the exercise process, parts of the body exercised, recommended precautions, required equipment and treatment-related symptoms.

Further information can also be inferred from Mr. Hunt's profile (Fig. 14), which shows that his main interests are sports such as hiking, running and tennis. By searching for "Stick Exercise" as a treatment for Frozen Shoulder, he can learn that the exercise treats the acromioclavicular joint, the gleno-humeral joint, and the scapula. Therefore, OntoRis will use its knowledge of Ethan Hunt's current condition to provide advice on any sport involving the use of the body parts already affected. For instance, tennis involves the use of the acromioclavicular joint and gleno-humeral joint as shown in Table 2, and Hunt is interested in tennis. The inference process is shown as Fig. 18.

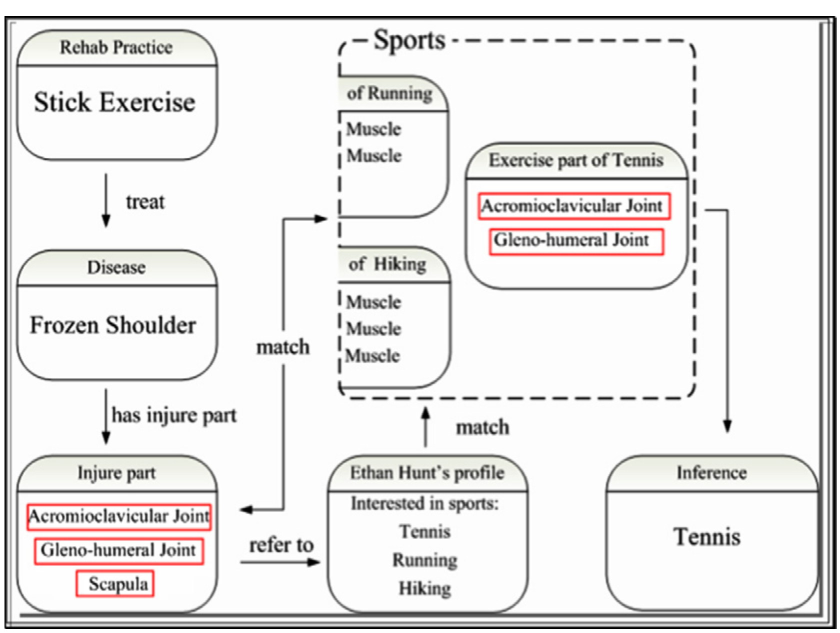

Fig. 18. Inference process.

Fig. 19. Web 2.0-based discussion forum.

Suppose Mr. Hunt updates his profile to include a new sport, such as table tennis. Given its knowledge of Mr. Hunt's condition, along with its knowledge of the physical requirements of table tennis, OntoRis will autonomously infer that Mr. Hunt should avoid table tennis (as shown in Figs. 15–17) because it involves the acromioclavicular joint, gleno-humeral joint and scapula as shown in Table 2.

After obtaining this information from the Knowledge Engine, Mr. Hunt may visit the OntoRis Web 2.0-based discussion forum to exchange, share, and discuss his experience with other users. For example, he could share his experience with the Stick Exercise, as shown in Fig. 19.

The exchange and sharing of experience can inspire and generate new ideas or useful advice in the rehabilitation process. Another user, Neo, suggests that acupuncture, used in conjunction with Stick Exercise is more effective in relieving Frozen Shoulder pain (Fig. 20). However, the validity and applicability of Neo's suggestion must first be scientifically assessed. Therefore, the OntoRis administrator can link to a Evidence-Based Medicine (EBM) web repository, such as the Cochrane Library, to search for supporting references for the information published in the forum. If the information is supported by EBM, the OntoRis administrator can then integrate it into the Rehabilitation Ontology, creating a knowledge instance in OntoRis.

5. Empirical usability evaluation

The usability evaluation attempts to assess the quality of human-computer interaction in a system and appraise the user's perception of the system after an interaction experience. According to ISO 924-11 definition, usability is the extent to which specified users can use a system to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. The most common usability issues of a system include comprehensibility and navigation (Kuziemsky & Lau, in press). An evaluation of system usability focusing on these two issues by use of a questionnaire was conducted to show the effectiveness of the proposed OntoRis. The questionnaire was distributed to sixty people consisting of experienced and un-experienced users who are interested in acquiring knowledge regarding rehabilitation. Respondent profiles are summarized in Table 3.

Table 3
Respondent profiles.

