Knowledge-driven delivery of home care services

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Abstract Home Care (HC) assistance is emerging as an effective and efficient alternative to institutionalized care, especially for the case of senior patients that present multiple co-morbidities and require life long treatments under continuous supervision. The care of such patients requires the definition of specially tailored treatments and their delivery involves the coordination of a team of professionals from different institutions, requiring the management of many kinds of knowledge (medical, organizational, social and procedural). The K4Care project aims to assist the HC of elderly patients by proposing a standard HC model and implementing it in a knowledge-driven e-health platform aimed to support the provision of HC services.

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This paper focuses on two knowledge-based personalization aspects incorporated in the platform that aim to overcome the difficulties of HC delivery. The first one is the assistance to medical practitioners in the process of defining a customized treatment adjusted to the medical and social conditions of a particular patient in order to consider multiple co-morbidities. The second one is the possibility of tailoring the profiles of the care professionals according to the medical and organizational daily requirements in order to allow a flexible care delivery. Those two aspects, guided by the knowledge explicitly represented in the platform, play a crucial role in the medical and social acceptance of this kind of e-health systems. The paper also includes a real case study designed and tested by healthcare professionals and includes encouraging results from the test of the platform in a real health care environment in the city of Pollenza (Italy).

Keywords Formal intervention plans · Home care · Ontologies · Personalized healthcare delivery · User profile tailoring

1 Introduction

Healthcare costs have been continuously increasing in the last decades, and they now constitute an important percentage of the budgets of European countries. In particular, the care of old people that suffer chronic diseases requires long and expensive treatments under continuous supervision. One of the solutions that has been proposed to reduce the costs in this field is to prioritize and improve the provision of *Home Care* (HC) services (Jones et al. 1999). The typical *Home Care patient* (HCP) is an elderly patient, with co-morbid conditions and diseases, cognitive and/or physical impairment, functional loss from multiple disabilities and impaired self-dependency (Campana et al. 2008). It is widely recognized that hospitalization of these patients is both inappropriate and costly (Landi et al. 2001), because they usually do not have an acute medical condition; on the contrary, they require rehabilitation, family support and the possibility of receiving specialist continuous care (Beers 2005). HC assistance is a strategic goal in Europe because of the huge impact of senior people's needs in public health systems (De Rouck et al. 2008).

The effective and efficient treatment of HCPs requires the integration of skills, knowledge and abilities from a wide range of professionals (family doctors, specialists, nurses, social workers, experts on Geriatrics and rehabilitation, etc.), which usually constitute a multidisciplinary team, physically scattered in different institutions or departments, often depending from different administrations (Health ministry, Social affairs ministry, etc). The efficient exchange of information within this distributed team and the timely coordination of their activities are crucial to provide a high quality care. Moreover, the presence of different medical conditions on elderly patients complicates their treatment enormously, making it very hard to apply standard clinical practice guidelines (Boyd et al. 2005; Tinetti et al. 2004). Under these circumstances, it is necessary to adapt those general guidelines to each particular patient according to his/her specific medical and social circumstances.

The multidisciplinary and personalized nature of HC assistance make it a very challenging and complex environment to automate, in which many different kinds of knowledge must be integrated to provide an appropriate level of care. It is necessary to represent and take into account *organizational knowledge* (*e.g.*, which are the types of actors involved in HC and which are the actions, duties and liabilities related to each of them), *medical knowledge* (*e.g.*, which are the more usual syndromes in HCPs, which diseases are related to each syndrome, which are the symptoms of each disease), *procedural knowledge* (*e.g.*, which are the basic clinical guidelines needed to treat HCPs, who can execute each of the actions in the guideline) and *social knowledge* (*e.g.*, which are the social factors affecting HC assistance and how they can be assessed). Furthermore, the professionals involved in HC must be able to access all this knowledge efficiently and to use it appropriately in order to elaborate individual plans of action for each HCP.

In European Countries, healthcare (and, in particular, HC) is structured in different ways according to local rules, laws and funding. Thus, traditionally, the systems developed for HC have been designed specifically for a country, or even for a particular region or hospital (De Rouck et al. 2008). These ad-hoc systems are not flexible enough to be adapted to the differences on each country or even on each medical institution, as usually all the different kinds of knowledge (especially the organizational and procedural aspects) are hard-coded in the system's implementation. This hampers their usefulness and limits their applicability and reusability. Furthermore, the dynamics of the daily activity of the medical personnel (*e.g.*, temporal or permanent changes in care delivery, responsibilities or duties) are hardly supported by this kind of systems. Therefore, it can be argued that there is a strong need to show how it is possible to design and implement intelligent systems that provide e-health services in a way that is generic enough to be easily applicable in a wide range of medical and organizational settings. The system must be also flexible and customizable in order to easily incorporate the particularities of each medical center as well as to allow seamless adaptation to dynamic changes in daily activities.

The K4Care European research project (Knowledge-based home care e-services for an ageing Europe), developed by a consortium of 13 medical and Computer Science partners from 7 European countries, proposes a paradigmatic HC model flexible enough to be adopted in any EU country. This HC model is defined in a standard, modular and scalable manner, in order to improve the interoperability, flexibility and reusability of actual systems (Campana et al. 2008). It is supported by a Web-accessible agent-based platform that provides e-services to health professionals. In a nutshell, the system supports the basic management of patients, their assessment and diagnosis, and the knowledge-assisted design of treatments adapted to the individual circumstances of each patient. In addition, the system monitors and coordinates the execution of these treatments by multidisciplinary teams taking into account the requirements and daily workflow of medical practitioners. This paper focuses on the description of how different kinds of knowledge are used to personalize the definition of customized treatments and to adapt the system's behavior to the daily needs of medical professionals. Additional material with a more detailed description of the platform architecture, the medical and organizational ontologies used by the system, and the ontology-guided development of the system can be found in Isern et al. (2010).

The K4Care system provides all the data and knowledge necessary to build an individually tailored treatment for each concrete patient, including the clinical history of the patient, the results of the patient assessment and the internationally approved guidelines for the treatment of each of the symptoms, syndromes and diseases that the patient suffers. The interdisciplinary team that is in charge of the care of the patient can build the personalized care plan via an intuitive visual editor, by merging appropriately the different guidelines and customizing the treatment to the particular medical and social circumstances of the patient. An important aspect is that the editor also ensures the coherence of the designed treatment with respect to the organizational structure of the medical center in which it should be executed (*e.g.*, checking that a professional with the appropriate skills and permissions is available to execute each particular action at the appropriate time). In addition, the execution logic of the K4Care platform, implemented via a multi-agent system, supports the enactment of the designed patient's treatment by providing a seamless coordination of administrative actions, medical procedures and the flow of information between the heterogeneous and spatially distributed members of the care team. The interested reader may find more details on the agent-based execution of personalized treatments in Isern et al. (2010).

A pillar of the K4Care platform's design is the knowledge-driven implementation of the HC model. Unlike the traditional e-health systems, in which usually all the knowledge (especially the organizational aspects) is embedded in the code, in K4Care the knowledge structures and data sources are completely separated from the execution layers. Through the use of especially designed ontologies, that model user profiles and the medical and organizational workflows, the system provides a high level of flexibility. Another interesting and novel aspect of the system is that the ontologies can be individually tailored to provide the necessary dynamicity in daily care activities and to be reused in other healthcare centers. Thanks to the knowledge-driven design, these changes on the ontologies are automatically and transparently incorporated into the platform, providing a personalized view of care duties and activities. In that way, the system automatically adapts its behavior to the daily workflow of medical practitioners, making them feel comfortable with the use of the platform and facilitating the adoption of this tool in the management of their daily activities.

The main original contributions of this paper may be summarized as follows:

- It is proven, through the description of the design, implementation and test of a complex system that supports practitioners in the delivery of Home Care services, how the decoupling of knowledge and execution permits to build a modular, flexible and dynamic system, overcoming the usual shortcomings of traditional e-health systems.
- It is shown how the explicit organizational description of the home care actors, procedures and services is used by the system to ensure the coherence of the definition and delivery of the personalized treatment plans. The definition is assisted via a graphical editor which allows reusing and combining standard clinical practice guidelines, whereas care delivery is coherently enacted according to the organizational rules of the concrete medical institution.
- The paper presents a novel customization mechanism, based on the creation and adaptation of individual organizational ontologies, which allows accommodating the system's behavior to each professional by incorporating his/her specific and dynamically changing daily needs.
- It is also described how the implemented system was tested and validated in a real environment in the Italian city of Pollenza in order to assess the feasibility of the system under the dimensions of ease of use and usefulness in contrast to other systems or the traditional way of doing. A previous evaluation and validation of

the HC model in which the system is based may be found in Isern et al. (2010). The possibilities of the system and the benefits from the end user point of view are also illustrated by means of a real case study that covers a complete cycle of care delivery.

The outline of the paper is the following. The next section introduces briefly the basic components of the K4Care HC model, the three-layered architecture of the K4Care platform and the formal language in which medical guidelines and administrative procedures are represented (SDA* (Riaño 2007)). Section 3 describes how the knowledge structures managed by the system are used both to support the definition of customized medical treatments (Individual Intervention Plans) and to adapt the careflow to the daily requirements of medical practitioners. The following section presents a summary of the practical validation of the system in the Italian town of Pollenza. Section 5 illustrates the theoretical explanations by presenting a complete case study, following all the steps involved in the care of a co-morbid patient from his admission in the HC unit to the execution of a personalized care. Section 6 comments some related works. The paper finishes with some conclusions and a brief description of lines of future work.

2 The K4Care platform

The K4Care project has proposed a shareable HC model that is easily adoptable by the EU healthcare organizations because it is modular, with a backbone structure that only sets some nuclear services that are common in the European countries, to which other additional services can be incorporated (Campana et al. 2008). The model has been designed by a consortium of medical experts in the fields of Geriatrics and Home Care from both old and new European countries, with the help of expert knowledge engineers. It includes the formalization of the HC knowledge as well as the design of a platform that permits to store and enact the careflow plans designed over the patients. These two elements will be summarized in this section in order to provide the basic information needed to understand the knowledge-based personalization methods explained in the rest of the paper.

2.1 Overview: HC model and platform

The designed HC model formalizes the organizational structure of a health institution. It is based on two basic entities: *Actors* and *Services*. On one hand, *Actors* refer to any person involved in HC (medical professionals, continuous care providers, etc.). The model contains several aspects of an *Actor*'s interaction, duties and skills, in order to allow the detailed definition of professional roles. Different types of actors are defined according to their professional profile (Family Doctor, Head Nurse, Social Worker, Nurse, Psychologist, Patient, etc.). In addition, some special medical teams can also be defined, such as an Evaluation Unit, which is a group of actors in charge of the assessment and re-evaluation of a patient.

On the other hand, care activities are organized into *Services*. *Services* are all the facilities provided by the HC structure for the care of the patient. A *Service* is executed by means of *Procedures* that mainly model the workflow to be followed during the HC delivery, in terms of *Actions*. Services have been classified in a hierarchical structure, distinguishing three main types: access services, patient care services and information services.

According to their competencies, the different types of *Actors* can only perform some specific *Actions*. The results of the *Actions* performed on the care of a patient are stored in the form of *Documents*. Different types of *Documents* have been distinguished and their internal structure has also been defined. *Documents* compose the patient's medical history and are the basis for medical professionals to decide upon the new *Services* needed for the patient. Read and write permissions over each document have also been defined in the K4Care HC model. Those permissions are important to ensure the confidentiality of personal data.

