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Towards an intelligent exploitation of heterogeneous and distributed resources in cooperative environments of eHealth

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Abstract

The objective of this research work is to empower healthcare information systems to deliver high quality information anytime and anywhere and to present distributed and heterogeneous resources access solutions which perfectly meet user requirements in different contexts. To reach this objective, we propose in this paper a new framework, called ONtology Oriented Framework for Pervasive Applications and Services (ONOF-PAS), and mainly based on: 1) interrelated ontological models representing the main entities in pervasive computing, such as Organization, Actor, Task, Service, Process, Object, Resources, etc.; 2) rule-based reasoning to infer the available and capable resources required by each task. The main functionality of the ONOF-PAS framework is to capture and to process the acquired knowledge about the user's context, the tasks they perform, the availability and capabilities of the required resources, and the organizations that own or manage these resources. Our framework allows healthcare information systems to infer the needed resources by linking each user-task with the required, available and capable resources taking into account the clinical conditions of the patients. The ONOF-PAS framework has been successfully applied in the telemedicine domain in order to provide practical and efficient resources access solutions that better meet the contexts and the expectations of the eHealth actors.

1. Introduction

The main limitations of current pervasive healthcare information systems are the lack of personalization and adaptation to user profiles, to user needs and to different contexts of use [1,2]. In general, the most important factors that determine the effectiveness of pervasive services, are the relevance, the quality and availability, where and when needed, of the provided information. However, it is a challenge to provide anywhere and anytime the same quality level of information because of the great variety of scenarios. Some of these scenarios are well known and based on pre-defined protocols and standards, e.g. flight tickets reservation, hotel room booking, etc. But, others are contextual and more complex, e.g. patient tele-assistance or orientation in hostile environments such as geographically critical and isolated areas [3]. In such scenarios, it is extremely difficult to standardize the tasks and processes that meet the users' needs. In addition, the decisions that should be made are usually subjective and depend on the aptitude and skills of the actors who are involved in the business processes.

Therefore, to face this challenge of decision making in non predefined scenarios and to meet the user's needs diversity in different contextual situations, there is an essential need to design models able to capture knowledge about:

- the actors who perform multiple tasks in a given domain and in different contexts;
- the heterogeneous types of resources required for performing the tasks;
- the knowledge related to the organizations that own or manage these resources.

It is however a critical issue to design effective and synergetic models that are able to realize knowledge acquisition from actors and other main entities in a given domain. Moreover, to achieve successful knowledge modeling, we should focus on well-defined objectives and exploit the existing technologies, standards, and protocols.

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To effectively support tasks and processes execution within a pervasive application and to improve information quality in both simple and complex scenarios, we firstly propose a knowledge meta-model based on ontologies that describes the different entities from a given domain. We then construct an architectural framework, called ONtology Oriented Framework for Pervasive Applications and Services (ONOF-PAS) that can be extended and implemented in different specific domains such as eHealth [4]. The proposed knowledge meta-model will have the ability to handle different contexts of use taking into account the availability and the capabilities of the required material, communication, and human resources. The task execution process is based on predefined rules that will be applied by an inference engine. The rule base includes logical statements that specify how to handle the contextual situation by linking the context elements such as actor profile, task type, concerned object, its status, the required resources, etc. Meanwhile, the rules shall allow optimizing the management of the priority of the messages exchanged among the different actors.

This paper is organized as follows. Section 2 provides a synthesis of research works related to the Task concept in knowledge modeling. In Section 3, we present our methodology to build ONOF-PAS. Section 4 describes the overall knowledge meta-model including its formalization. Section 5 examines how ONOF-PAS can be automatically extended to the telemedicine domain taking as an example a "Patient Transfer" scenario, for supporting various healthcare providers in performing decision processes in telemedicine related tasks. The technical architecture and the empirical results are discussed in Section 6.

2. Related works

The research work we have performed concerns the building of knowledge-based systems for task management and decision support in healthcare. We synthesize here-after the most relevant research works concerning task-based computing as well as knowledge-based context management systems in eHealth. The idea of Task/Activity-based computing is that the whole computing environment is focused on a single activity. Rather than opening several programs, one opens an activity, and this activity is linked to the programs necessary to make progress on that activity [5]. Numerous research works have used task-based computing approaches to manage data and context in healthcare [6–8].

Knowledge-based systems have been widely used to handle context. Strassner and O'Sullivan [9] have presented a policy-based approach for representing, using and managing knowledge in ubiquitous computing systems. Similarly, Bicocchi et al. [10] have presented a knowledge network prototype intended as a tool to support self-organization and self-aggregation of contextual data items and to facilitate their exploitation by pervasive services. Additionally, Christopoulou et al. [11] have used ontologies for context management and reasoning in ubiquitous computing applications. Likewise, Matheus et al. [12] used Semantic Web Rule Language (SWRL) [13] and ontologies to capture domain knowledge for situation awareness.

In the eHealth domain, ontological models are used to create medical decision support systems [14,15]. Ontology-based and knowledge sharing approaches have been suggested to model patient healthcare systems. Most of the proposed solutions treat scenarios like patient monitoring and follow up at home or during hospitalization [16–19]. An ontological knowledge framework based on Service Oriented Architecture (SOA) and Semantic Web (SW) has been proposed by Dang et al. [20] to capture all necessary knowledge for personalized healthcare scenarios involving patient care, insurance policies, drug prescription, and compliances. The framework suggested by Sahoo et al. [21] gives an example of knowledge modeling applications in life sciences. Ayna et al. [22] have proposed a framework for context-aware knowledge modeling in eHealth which has as objective to support decision making in different and distant organizations taking into account the context of local work settings, e.g. local work culture, available expertise, available technologies, as well as people's perspectives and attitudes. An interesting research work has been proposed in Massey and Gao [23] which simulates how mobile health systems can optimize resources in emergency response situations.

In agreement with our objectives, the aforementioned approaches present context modeling solutions based on the data captured by distributed sensors in pervasive environments, using common scenarios and standardized protocols. But, these works do not provide solutions that consider other environments where there are no sensors to capture context data and no predefined and standardized protocols for data acquisition. In addition, these approaches have not considered the heterogeneous resources management problems, i.e., resources discovery, availability, accessibility, and capability, which are key factors for tasks and processes performed in healthcare applications. In ONOF-PAS we have deeply considered all the above issues to provide a more general solution.

3. Methodology for knowledge-based framework construction in pervasive computing

Fig. 1 summarizes the consecutive phases of the methodology we have created to realize the knowledge-based framework. It displays the most general steps involved in the knowledge framework building process. The goal of the first two phases is to construct a basic and domain-independent knowledge meta-model. The first phase is the identification of the main and general concepts. Mainly, this step starts by an abstraction process of the available knowledge in order to identify the most general concepts, *i.e. Actor, Task, Process, Service, Resource, Organization, etc*, that can be instantiated in several domains. In the second phase, the knowledge meta-model will be formalized using a standard ontology description language. This phase is an essential step in order that the knowledge represented by the ontology can be interpreted by a computer. It will indeed be used by the reasoning processes in order to infer new knowledge. Currently, there are different types of formalisms and languages, e.g., XML, Resource Description Framework Schema (RDFS), and Ontology Web Language (OWL), which allow to formally represent knowledge as an ontology.