Personal information		Number	%
Age	20–30	41	68.4
	30–40	15	25.0
	40–50	2	3.3
	>50	2	3.3
	Total	60	100.0
Gender	Male	34	56.7
	Female	26	43.3
	Total	60	100.0
Education	College	6	10.0
	University	42	70.0
	Master	9	15.0
	Ph.D.	3	5.0
	Total	60	100.0
Monthly income (NT$)	< $10,000	10	16.7
	$10,000–$20,000	21	35.0
	$20,000–$30,000	13	21.7
	$30,000–$40,000	11	18.3
	>$40,000	5	8.3
	Total	60	100.0

Fig. 21 shows the usability results obtained from the questionnaire, in which a question is usually followed by a reversed question (e.g., even number questions) to reveal opposing facts.

Questionnaire content:

1. I found the OntoRis user-friendly.
2. I found the OntoRis unnecessarily complex.
3. The OntoRis was easy to use.
4. I would need a technical person to assist me.
5. OntoRis provides sufficient information for me.
6. I sometimes failed to find the information that I need in OntoRis.
7. OntoRis provided me with more relevant information than common search engines.
8. OntoRis provides results similar to common search engines.
9. The navigation is well-integrated.
10. There were inconsistencies in the navigation.
11. The interaction components (buttons, menus, text fields, drop-down lists etc) can be easily understood.

Fig. 20. Experience exchange in the OntoRis forum.

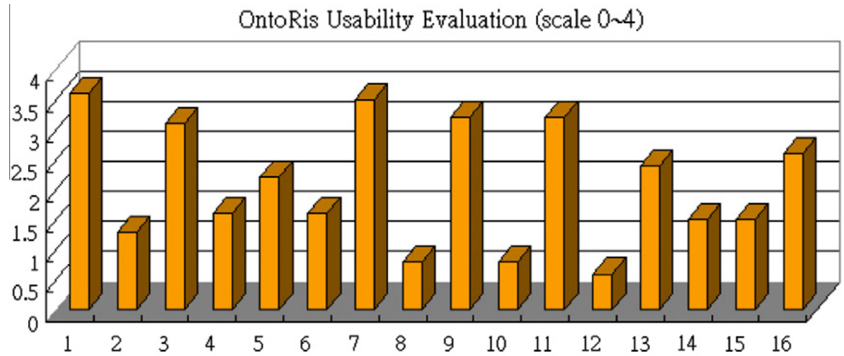

Fig. 21. User evaluation of system usability.

12. I need to learn many things before using OntoRis.
13. Sharing my experiences in the forum is easy and effective.
14. I found the forum is difficult to use.
15. I found the forum useful.
16. The forum does not provide much information yet.

From the questionnaire results, one could argue that the usability/readability of the OntoRis is reasonably high. However, as indicated by the response to questions 6 and 16, the information provided in the prototype phase is not yet sufficiently rich.

6. Conclusions

In OntoRis, a Rehabilitation Ontology defines the entities and their relationships with each other, comprising a vocabulary of rehabilitation medicine as well as rules for combining terms and relations to define vocabulary extensions, a function which is especially suited to capturing the rich relationships between entities in rehabilitation medicine.

In addition, through the inference engine, new knowledge can be derived from existing knowledge in rehabilitation medicine, taking an "asserted" model as input and creating an "inferred" model as output. Usability of the system was verified through a questionnaire.

OntoRis provides a new opportunity to acquire rehabilitation-related knowledge. The patient can use OntoRis to acquire comprehensive information about his/her prescribed rehabilitation. Moreover, OntoRis can also serve as an interactive learning platform for people who are interested in rehabilitation medicine.

6.1. Limitations and future works

A domain ontology models a specific domain, or part of the world. It represents the particular meanings of terms as they apply to that domain. With domain ontology, knowledge can be formally modeled by a set of concepts within a domain and by the relationships between those concepts. Domain ontologies are often incompatible because they represent concepts in very specific and often eclectic ways. The expansion of systems that rely on domain ontologies often requires the merging of domain ontologies into a more general representation. This presents a challenge to the ontology designer. Different ontologies in the same domain can also arise due to different perceptions of the domain based on cultural background, education, or ideology, or because a different representation language was chosen (Sage & Rouse, 2009).

At this juncture, merging ontologies that are not developed from a common foundation ontology is mainly performed by a manual, and thus time-consuming and expensive, process. Domain ontologies that use the same foundation ontology to provide a set of basic elements with which to specify the meanings of the domain ontology elements can be merged automatically. Several attempts have been made to develop generalized techniques for merging ontologies (Colomb & Ahmad, 2007); yet this area of research is still largely theoretical. In this research, the issue of ontology integration is not addressed. The issue might be confronted by mapping discovery and schema integration as suggested in Gennari, Neal, Galdzicki, and Cook (2010), Guzman-Arenas and Cuevas, (2010), Lambrix and Tan (2006) and Kotis, Vouros, and Stergio (2006).

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