Actors, Actions and *Services* are also organized according to the *Care Units* to which they can belong. For example, a Nurse can work in a Rehabilitation Care Unit or in the General Home Care Unit, while a Physical Therapist only works in Rehabilitation Care Units.

The K4Care platform is a Web-based application that facilitates the provision of HC services following the HC model previously defined. The users of the system are the different kinds of medical professionals, the additional care givers (*e.g.*, volunteers, relatives of the patient) and the patients themselves. Each user interacts with the system according to the rules established in the HC model. The system facilitates the coordination between the different types of actors that work together in the delivery of care to a particular patient. This process is done by means of the automatic adaptation of the functionalities available in the system for a given user, such as his/her list of pending tasks, or the set of accessible documents.

The structure of the K4Care platform is shown in Fig. 1. An important characteristic of this platform is that it separates the medical and organizational knowledge, modeled by means of several machine readable knowledge and data sources, from the software components devoted to the execution of the system. With this approach, a knowledge-driven system has been developed, permitting to dynamically adapt its behavior when there is a modification of the knowledge base.

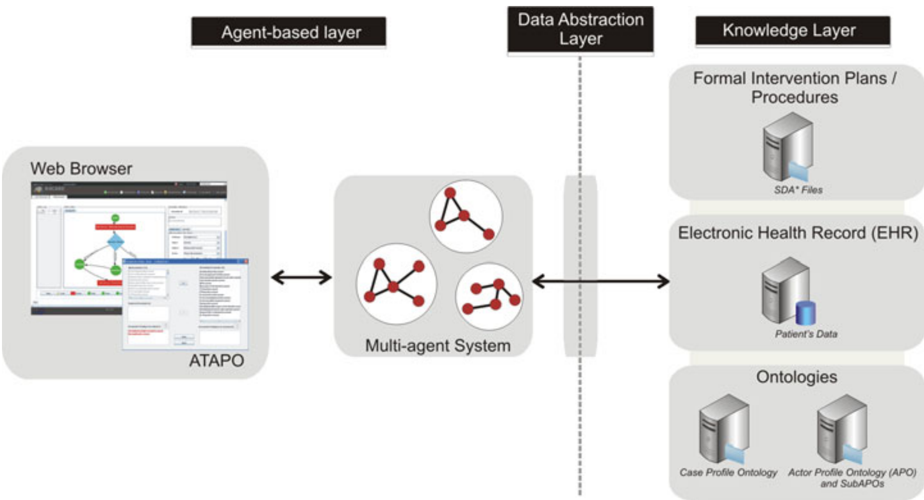

Fig. 1 K4Care platform architecture

The *Knowledge Layer* includes different types of knowledge resources and data repositories to keep patient data and medical histories. First, this layer contains the electronic health record (EHR) which stores information about the patients (personal data and information about ongoing treatments) using standard XML documents. Secondly, knowledge regarding the organization and the healthcare context is represented and stored by means of ontologies, which offer a formal framework to represent complex domain knowledge in a computer readable manner. Two ontologies have been designed: the *Case Profile Ontology* and the *Actor Profile Ontology*; both ontologies are encoded in OWL-DL (Bechhofer et al. 2008). The *Case Profile Ontology* (CPO) models the knowledge of the HC medical concepts that the system is able to recognize, including syndromes, symptoms, diseases, assessment tests, clinical interventions, laboratory analysis and social issues, as well as the relationships among them (Riaño et al. 2009). On the other hand, the *Actor Profile Ontology* (APO) represents the organizational knowledge of a healthcare center following the K4Care HC model based on *actors–services* introduced before. It formalizes the roles of the actors involved in the Home Care delivery, as well as the relationships among services, actions and documents (Valls et al. 2010).

The *Knowledge Layer* also includes two more databases including careflow information. One of them is a database of *procedures* that indicate the steps to be followed during administrative and care processes (*e.g.*, a patient admission). The other database is a repository of careflow treatments called *formal intervention plans* (FIP, K4Care 2009a) designed to handle particular pathologies (*e.g.*, anaemia, hypertension, and post-stroke rehabilitation).

The *Data Abstraction Layer* is an mediator component between the *Knowledge Layer* and the platform that permits to transmit the required data and knowledge in a transparent way, providing independence from the location and structure of the resources (Batet et al. 2007). This feature is really interesting in Home Care because the users may belong to different institutions which are physically spread in different places, so the data can be located in different machines.

The execution logic of the K4Care platform is implemented using a multi-agent system (MAS, Wooldridge 2009). The MAS includes one agent per actor registered on the system and permits the coordination of activities between all of them during the execution of administrative procedures and intervention plans. Agents are not hard-coded, on the contrary, their behavior is automatically determined by the information available at the knowledge layer at each particular moment (Isern et al. 2010).

Users can interact with their agents through a Web-based application. As shown in Fig. 1, the K4Care platform includes two clients: a Web browser and the ATAPO tool. The first element is used by registered users (practitioners) to log into the system in order to retrieve data, confirm pending actions received from other agents, and to fill documents with data acquired in medical visits or tests. The second module is a facility to adapt the organizational model stored in the APO to a particular practitioner (see more details in Section 3.2).

2.2 Intervention plans

Clinical guidelines (CG) are defined as systematically developed statements to assist practitioners about the appropriate healthcare decisions under specific clinical circumstances (Field and Lohr 1990). CGs are intended to describe the diagnosis and management of a particular disease, and they should provide a clear indication of the best choices for the clinical management of the patient.

A *formal intervention plan* (FIP, K4Care 2009a) is an enriched form of CG (Campana et al. 2008). FIPs are formal structures representing health care procedures aimed to assist patients suffering from a particular ailment or disease. In addition to the medical data already stored in CGs, they also contain references to all the actors involved in the care process (healthcare professionals, patients and relatives, etc.) in order to provide the best coordinated action plan in a particular healthcare organization.

In Home Care, as stated before, the target patient is an elderly person that suffers co-morbidity. However, the recommendations of those FIPs are not enough to treat all the pathologies of the patient and, even more, they can be contradictory. To personalize the care of this type of patients, the K4Care platform includes a novel functionality that permits the definition of patient-specific treatments by integrating and adapting several FIPs to the circumstances of a particular patient. These final careflows are called *individual intervention plans* (IIP) and are customized to the needs of a particular patient.

As stated in Isern and Moreno (2008) and Peleg et al. (2003), there are different formalisms to encode careflow plans, such as PRO*forma*, Asbru and GLARE. K4Care adopts the SDA* (Riaño 2007) formal language to represent those IIPs, because it allows to specify structured careflow plans as well as time constraints between elements.

The basic components of the SDA* structures are (see the example shown in Fig. 2):

- *States*, which represent statements that are useful to determine the condition of the patient at a certain stage. For instance, after a clinical assessment of the patient, the family doctor confirms if the state of the patient corresponds to the cognitive impairment syndrome. There are also special states indicating the entry and exit points of the structure, labeled as Start and End respectively.
- *Decisions*, which are required by medical experts to choose among alternative medical, surgical, clinical or management actions within a treatment. A decision variable contains a set of logical conditions that should be evaluated before proceeding. Some of the values required in these conditions can be retrieved from the patient's record, while others may be entered by the practitioner during the medical visit.
- *Actions*, which represent medical, surgical, clinical or management actions that should be performed during the treatment of a patient (*e.g.*, define or change a drug therapy). A concrete type of actor (*e.g.*, Family Doctor) involved in the process of care delivery may be specified as the responsible of the execution of those actions. Action completion typically results in a set of documents to be filled and stored in the patient's health record for future reference.

The combination of these basic elements using directed edges permits to declare the careflow of a treatment. Temporal constraints can be specified at the element and link levels in order to introduce cycles (*e.g.*, apply a treatment three times in a month), deadlines or delays between actions (*e.g.*, take a medication and wait a month until reassessment). Moreover, if particular medical data are required,

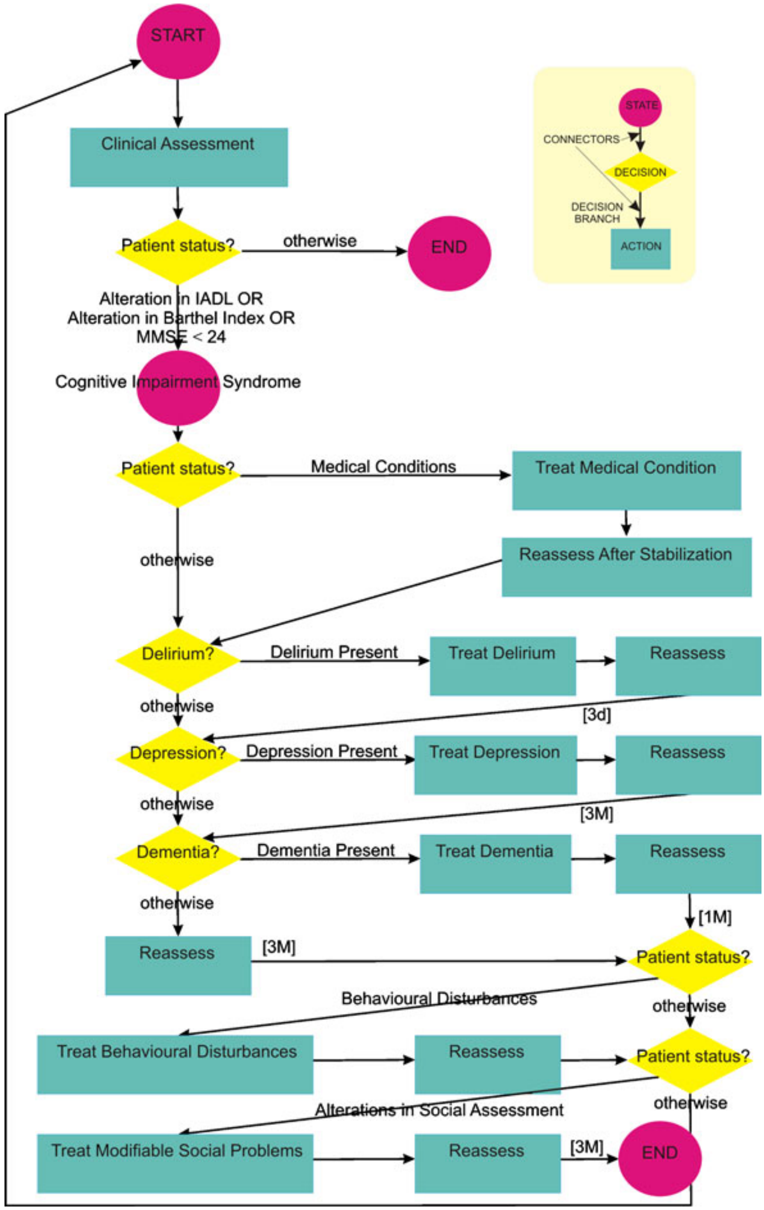

Fig. 2 SDA* flowchart for the FIP of cognitive impairment (adapted from K4Care 2009a). *IADL* Instrumental Activities of Daily Living. *MMSE* Mini-Mental Scale Examination. *M* months, *d* days

documents stored in the patient's health record can be associated to action and decision variables.

SDA* defines a graphical format that eases the representation and edition of intervention plans; resulting files are stored as XML documents. Figure 3 shows parts of a SDA* XML file concerning the definition of the basic elements (a *state*,

```
<sda_state display_name="Cognitive Impairment Syndrome" id="VertexState#3">
<next>
<element>VertexDecision#4</element>
</next>
</sda_state>
...
<sda_decision display_name="" id="VertexDecision#4" question="  Patient status?">
<sda_branch>
<sda_term name="Medical conditions"/>
<sda_connector>
<element>VertexAction#9</element>
</sda_connector>
</sda_branch>
<sda_branch>
<sda_term name="otherwise"/>
<sda_connector>
<element>VertexDecision#5</element>
</sda_connector>
</sda_branch>
</sda_decision>
...
<sda_actionblock display_name="" id="VertexAction#9">
<sda_action name="Treat Medical condition" type="[ANY]">
<frequency>0</frequency>
<petitioner>[FamilyDoctor]</petitioner>
<performer>[FamilyDoctor]</performer>
<document id="9630" newInstance="false" type="ad01">
</document>
</sda_action>
<next>
<element>VertexAction#10</element>
</next>
</sda_actionblock>
```

Fig. 3 Parts of the XML-like codification of a SDA* flowchart for the FIP of Cognitive Impairment shown in Fig 2; description of a *state*, a *decision* and an *action*

a *decision* and an *action*), and their internal details. For instance, it is shown how the information required in a decision is stored (*question, sda_terms*), how an action embeds the function to achieve (*sda_action_name*), its responsible (*performer*), and the related documents (*document id*), and finally, how all elements store information about the next element/s connected to them in order to maintain a graph-like structure (*next*).

3 Definition of user-centered knowledge

The Knowledge Layer repositories are the basis for the execution of the K4Care system. They include the medical terminology of the HC processes (CPO), the standard workflows for the patients' treatments (FIPs and procedures) and the organizational model of HC (APO). This information represents a general model of Home Care delivery.

Moreover, the HC knowledge has been defined in a modular way in order to be easily adaptable to the current situation of each medical center, according to its particularities. In addition, for data representation, standard and flexible languages have been selected in order to facilitate the customization of the knowledge when needed.

In this section we address two aspects of knowledge adaptation that are directly related to the user of the system: the adaptation of Formal Intervention Plans to the conditions of a particular patient that is treated in a particular medical center (IIPs) and the adaptation of the user profile of the medical professionals to their daily needs (sub-APOs).

3.1 Individual intervention plans

As stated above, FIPs represent general healthcare workflows defined to treat a specific pathology, while IIPs are patient-centered treatments constructed from the adaptation and/or combination of several FIPs according to the co-morbidities observed for a concrete patient. IIPs also differentiate themselves from more general FIPs in the fact that action performance and decision evaluation are framed in the scope of the concrete organization in which the HC is delivered (*i.e.*, according to the available actors and their corresponding skills and duties). The K4Care system also supports the enactment of IIPs in a semi-automatic manner by transparently coordinating the efforts of the different actors involved in the process of healthcare, according to their current roles and duties, which can be kept up to date by means of the customization of the user profile.

With respect to the creation of the personalized IIP, the K4Care platform provides several tools to assist the coordinated creation of IIPs and to ensure their consistency with respect to the organizational structure of the medical center in which the HC is framed, which are explained in this section.

The creation of each patient-dependent IIP follows a complex procedure that involves the coordinated effort of a multidisciplinary team called *Evaluation Unit* (EU; Isern et al. 2008). An EU includes four kinds of actors: the Physician in Charge of the Home Care unit (PC), a Family Doctor (FD), a Social Worker (SW) and the Head Nurse (HN) of the Home Care unit.

After the patient is admitted, a concrete EU is created by the HN, who requests the confirmation from the other actors. The first step in the patient's care is the execution of a *Comprehensive Assessment* (CA), which includes a *Multi-dimensional Evaluation* (made by all members of the EU, filling out a set of internationally standardized scales), a *Clinical Assessment* and a *Physical Examination* (which may be performed either by the PC or the FD), and a *Social Needs and Social Network Assessment* (performed by the SW). Once all the results are available, the EU members analyze them and determine the syndromes, symptoms and diseases of the patient, which lead to some FIPs. In order to assist the creation of the treatment, the K4Care platform automatically retrieves all available FIPs related to the assessed conditions from its repository.

Then, the EU members are asked to combine and adapt the relevant sections of those FIPs, giving form to a customized IIP for the concrete patient. The SDA* graphical editor provided by the K4Care platform eases the creation of IIPs from the combination of several FIPs. As shown in Fig. 4, after retrieving those FIPs (in that

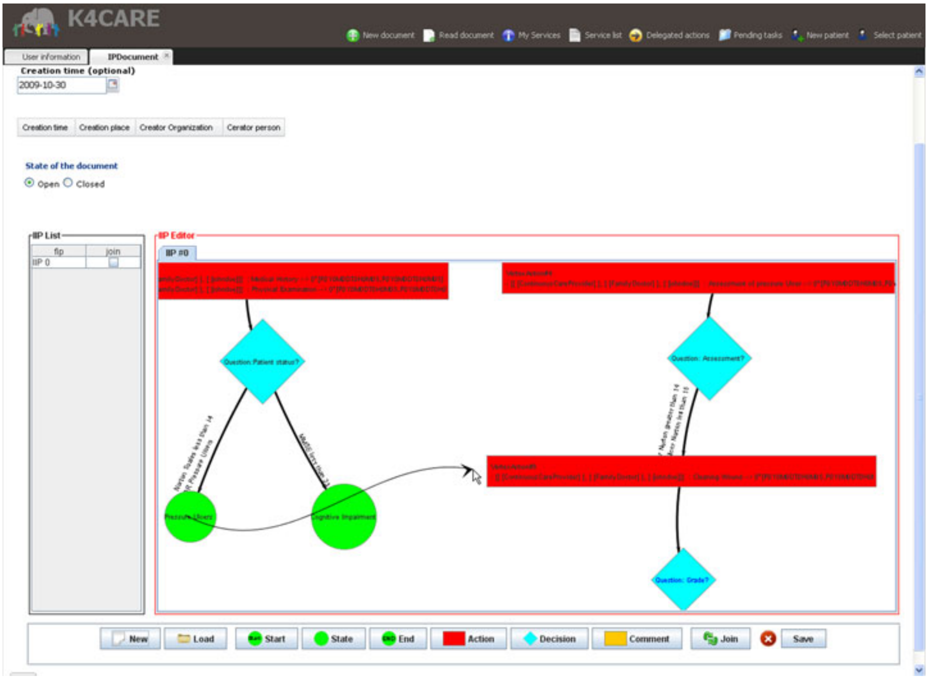

Fig. 4 Visual editor of Individual Intervention Plans

case regarding Cognitive Impairment diagnosis and Pressure Ulcers treatment), any EU member can graphically create, delete or edit SDA* nodes (states, decisions or actions) and create new edges between nodes in order to represent the interactions between several co-morbidities.

From a logical point of view, a FIP contains a set of entry points, which represent possible starting states in the provision of the treatment. In the SDA* model, states contain a set of variables representing logical conditions regarding the patient status. However, an IIP should have a unique entry point. Thus, the EU has to decide, from the possible entry points available in the loaded FIPs, which one represents the initial stage of the IIP. For instance, in the example shown in Fig. 2, a practitioner may decide to start the treatment in the state labeled "Cognitive impairment syndrome" if the patient has been previously diagnosed to suffer this syndrome. Additionally, variables involved in the SDA* nodes can be manually edited in order to state, for example, personalized drug quantifications or time constraints in the execution of actions.

The editor ensures the logical coherence of the resulting SDA* structure by continuously monitoring user actions and providing warnings if some parts are missing (*e.g.*, initial and final states are mandatory) or if the plan would not be properly executed (*e.g.*, all the elements have to be connected and accessible from the initial state). SDA* edition is also guided to ensure the completeness of the structure (*e.g.*, when an action is created, the user is requested to establish its characteristics before continuing) and to avoid the creation of invalid structures (*e.g.*, several initial states).

The SDA* structure resulting from the edition of several FIPs represents the customized medical workflow adapted to the patient conditions. In addition, in order to properly enact the personalized intervention plan in the context of a concrete medical organization, the involved actions and decisions can be associated to the professional actors' roles able to perform or evaluate them. In this particular point, the organizational knowledge available in the K4Care knowledge sources is exploited to associate these data to IIP nodes with the help of the tools included in the system. In order to assist this task, the SDA* editor automatically consults the *Actor Profile Ontology* to provide to the user the list of actor roles which are able to perform a certain action, according to the professional skills and duties modeled in the ontology. In this manner, we ensure that the IIP resulting from the edition process is coherent, from the execution point of view, with the organizational structure of the center in which it will be enacted.

Once the final IIP is ready, it is saved in the Electronic Health Record of the patient as part of his/her personal information. The execution begins when the PC logs into the system and requests the execution of the new IIP on the patient. After that, the agent platform coordinates their activities along the treatment (for more details about the execution, see Isern et al. 2010). The IIP usually contains follow-up actions in which the state of the patient is checked. If the evolution of the patient conditions follows an undesirable course, the EU can consider changing or even cancelling the IIP.

The fact that the resulting structures are also stored in a standard format and associated to the structured patient data contained in the EHR can also suppose a valuable source for further consultation and medical research (Taboada et al. 2009).

3.2 Customizing user models

The *Actor Profile Ontology* (APO) contains the organizational knowledge defined in the K4Care Home Care model (Section 2.1) as a set of basic entities: Actor, Service, Procedure, Action, Document and Care Unit. Those entities are structured by means of taxonomical relations that define different levels of specialty (*is-a* relations) and other semantic relations (*e.g.* actor_i *can_perform* action_j, document_i *is_result_of* action_j). The details of its design and the ontology content can be found in Gibert et al. (2008).

Figure 5 shows a screenshot of the APO ontology loaded in the Protégé editor. The figure highlights the *Physician in Charge* role and its organizational dependencies and permissions. It also highlights that the Physician in Charge is able to initiate the admission of a patient service (named *HCPAdmissionService*). One of the actions required by this service is *SuperviseHCPInformation*, which is also a responsibility of the Physician in Charge who would be able to store, as a result, the information about the patient in his/her EHR in the document called *HCPAdmissionDocument*.

As previously said, the main goal of the APO is to facilitate the integration and coordination of the different actors that are needed to provide the medical services. In this sense, part of the code of the Actor agent is automatically generated using the information stored in the APO, ensuring also that the agent implementation is coherent with the HC model (Hajnal et al. 2007). This knowledge-driven design facilitates the implementation of the *K4Care Platform* with generic components, whose functional behavior is automatically extracted from the knowledge sources.

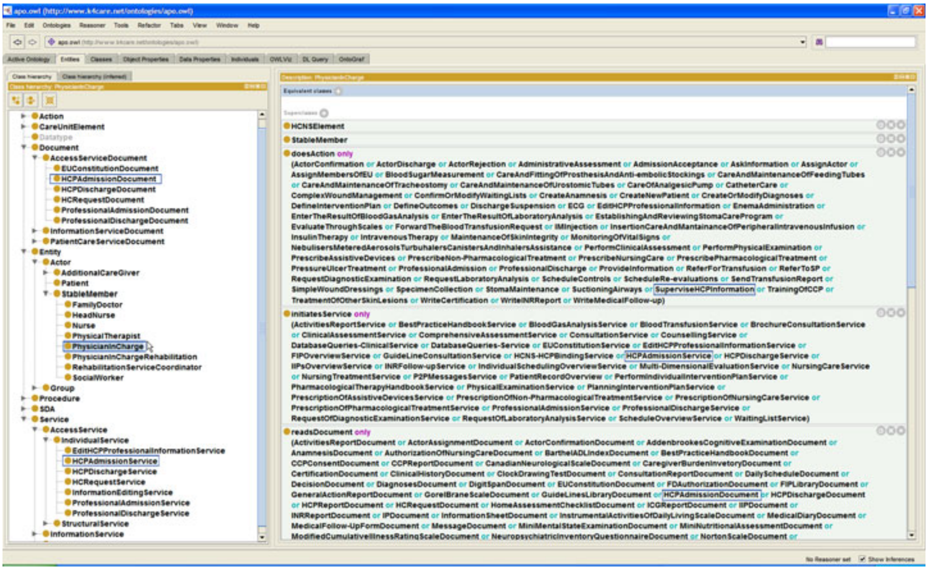

Fig. 5 Protégé screenshot of a portion of the APO

Moreover, the organizational knowledge modeled in the APO is also used during the definition of IIPs guaranteeing that the plan that is being defined respects the HC model.

However, not only the healthcare workflow is guided by the knowledge stored in the APO, but also the user's interaction with the system is determined by this ontology, because it defines the actor's profiles, establishing the roles of the different types of users in the K4Care System. These profiles mainly determine the set of actions and services that can be performed by each person, as well as the read/write access permissions on the documents available in the system. So, users will have a partial and simplified view of the entire platform functionalities according to their profile, forcing them to act according to their liabilities in the medical organization.

Both of those elements (actions and documents) can be personalized to the needs of each particular user by means of creating individual user profiles, as it is explained in the rest of this section. In this way, the same HC Model can be seen from different views, depending on the actors' roles and reflecting their daily needs. In particular, the system provides to a concrete user the possibility of consulting some documents which initially were not permitted in his/her profile, but that are interesting for the treatment of some particular HC patient that suffers from diverse syndromes (this extension in permissions will only provide additional *read* access to those documents, but never *writing* access). With respect to the professional liabilities of the users, although the set of possible actions to be performed by actors is strictly defined by the K4Care HC Model, an actor may request to temporally remove some of the Actions associated to his/her profile, because he/she will be concentrated on performing other activities or because he/she is relieved from some duties for some period of time (*e.g.* maternity). The new organizational procedure is automatically adopted by the system thanks to the knowledge-driven execution, keeping it up-to-date in correspondence with the needs of the current situation.

It is important to note that the modifications do not need to be permanent. On the contrary, the customization is typically done to adapt the behavior of the system during a given period of time. After this period has expired, the user can revert the temporal changes.

In Batet et al. (2008) different ways of implementing the personalization of the actors' profiles are discussed. From this study, it was decided that a subset of the APO ontology (sub-APO) is created for each user that requires some personal adaptation of his/her profile. The sub-APO maintains the same structure of the APO, so that it can be used by the agents for reasoning in the same way that it is done with the APO. The creation and management of this personal information is done by a tool called ATAPO: Automatic Tailoring of the Actor Profile Ontology. In (Batet et al. 2009) the connection between ATAPO and the K4Care platform is explained, giving details on how the agents access the personalized sub-APOs of the users.

The ATAPO tool is always available to the users to assist them in the creation and modification of their personal sub-APOs, in order to reflect some changes in their normal activity. Figure 6 shows the set of documents available to Mr. Benton (a social worker) according to his standard profile. In Fig. 7, we can see that additional documents with temporal access permission appear in the profile of Mr. Benton. In this case, this social worker has read access to the Clinical History Document of a patient that requires some special treatment.

The APO tailoring includes an authorization process to inform the Physician in Charge of the corresponding care unit and request his/her approval. The authorization is required because the modifications on the document access must follow the

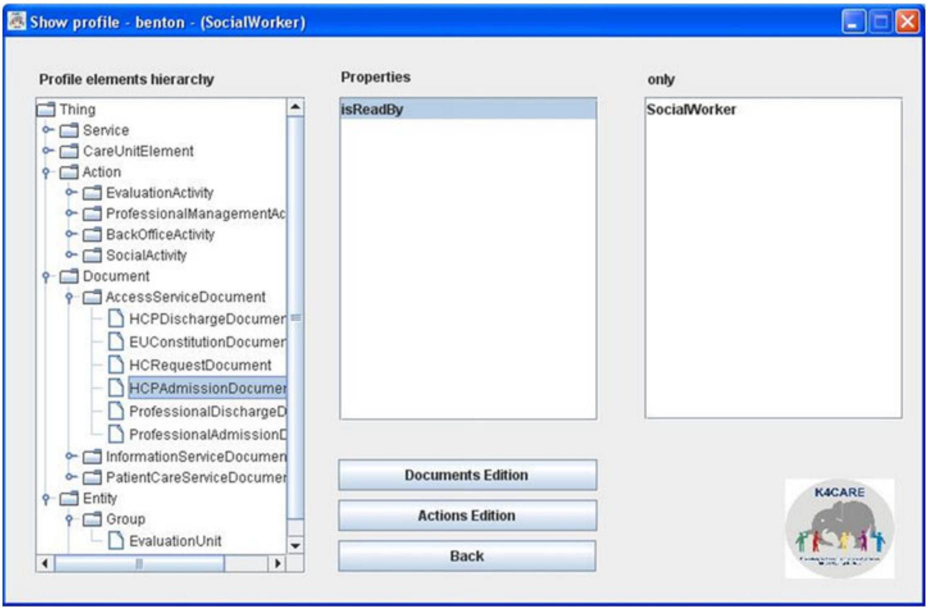

Fig. 6 Initial profile of Mr. Benton (a Social Worker) according to the HC model

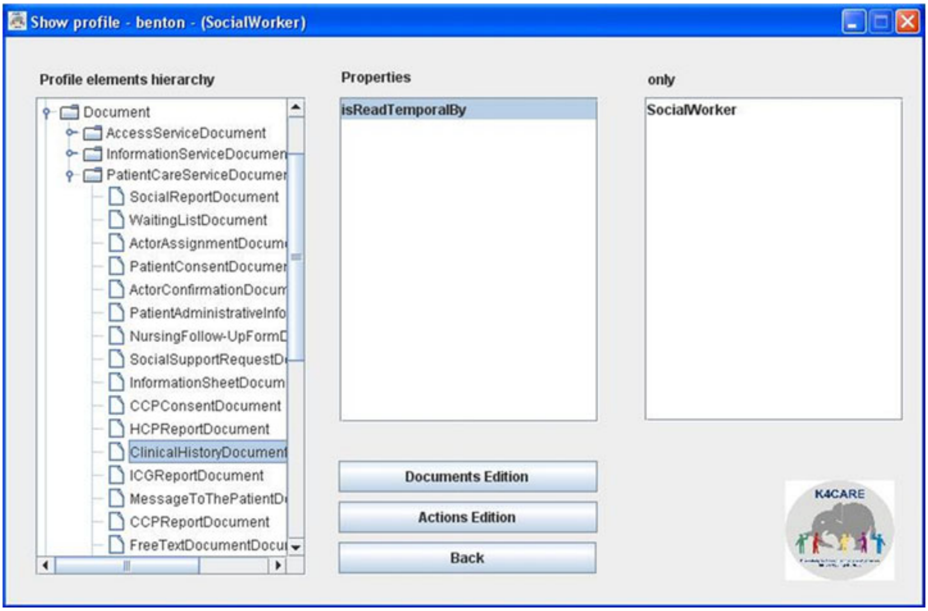

Fig. 7 Personalized profile of Mr. Benton (a Social Worker)

legislation concerning privacy issues and the changes in the distribution of tasks must guarantee that there is enough personnel available to provide all the medical services.

To ensure the integrity of the organizational model, the ATAPO system verifies that the changes follow some specific protocols. Those tailoring protocols are shown in Fig. 8. These diagrams indicate the permitted states in the tailoring process. For example, in the personalization of documents, the initial state (at the top) is a document without read access. Then, the user makes a petition for reading this document and the Physician in Charge (PC) can authorize it or not. If the access is granted, the system stays in state "*Temporal Access Read*" until the user requests to cancel this temporal permission. This second request can also be authorized or not, depending on the considerations of the PC. Notice that in this tailoring model it is not possible to remove the read permissions established by default in the APO.

The implementation of these protocols is done by means of new specific relations that are introduced in the user's sub-APO to represent the personal requirements.

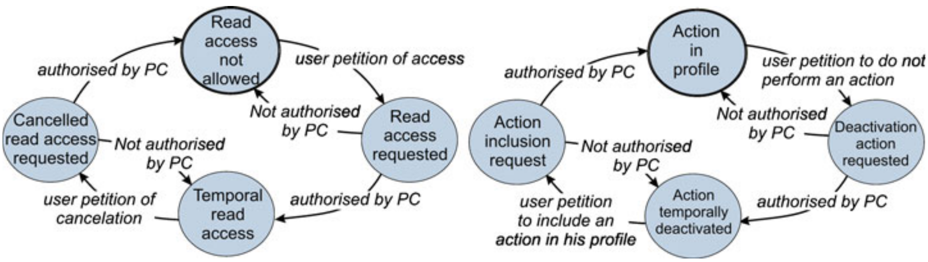

Fig. 8 APO tailoring protocols, for documents (*left*) and for actions (*right*)

This tailoring method is also knowledge-driven because the APO guides each of the adaptation steps to ensure that the tailoring of the sub-APO is done according to the general K4Care HC organizational model.

4 Validation

In order to test the viability of both the HC model and the knowledge-based K4Care platform as a real solution for HC, an evaluation and validation process in a real medical environment was carried out in Pollenza (Italy). Pollenza is a small town with 6439 inhabitants, with 1400 of them being over 65 years old. The professionals participating in the evaluation were four Family Doctors specialized in Geriatrics, one Physician in Charge, four Nurses, being one the Head Nurse, and one Social Worker. Patient data were taken from 23 volunteer patients. It is important to note that, in order to enable an objective and realistic evaluation, evaluators were real healthcare professionals not involved in the K4Care research, HC model design or platform development. The mean age of the patients whose data were used in the test was above 65 years, defining a target population of mainly geriatric users. The most common conditions of those patients were coronary heart diseases, cerebrovascular diseases, arthritis, hip fractures, diabetes and hypertension. Accordingly, 38 standards FIPs (K4Care 2009a) were introduced in the platform, covering conditions such as anemia, arthritis, heart failures, cognitive impairment, heart diseases, delirium, dementia, depression, diabetes, hypertension, immobility, Parkinson, post-stroke and pressure ulcer.

An initial stage involved several working sessions and tutorials in which participant staff learned to use the platform with the assistance of IT experts and trained Geriatricians from two medical partners of K4Care (Azienda Sanitaria Locale Roma B and Fundazione Santa Lucia). After that, the platform management was completely transferred to the Pollenza staff which was asked to execute procedures of usual care over the selected patients, trying to use as much as possible the K4Care platform to support their daily activities. As the HC model specifies and the APO ontology models, many of those activities required the interaction of several groups of actors which worked concurrently, keeping track of each step of the care process. Participants remotely accessed the platform server via on-line connection through laptops or desktops located at patients' homes or professionals' offices. Complete workflows were executed for the involved patients resulting in the execution of both administrative and health care procedures and the definition and execution of personalized IIPs. Quantitatively, the testing resulted in the introduction of 23 patients with their appropriate EHR data, the constitution of 10 different Evaluation Units composed by the staff involved in the test, the execution of 184 Actions and the creation of 26 Documents. It is important to note that this volume of work typically accounts for months rather than the—intensive—week in which the evaluation stage took place (K4Care 2009b).

After the testing, a structured evaluation questionnaire was provided, asking the participants (healthcare professionals) to rate 20 items in a scale from 1 (minimum) to 7 (maximum). The main goal was to collect feedback from the potential users of the system from a non-technical but practical perspective. Questionnaires were designed following the Technology Acceptance Model (TAM; Malhotra and Galletta

1999) which aims to quantify how users come to accept and use a technology focusing on its perceived usefulness, the improvement of their productivity and the ease-of-use. The concrete questions (which are detailed in K4Care 2009b) evaluated the adherence to the needs and duties related to home care, the possibility of use in every day activity, the capability of collecting and integrating information from different sources, and the possibility of defining and executing personalized health care procedures and intervention plans.

The first set of questions evaluated the perceived ease of use of the K4Care platform from the point of view of healthcare personnel. The average score of this section was 5.8. Testers rated the smoothness of the learning curve of the platform with an average of 6.1, whereas the clearness of the system's interaction and its flexibility were rated both with a 5.7. It is important to note that the knowledge-driven design and the tailoring possibilities it offered, which have been exploited in the K4Care platform, had a direct influence in the high ratings received in these aspects, especially considering the complexity of the daily interaction between healthcare professionals and the dynamicity of care delivery in a real setting. On one hand, profile tailoring and IIP tailoring enable a high degree of flexibility, allowing on-line modifications of user profiles which are seamlessly incorporated by the system and the coordinated definition of personalized care plans. On the other hand, the profile-based interaction towards the system simplifies the interface, presenting only the options associated to a particular profile.

The second set of questions were aimed to rate the perceived usefulness of the K4Care platform when compared to the usual way of working. The average score for this section was 5.9. Professionals rated the possibility to accomplish tasks more quickly with the platform than with their traditional way of doing with a 5.9, whereas the improvement of job performance and productivity were rated with a high 6.0. Professionals also rated the enhancement of job effectiveness with a 5.8 concluding that K4Care was considered useful for their work (5.9). In this aspect, professionals with higher responsibilities (such as Physicians and the Head Nurse) provided higher average ratings (6.1) than other staff (nurses rated an average of 5.2). The reason is that these professionals are responsible of many daily management activities (such as service activation and monitoring, actor assignments, supervision of duties, etc.), which are completely carried out or semi-automated by the K4Care platform.

A third set of questions evaluated the different sections of the K4Care platform, which were rated with an average 5.6. Data and service management obtained a rating of 5.7.

The final set of questions requested the general opinion of healthcare professionals when comparing K4Care with other IT-based care assisting tools and their usual way of doing. When asked about their awareness of similar tools, professionals rated with a low 1.9, whereas when asked if a tool like K4Care is needed in healthcare, the rating was a very high 6.3. These results indicate that healthcare professionals appreciated the novelty and the possibilities of the K4Care platform and the lack of similar approaches in the care context.

5 Case study

In the following, we review, as a case study, one of the real scenarios designed, executed and validated by medical staff during the testing process. The main aims of this example are to show the benefits and the added flexibility offered by the customization of general FIPs to patient-specific IIPs and the tailoring of the general APO into personal sub-APOs, as well as to explain the internal flow of data and the system behavior through a common task involving several administrative actions and the execution of the IIP. This will also illustrate the benefits provided by K4Care regarding transparent data management, seamless service and action management, scheduling supervision, assisted care delivery and profile-based action negotiation, aspects which had a direct influence from the end-user perspective in the perceived usefulness and the improvements in job performance and effectiveness observed during the evaluation.

Firstly, the example shows the common process associated to the assessment of a patient, followed by the creation of an IIP by merging and tailoring several FIPs according to the diverse syndromes of the patient. Secondly, it explains how actors may update their profile by modifying their personal sub-APOs. Finally, the system enacts the IIP by coordinating the execution of the different agents and corresponding actors in a transparent manner, and taking into account the—potentially tailored—actor's responsibilities, duties and permissions.

It is important to note that the definition of IIPs was carried out by real healthcare personnel in a real organization and dealing with real medical data. For privacy issues, real actors are presented with fictitious names. The patient is Mr. Rigate, an 84 years old Italian man. He has recently suffered a hip fracture from which he is recovering and he remains immobilized and bed ridden. During a periodical visit of his family doctor, Dr. Pennette, he diagnoses a Decubitus Ulcer produced by the long term stay in bed. Due to the age and the multiple conditions of Mr. Rigate, the FD decides to incorporate the patient into the K4Care platform to execute a personalized HC treatment.

5.1 Patient assessment and IIP construction

When Mr. Rigate is registered into the system by the FD, his corresponding Actor Agent is automatically created and the medical record is initialized and stored. The system automatically creates an Evaluation Unit (EU) which is assigned to Mr. Rigate by incorporating the appropriate professional roles found in the system, automatically (in the case of stable members) or contacting actors in a proactive manner (in the case of additional care givers). This is done transparently by means of communicating with their adequate actor agents (which act in behalf of the real actor in case of simple administrative actions) according to their profiles modeled in the corresponding APOs. This saves a considerable amount of work for the Head Nurse, who typically has to manually contact each professional in order to establish the EU. In this case, the EU includes his FD, Mr. Pennette, the PC, Ms. Perciatelli, the HN, Ms. Parma, and a SW selected by the HN, Ms. Granazza. After the constitution of the EU, the PC requests a comprehensive assessment of the patient by initiating the corresponding service through his web interface. As it has been said, the procedures of the services are represented in the SDA* notation so that they can be automatically managed by the agents, which proactively activate them and negotiate via inter-agent communication in order to assign them to appropriate actors according to their user profile. Again, the transparent action management process saves a considerable amount of administrative work and ensures the coherency of the service execution with respect to its formal definition and the skills and duties of each individual professional. In this case, the execution of the comprehensive assessment includes the following steps:

a. Evaluation of the level of impairment through different standard scales (K4Care 2006), an action which is automatically assigned to the PC, who receives an automatic alert through his web interface and the set of documents to be filled electronically as a result of the patient examination. The results, which are automatically stored in the system's EHR, indicate that the patient has a level of instrumental activities of daily living (IADL) of 0.3, a value in the Norton scale of 15, a Barthel ADL index of 3 and a mini-mental scale examination (MMSE) score of 15. Those are quite low values which indicate that the patient may suffer some kind of cognitive impairment.
b. Clinical assessment, an action consisting on evaluating the patient's EHR, which is also performed by the PC. The examination of Mr. Rigate's recent clinical history (automatically retrieved from his EHR when the action is activated), includes the mentioned hip fracture and also an intestinal obstruction, gallstone and bowel incontinence.
c. Physical examination of the patient, an action also carried out by the PC. After Mr. Rigate is examined, the PC fills the document shown in Fig. 9 (which is automatically presented by the system as a result of the action assignment and execution) with the following data: Blood pressure: 110/65, heart rate: 56, respiration rate: 15, weight: 70 kg, height: 167 cm and body mass index: 25. In particular, the examination confirms the presence of a grade-3 pressure ulcer and the PC reports its characteristics in the document.
d. Social needs and social network assessment. This action is automatically assigned to the SW of the patient's Evaluation Unit. She analyses the social framework of the patient through a standard social assessment scale which is automatically

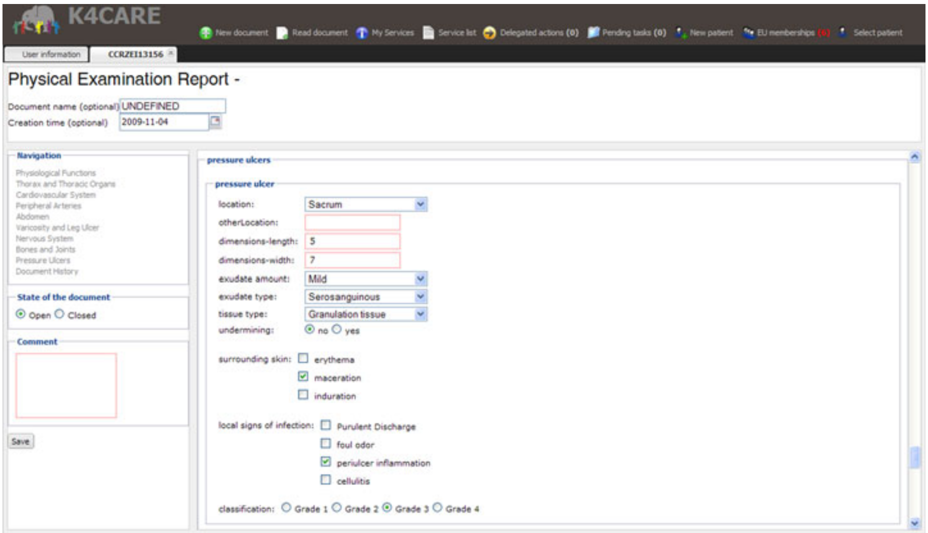

Fig. 9 Physical examination report filled by the PC

presented via the SW's web interface. The patient is married, he reached a primary school study level, he was previously employed, he has low income (<1000 Euros per month) and an old age pension, the income administration is performed by himself and he lives with his partner. The SW also identifies several obstacles at his home: step, stairs and danger of stumbling.

The execution of those actions results in the completion of several documents which are automatically stored into the patient's EHR. It is important to note that all data are retrieved, filled and stored electronically, substantially reducing the paper work involved in the patient assessment. All data are stored in XML standard format separating the useful information from its representation (which can be adapted to different views or formatting standards).

It is worth noting that, in order to execute the patient assessment (which was requested by the PC), a seamless coordination of several actors with different profiles has been performed. Individual actors proactively received alerts via their web interfaces for action assignments (according to their profiles and duties) and the whole standard service was executed in a transparent manner. Moreover, any actor, at any moment, can consult the context in which an assigned or delegated action is framed (*i.e.*, patient, service, expected workflow, associated documents, etc.).

At the end of the execution of the comprehensive assessment service, the EU has enough information to evaluate the patient and to propose a personalized treatment by constructing an IIP according to the co-morbidities observed in the patient. The platform assists the interactive creation of IIPs by providing the graphical editor introduced in Section 3 and the repository of standard FIPs covering the mentioned disorders. In this case, the PC initiates the creation of the IIP by executing the appropriate service and, after the examination of the patient's EHR stored in the platform and presented in the form of standard documents, requests the platform to retrieve the FIPs for the treatment of the Immobility syndrome, the management of Pressure Ulcers and for the treatment of Cognitive Impairment which are graphically and interactively presented. At this point he has to decide which parts of the FIPs should be included in the final IIP and how they should be combined in order to deal with the patient's conditions. This is done by means of the mentioned graphical editor which eases the reuse of standard protocols (complete or partial FIPs) and, at the same time, checks and ensures the coherency of the final structure (*i.e.* if it is executable according to the defined workflow, involved actions and actor responsibilities). This facilitates the task to the users, saves time and reduces the amount of mistakes. As stated in Section 3, this is possible thanks to the wizard-like edition of SDA structures and the exploitation of the organizational information contained in the APO.

We would like to stress the convenience of this tool which, on one hand, enables the immediate and seamless reuse and adoption of standard suitable care workflows (FIPs) according to the patient conditions and, on the other hand, allows a high degree of flexibility in adapting workflows to his/her co-morbidities while transparently maintaining the coherence of the resulting structure with regards to the medical organization in which it will be executed.

Figure 10 shows in different colors the parts of the three FIPs that have been selected for the final IIP. In particular, for the Immobility FIP, the Malnutrition part has been discarded, since it is not applicable to this patient. The Pressure Ulcers condition is linked to the appropriate treatment suggested by the second

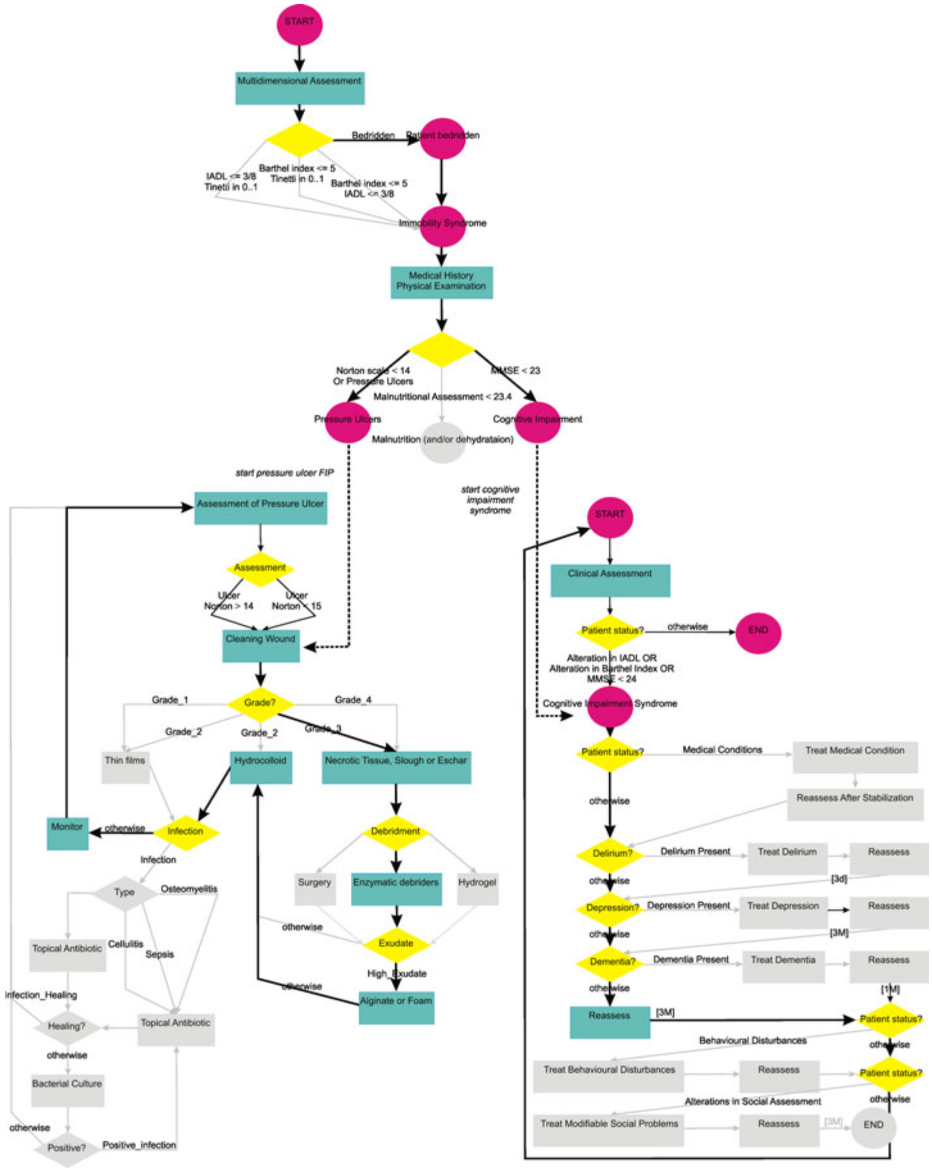

Fig. 10 FIPs and interrelations indicated by the FD for the co-morbidities observed for the patient. FIPs of Immobility syndrome (*top*), Pressure Ulcers (*left*) and Cognitive Impairment (*right*)

FIP, concretely to those actions related to the treatment of Grade 3 Pressure Ulcers (discarding the rest of possible Grades). Finally, for the Cognitive Impairment syndrome, since the Comprehensive Assessment has already given the results of the tests indicated in the FIP, the appropriate branch is selected.

As a result of the edition process of the selected parts of the FIPs, the IIP shown in Fig. 11 is obtained. This IIP indicates the personalized treatment for Mr. Rigate

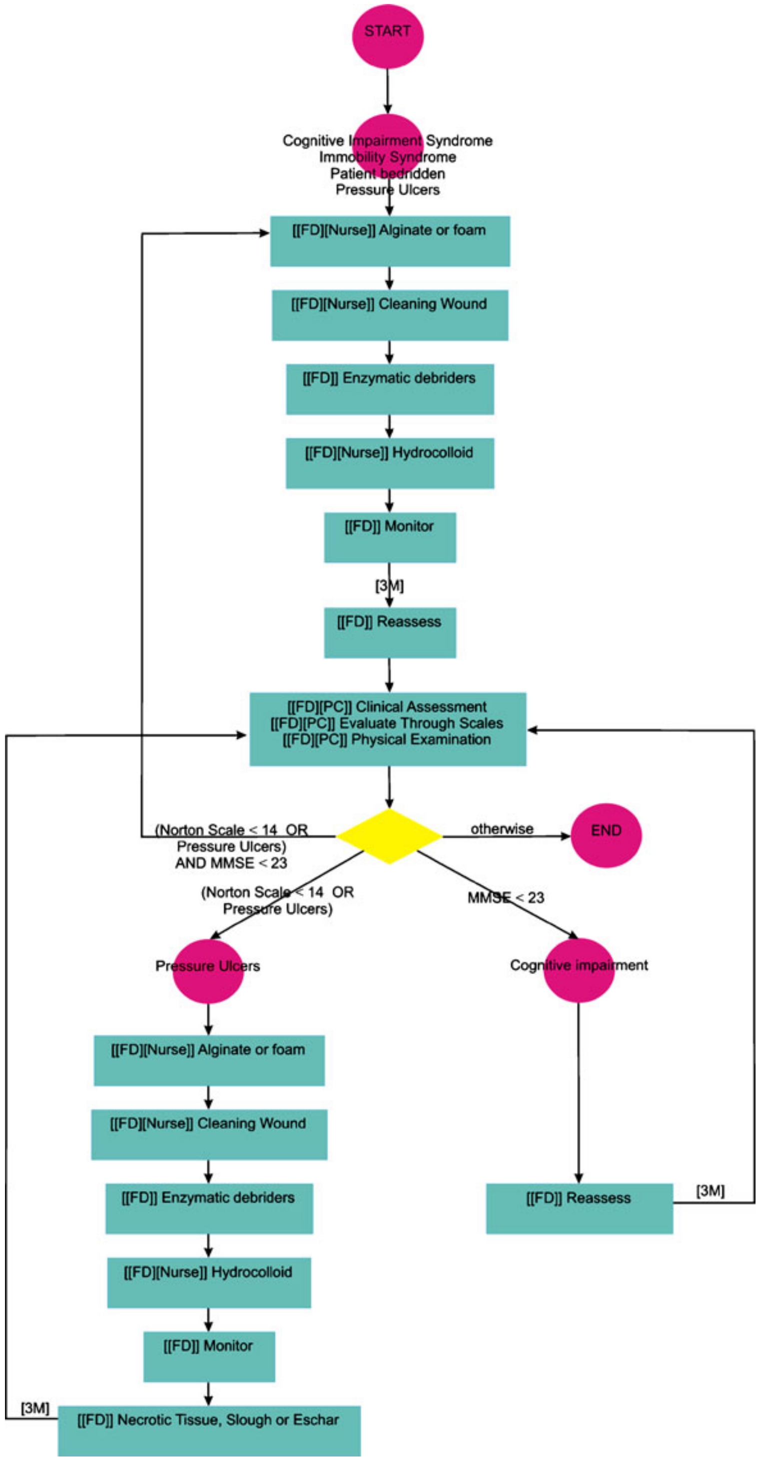

Fig. 11 IIP from the edition and merging of the three FIPs

according to his personal conditions. This is a simplified version of the union of the three FIPs, which has been tailored according to the results of the HC assessment. The IIP also reflects that the PC has decided to reassess the patient's Cognitive Impairment after 3 months. After this re-examination, three states are possible: Mr. Rigate still suffers from both conditions (in this case the whole treatment is re-executed), suffers only one of them (in this case, only condition-related actions are re-executed) or none of them (the IIP ends). Once the IIP is created and validated by the EU, it is stored in the patient's EHR.

5.2 Actor profile tailoring

Regarding the personalization of professional's profiles, let us consider that Mr. Pennette, the Family Doctor, is very busy due to an increase of hospitalizations in the last two days and decides not to perform Nursing actions during one week. As stated in Section 3.2, the K4Care platform provides him the possibility (via the ATAPO tool) of sending a request for removing all the Nursing actions from his profile. The PC, who is the responsible of the care unit, must authorize this change in the actor liabilities, according to the availability of nurses to perform those medical activities. This is informed by means of a proactive alert in the PC's web interface. In this case, all the nurses are currently working (none is sick or on vacation) and there is enough task force to deal with the nursing actions without Mr. Pennette. Following the tailoring protocol, the PC gives the authorization to this petition and the necessary modifications in the sub-APO of Mr. Pennette are stored, seamlessly incorporating those changes in the daily workflow (*e.g.* during action assignment negotiation). In the future, when the situation finishes and the FD is able to deal with some Nursing actions, he will use the ATAPO tool to change again his profile.

This personalization tool, which permits the modification of the duties of some actors with the consent of the Physician in Charge, was considered very valuable by the professionals participating in the K4Care Project, because it permits to have a strict control of the modifications of activities requested by the personnel at any moment, allowing a correct distribution of tasks. Having this tool available on the personal computer also saves time to the users that require some change in their activities, as well as to the Physician in Charge that automatically receives all the petitions made by the personnel in a centralized way. Moreover, it is worth to note that when a change is authorized, the involved user (*e.g.* Mr. Pennette) is automatically relieved of these activities (*i.e.* nursing actions). In case that the personalization involves the access to some documents, the authorization of the PC automatically activates the access to the new information and it becomes immediately available to the user in his/her personal computer. This is illustrated in the next section.

5.3 IIP execution

As stated in Section 3, the K4Care multi-agent system assists the semi-supervised enactment of IIPs using the organizational workflow stored in the general APO as well as the tailored sub-APOs. In the same manner as for the administrative or patient assessment services, the system is in charge of the coherent execution of the IIP care flow, appropriately assigning actions to suitable professionals according to their profiles, proactively presenting documents to be filled and transparently retrieving and storing data associated to the patient's EHR. The care workflow is also carefully followed according to what has been stated in the IIP, adapting the execution according to possible temporal restrictions stated in the SDA* structure (*e.g.*, delaying the assignment of actions or repeating them until a condition is fulfilled). Professionals are contacted when necessary via alerts shown on their web interfaces.

In this case, the PC initiates the process by requesting the execution of the IIP for the patient Mr. Rigate. The system retrieves the current IIP from the patient's EHR and dynamically creates an agent which will be in charge of parsing the IIP's SDA* structure. Following the workflow presented in Fig. 11, the first executable step consists on applying Alginate to the pressure ulcer. The IIP indicates that this action should be executed either by the FD of the EU or by a Nurse. At this point, the system automatically contacts the Actor Agent of Dr. Pennette's (FD) to ask if he is able to do the action. Then, his sub-APO is consulted, since it contains the up-to-date information about his customized profile in the present moment. Dr. Pennette has requested to remove nursing activities from his responsibilities, a circumstance which is represented in this sub-APO. In consequence, Dr. Pennette's agent automatically refuses the execution of this action.

As nurses are also skilled to execute the action, the system proceeds to contact all the nurses to check their availability. As none of them have requested a tailoring in their duties, all of them are able to execute the action. The HN is requested to select a concrete Nurse to execute the action. When Ms. Parma (HN) logs into the system, an Actor Assignment action is requested pro-actively by the system and the list of available nurses is shown. After the selection, the system delegates the action execution to Ms. Mira, so that this Nurse will see the pending action in the web interface when she logs in. Ms Mira has to confirm the assignment in the system and to perform the action in order to continue with the IIP enactment.

At the first examination by Ms. Mira, she notices an unusual blood stain. So, she decides to ask permission to read the INR[1] reports of Mr. Rigate, which are not part of the EHR documents she has access to by default. Similarly to the FD, she uses the ATAPO tool to send the request. Then, the PC authorizes it and the change is incorporated in her sub-APO. As a result, Ms. Mira will immediately see the new document on the list of readable ones (according to the new permissions stored in her sub-APO). Once she has checked that there is not any abnormal value in the last INR report, she proceeds to apply the Alignate dressing.

The IIP execution continues with the subsequent actions: Cleaning the Wound (delegated to the same Nurse), Enzymatic Debriders (assigned to the FD) and Hydrocolloid (again performed by Ms. Mira).

At this point, the treatment for Grade 3 Pressure Ulcers finishes. Then, as stated in the IIP, the patient should be reassessed after three months. In order to introduce this temporal constraint, the system stores the IIP execution state and the agent in charge of the SDA execution suspends its execution by introducing a timer for that period of time. When the period expires, the agent awakes and the next action (Reassess) is processed and delegated.

[1] INR (International Normalized Ratio) measures the time it takes for blood to clot and compares it to an average.

After that, the patient is evaluated again through scales and a new physical examination is performed. For each action, new documents are filled out and the patient's EHR is updated. In this case, the patient has progressed positively from his hip fracture and, as a result, his mobility has improved, and his pressure ulcer has been cured. His anomalous mental stated has also improved thanks to the good physical progression, resulting in a MMSE of 25 and a Norton Scale of 15. According to the evidences acquired from the patient, the PC should evaluate if he still suffers from both conditions, one of them or none of them. This is performed when the decision node is reached. The system presents to the PC via the Web interface the possible answers to the decision, according to the values of the scale and/or the presence of Pressure Ulcers. It also presents the appropriate documents (scales, clinical history and physical report) from the patient's EHR in order to take an informed decision. In this case, the PC decides that the patient has been cured and the IIP execution ends.

The execution of this care flow illustrates how the overhead of administrative and management activities is significantly reduced as they are transparently handled by the system. As a result, professionals can focus on care delivery and medical activities. Scheduling and negotiation between professionals are also automatized and coherently performed according to actor's profiles. Coordination between professionals is also ensured in the context of the patient's EU which is maintained through the care delivery and avoids requesting and contacting individual actors for each new action.

From the point of view of the final user, the knowledge-driven access to the system via a profile-oriented Web interface eases the interaction, adapting the view to what the actor is able to do. It also allows a remote access to electronic data (according to the permissions of each user) facilitating service management and coordination among the different actors involved in HC. Moreover, a high degree of flexibility is supported allowing seamless changes in professional profiles which are immediately incorporated into the system allowing temporal access to privileged data or delegation of duties if necessary.

6 Related work

As described in the previous sections, one of the basic aspects in the design and implementation of the K4Care system has been the explicitness of the medical and organizational knowledge required in Home Care. This technical decision, hardly common in the systems developed in this domain, provides many advantages, not only in general terms (modularity, reusability, adaptability to different settings) but also in the feasibility of implementing methods that allow to customize the health care both from the patients and the professionals points of view. In particular, in this paper we have focused in two main issues: the use of personal, medical and organizational knowledge to ease the manual expert integration of a set of Formal Intervention Plans into an Individual Intervention Plan, and the personalized management of organizational knowledge to allow practitioners to adapt the clinical workflow to their daily needs. This section describes some previous works related to the design and execution of individual treatments (especially in the case of co-morbid patients) and to the tailoring of different kinds of systems through the exploitation of user profiles, commenting their main differences with our work.

6.1 Personalized treatments

Clinical guidelines usually focus on the treatment of a single disease, and several research groups have constructed systems that help to automate the execution of a particular guideline on a specific patient (a recent comprehensive survey of this field may be found in Isern and Moreno 2008). These state-of-the-art systems basically aim to support the practitioners to follow a single particular predefined guideline, and their design is usually closed and targeted towards their integration with existing Hospital Information Systems (HIS). However, none of them considers neither the problem of applying different guidelines to comorbid patients, nor the feasibility of introducing mechanisms to customize the daily care provision according to the medical practitioner's dynamic needs. These systems seldom manage organizational knowledge, as they leave this issue to the HIS in which they are embedded.

The guideline-based treatment of patients is much harder when they present co-morbid conditions, because of the multiple interactions that may occur between them (Fox et al. 2009). For instance, Boyd et al. (2005) show, in an example in which nine guidelines are applied, some of the problems that could appear (interaction between a medication and a disease different from the one for which it was prescribed, incompatibility between medications, repetition of tests, etc.). That article suggests the design of guidelines that consider the most common combinations of diseases, although it would probably be very complex to set up appropriate randomized clinical trials to analyze a large number of potential combinations. In our view, it is probably more viable to explicit the medical knowledge related to each pathology and to design systems that can analyze and present this information to the medical practitioners, so that the computerized systems can assist them in the decision on how to merge the different recommendations depending on the particular physical, social and medical characteristics of the patient. Tinetti et al. (2004) also comment the difficulty of guideline-based treatments of co-morbid patients, and suggest the idea of using information technologies to help the doctors reach an equilibrium between the medications given to the patient and both their potential risk of interactions and the preferences of the patient. In a recent paper, Shaneyfelt and Centor (2009) advocate the use of more flexible guidelines, that give recommendations based on co-morbidities, the characteristics of the health center and the patient's preferences. In our opinion, the design of this kind of guidelines would ease the fusion of different guidelines and their personalization. However, current guidelines lack this flexibility.

In the Computer Science field there have been some researchers that have started to propose in the last years computational methods to coordinate the application of the clinical guidelines corresponding to the individual diseases of a patient. Some of the most interesting proposals are commented and compared with our own in the following paragraphs.

In Abidi and Abidi (2009) and Daniyal et al. (2009) the authors propose a method to merge clinical pathways of co-morbidities, in which a strong collaboration with medical experts is needed. They emphasize the importance of merging pathways at the *knowledge* level, by establishing a conceptual mapping between the concepts common to different clinical pathways. Unlike in the approach described in this paper, they do not construct a whole treatment considering all the guidelines applicable to a patient before starting its execution. It has to be taken into account that home care usually involves long-term treatments, and doctors in this field find more appropriate to define a detailed long-term plan of action rather than reacting to daily events (which is very difficult, since the patient may not be hospitalized and is not being continuously monitored). Therefore, a reactive approach at execution time, like the ones proposed by these authors, is not convenient in the HC setting. Moreover, in these works there is not any explicit definition of the (non-medical) organizational aspects of each institution; therefore, they do not have the possibility to customize this knowledge to fit the dynamic requirements of the medical personnel.

Georg et al. (2004) built a decision support system that intends to help practitioners in the management of co-morbid patients, using a rule-based codification of guidelines. When a patient is being treated, a forward-chaining inference engine detects the applicable rules and studies the recommendations they make. There is a dynamic "synthesis" of the recommendations generated by the active rules, which can be merged (to avoid redundancies) or eliminated (to avoid incoherencies). There is not any mention of the organizational aspects or any attempt to personalize the delivery of the care according to the human and material resources available in the medical center. Weizi et al. (2009) follow a similar approach. They codify many different forms of knowledge (clinical pathways, medical knowledge, hospital resources, and patient preferences) into *norms*. A norm-based agent is continuously monitoring the evolution of the patient, applying the norms (as if they were rules) and suggesting to the doctor the treatment to use This system stores the medical and organizational knowledge in an explicit knowledge structure, as in our system; however, there is a hard work to construct this rule-based structure, since the system developers have to make previously a manual and costly semantic analysis and norm analysis. Thus, any change in this structure would have to be carefully supervised by the developers, and could hardly be made at run-time. In our case there is a simple tool that can be used by practitioners to customize their use of the system, and the medical and organizational ontologies are simple enough to be directly modifiable if necessary. As in the previous methodologies, both in Georg et al. (2004) and Weizi et al. (2009) the fusion of guidelines is made on-line, not before the start of the care, which makes them unsuitable in the Home Care setting.

In summary, there are already some decision support systems that recommend to the medical practitioners the actions to be applied on patients with several pathologies, but most of these systems are not flexible enough to provide customization services to the doctors. Moreover, with respect to the workflow of the patients' treatment, these systems work reactively at execution time, and cannot be used in Home Care where the main need is the construction of a personalized long-term care plan before starting its application.

6.2 Tailored user profiles

Personalizing a system consists on providing mechanisms that permit it to behave differently for each user. This is usually done by building user profiles (Schiaffino and Amandi 2009). The role of the user profile depends on the purpose of the system. There are several fields that have a tradition in building personalized tools. For instance, in intelligent tutoring systems the user profile is a student model that guides the learning process, in e-commerce applications the customer profile permits to make personalized offers, and in recommender systems the profile contains ratings for items, like movies or news. However, healthcare delivery has been rarely personalized adapting the behavior of the system to the characteristics of the healthcare organization and to the people needs. An example of the exploitation of user profiles is HeCase2, an agent-based system that provides basic medical services (Isern 2009), including tools for assisting the doctor in the application of a guideline. In that system each patient is represented by a User Agent that keeps, among other personal data, a personal profile that contains the preferences of the user with respect to medical centers or doctors. This information is only used to personalize the communication with the user (Isern et al. 2006).

In this section we review different types of user profiles and the usual techniques used in their tailoring, commenting their applicability for the case of HC. The basic representation formalism of the user' interests is by means of keyword-based models, as it is done in HeCaSe2. However, a more powerful representation of the user profile is through topic hierarchies or ontologies (Schiaffino and Amandi 2009). Ontological user profiles have been mainly used for information retrieval. In Anand et al. (2007), an ontological profile is employed for user recommendation in the Web (shopping, movies, etc.). The profile is a representation of the visits in terms of the ontology concepts. In Sieg et al. (2007), the personal ontology represents the user context for search. This individual ontology is annotated with interest scores for each concept, which are gradually modified based on the searches performed by the user. In a similar approach, Shen et al. (2005) propose that the scores in the user's ontology are calculated from the click-through history. Those scores can also be used to tag the relations between the concepts, in addition to the concepts themselves, as it is explained in Jiang and Tan (2009). In this work, the ontological user profile is treated as a semantic network and the interest scores are updated based on activation values, which are propagated through the network by means of the relations between concepts. In Sendhilkumar and Geetha (2008) the concepts of the user ontology have two components, the user interest and the set of relevant pages that have been visited. Going a step further, in Partarakis et al. (2009) it is defined an architecture for a development framework that supports the creation of adaptive Web User Interfaces based on ontologies describing the user profile (disability, Web familiarity, language, etc.), context profile (Input–Output devices, screen capabilities, etc.) and user interaction (monitoring user actions, user navigation paths, etc.).

In those papers, the user profile ontology is a copy of some reference ontology, which is customized by means of personal interest scores. They do not change the structure (concepts or relations) of the ontology as it is done in the tailoring method explained in this paper. For this reason, those approaches are not appropriate for the modifications of the organizational structure (*i.e.* permission relations, duties assignments) that are required to adapt the behavior of the Health Care system as it is proposed in this paper.

There are other approaches that create a new ontology for each user. In Seidenberg and Rector (2006) a basic segmentation algorithm is proposed to extract a partial view of a large ontology. The algorithm starts with one or more classes of the user's choice and creates an extract based around those and related concepts. In Bhatt et al. (2010) and Flahive et al. (2009) the MOVE system (Materialised Ontology View Extraction) for deriving semantically correct and independent sub-ontologies is presented. These sub-ontologies, which can be customized in order to represent the user's area of interest, are used for improving the effectiveness of information retrieval in specific medical information systems. In MOVE, the user attaches labels to the elements of the ontology in which he/she is interested. The labeled elements are the candidates to belong to the sub-ontology. Before building the ontology, the necessary actions to ensure the completeness and validity of the resulting sub-ontology are done. Then, the user can extend the sub-ontology with new elements to include new features (Flahive et al. 2009). In this approach the degree of freedom in the ontology customization is large because the user makes the selections of each individual item. Then, different verification algorithms are presented to check the consistency of the ontology obtained from this selection. This approach is not adequate for health care applications, where the liabilities and competencies of the medical personnel are well established and the general organizational rules must be followed.

Another approach consists in defining a specific ontology for representing the user profile. In Naudet et al. (2008) a user-profile ontology is used to recommend mobile TV. The ontology includes concepts such as person, role, interest, preferences and usage history. The data provided by the user at the explicit profiling phase is taken as a starting point. Then, in an implicit way, the update of the profile data is done by further analyzing the usage traces. In Brambilla and Tziviskou (2008), the ontology contains a main concept "user", which is linked to the rest of concepts by means of special relations. For instance, the relation *prefers* expresses the objects of interest for the user in the application domain ontology and the relation *requests* expresses the objects of the domain ontology requested by the user. The work in Katifori et al. (2007) presents an extendable ontology for modeling user profiles created with the purpose of being adaptable to the needs of every application, maintaining at the same time a general common structure in order to satisfy portability and communication between different applications. In this approach the system starts with a very simple ontology and powerful tools are designed to complete it with the preferences of the user without many restrictions. Again, this approach is more appropriate for domains where the user needs large freedom to build a personal profile; this is not the case of the application studied in this paper.

In short, the use of ontologies for user profiling is increasing. There are mainly three approaches to ontology personalization: the labeling of a reference ontology with interest scores, the extraction of sub-ontologies that can be personalized with new elements, and the definition of specific ontologies to manage the concepts of a personalization system. Some of these techniques have been applied to medical information systems, but they have focused basically on improving the information retrieval tasks. As far as we know, there are no attempts to use personalized ontologies for adapting the healthcare delivery organization and execution as the one presented in this paper does. As it can be seen, in those approaches the concept of authorization of the tailoring does not exist because it does not make sense in those fields of application. The method presented in this paper differs from the existing literature mainly in the fact that the process of customization is done in a controlled way, also introducing the issue of handling temporal profile adaptations.

7 Conclusions and future work

The automation of Home Care services presents many technological challenges. Among them, the most relevant ones are the following:

- A large amount of medical, social, organizational and procedural knowledge has to be properly represented and taken into account in the system. Moreover, most of this knowledge depends on the particular institution that has to deliver the care.
- In Home Care the co-morbidity of patients is the rule, rather than the exception. Therefore, a set of pathologies have to be addressed at the same time, and applying standard clinical practice guidelines is far from straightforward.
- Home Care assistance is given by a set of heterogeneous professionals from different organizations, which have the difficult task of defining a treatment, coordinating their efforts, sharing information and applying their skills and abilities to offer the best possible care without having many occasions of actually meeting in a physical place. Moreover, the work environment is very dynamic, and computerised support systems in this area have to offer enough flexibility to adapt their behavior easily to the continuous changes in workflow requirements of the care professionals.

The design and implementation of the K4Care system has addressed all these issues. Concerning the first one, all the knowledge needed in the system has been explicitly represented (using databases, electronic health records, ontologies and knowledge repositories), rather than hardwired in the code (a detailed account of these knowledge structures was out of the scope of this paper, but may be found in Isern et al. 2010). This knowledge-driven design decision is crucial for the personalization of the system's interaction and the care delivery, since it permits the system to adapt its behavior dynamically depending on the available knowledge, on the daily workflow of activities, on the personal requirements and needs of the medical practitioners and on the resources available at each medical centre. That makes K4Care flexible enough to be applicable in institutions or countries with very diverse ways of delivering Home Care. Even though the decoupling of the knowledge layer and the execution layer may look just like a standard good practice in software engineering, the analysis of similar systems in e-health (see Section 6.1) shows that it is certainly not the standard practice in this field; therefore, one of the original points of the K4Care design and implementation is to actually show in a practical complex problem the many advantages derived from this kind of design (modularity, flexibility, immediate reaction to dynamic changes, reusability, etc.).

In this paper, we have particularly focused on the tools that permit the adaptation of general knowledge models to cope both with co-morbid patients and with heterogeneous professionals and organizations.

Regarding the issue of co-morbidity, the system facilitates to the Evaluation Unit of each patient the definition of a fully personalized and customized Individual Intervention Plan. Care professionals are provided with the appropriate data to take into account not only the personal (medical and social) information of the patient, but also the international recommendations provided by the guidelines associated to the patient's pathologies (Formal Intervention Plans) and the resources and mechanisms of work of the actual medical organization in which the care is framed. As a result, the

Individual Intervention Plan construction is highly assisted by the system, providing the required medical knowledge and transparently ensuring its coherence from the organizational point of view. The obtained care flows based on a standard notation result in unambiguous treatment which can be coherently delivered according to the organization of the medical center. Therefore, the K4Care system offers to the heterogeneous members of the Evaluation Unit a very efficient, effective and convenient way of deciding the treatment to apply to each particular patient, without them having to physically meet to have access to the assessment results obtained by each of them. It is also worth noting that the K4Care platform (in particular, the multi-agent system) is in charge of the actual coordination at run-time between the healthcare professionals to execute the different steps in the personalized treatments, saving the practitioners from having to waste time and energy in tasks like assigning actions to be done, confirming the willingness to perform an action, searching for the personal or medical data of the patient, remembering the document to be filled after each action, etc. A detailed description of the agent-based enactment of IIPs may be found in Isern et al. (2010).

From the administrative perspective, the K4Care platform also offers the possibility of tailoring the profile of each particular professional at any time, since each actor can decide (with the appropriate authorization of the person in charge of the Home Care Unit) which actions he/she can perform or which documents he/she may access. This functionality is particularly important, since it is well known that medical practitioners often show a great reluctance to the adoption of technological tools, because of their steep learning curve and their difficult inclusion in the daily work procedures. Therefore, it is of paramount importance to define and implement systems that overcome these barriers and with which doctors feel comfortable. In this sense, APO tailoring offers a very flexible and easy to use mechanism that is seamlessly integrated within the IIP execution, allowing doctors to dynamically adapt their work to their particular circumstances, needs and preferences. As commented in Section 6, this tailoring mechanism is not included in any of the state-of-the-art systems on clinical guideline enactment (Isern and Moreno 2008), because they mostly assume that the organizational aspects are covered by external Hospital Information Systems. One of the original ideas of our work is to consider these aspects as essential in the management of Home Care processes, and to include them explicitly in the design of the system from the very beginning. One of the important lessons learnt from the K4Care experience is that the management of the human and material resources available in a medical centre is as important as the management of medical knowledge if the aim is to provide an efficient healthcare service in the complex setting of Home Care.

The main direct users of the K4Care system are the practitioners that are supported in the definition and execution of personalized care plans. However, it may also be argued that patients, as final recipients of the care, also receive indirectly the advantages of using the system: they receive a personalized treatment based on standard care flows, administrative errors are minimized, practitioners can expend more time for care delivery as they don't have to waste time searching for the patient's data or coordinating their activities with other members of the care team, all the activities performed on the patient are properly documented and stored for further reference, the results of any test or procedure performed on the patient are immediately available to all the people involved in the care, etc.

A very important aspect of the K4Care system presented in this paper is its dynamicity. All the personalization procedures (construction of an IIP, tailoring of an individual APO) are done in execution time and the system's behavior and workflow are automatically adapted to the medical and administrative knowledge in a seamless manner. The use of a multi-agent system, embedded within a Web-accessible platform, permits to support—effectively, efficiently and in a very flexible way, as proven empirically by the results of the validation in a real environment shown in Section 4—the distributed coordination and information sharing between the medical professionals involved in all the steps of the Home Care delivery.

In summary, the adoption of a knowledge-driven design that can be customized to the particular characteristics of the users (both patients and medical professionals) is the key to guarantee the adaptability of the system to the daily needs that appear when Home Care is delivered to particular patients with specific conditions in the scope of a medical organization. The possibility of personalizing the system, together with usability and security aspects, plays a crucial role in the professional and social acceptance of this kind of software tools.

To wrap up the conclusions, it can be argued that K4Care provides to the professionals involved in Home Care a number of benefits in their daily workflow with respect to other systems related to automated guideline execution or user profile tailoring:

- The great flexibility and adaptability of the system, both from the static point of view (the knowledge sources permit the precise definition of the medical, organizational, procedural and social knowledge to be used in a particular instantiation of the system) and the dynamic point of view (the definition of the personalized treatment of each patient and the customization of the practitioners' activities are integrated within the system and are performed at execution time).
- The members of the Evaluation Unit of a patient are given a web-accessible platform from which they can easily access all the knowledge needed to define the Individual Intervention Plan of a patient. Moreover, the platform acts as a decision support tool that facilitates both the reuse of general medical knowledge (expressed in the form of Formal Intervention Plans) and the construction of customized individual treatments, for instance ensuring their coherence with the available human resources and minimizing the possibility of making mistakes in their definition.
- Although it was not one of the aims of this paper, the agent-based coordination (Isern and Moreno 2008) ensures an efficient execution of each of the actions of the IIPs and administrative procedures, constantly monitoring the fulfillment of each action and its proper documentation, automating the assignment of actions to actors according to the available staff and their workload, and thereby speeding the whole care process and ensuring that management errors are not committed (e.g. documents related to performed actions are not missing, actions are not repeated, actions are not left to be executed because no one has been assigned to them, etc.).

Concerning the future work, and following the ideas of Tinetti et al. (2004), we believe that a system with such a vast amount of medical, procedural and organizational knowledge such as K4Care could be even more helpful to the doctors when they are constructing an Individual Intervention Plan. Of course, in a medical domain the responsibility of the definition of a treatment should always be on the human side, so doctors cannot and should not be taken out of the loop; we are referring to aspects that can be easily checked by an algorithm and that can be reported to doctors so that the construction of the IIP is made faster and easier, and some errors are avoided. For instance, the system could check if a medical test appears in different FIPs (to avoid repetitions), or could check, with the assistance of the medical knowledge stored in the CPO, if the medications recommended in two FIPs are incompatible. Some of the ideas of the work from Abidi (2008) reported in the previous section, concerning the syntactic, terminological and conceptual mapping between treatments, could be applied in K4Care. It is worth mentioning that within the K4Care project there were some preliminary ideas on the semi-automatic merging of clinical guidelines that could be applied in future versions of the system. For instance, Real and Riaño (2008) proposed the sketch of an algorithm for automatically merging SDA* clinical algorithms, which could be integrated in the IIP editor. In another example, Isern et al. (2008) proposed the formal analysis of the entry points of a set of Formal Intervention Plans to guide the definition of the entry points of the resulting Individual Intervention Plan.

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