An Ontology for the Care of the Elder at Home (Full version)

David Riaño, MSc, PhD[1], Francis Real, MSc[1], Fabio Campana, MD, PhD[2], Sara Ercolani, MD[3], Roberta Annicchiarico, MD, PdD[4]

[1]Research Group on Artificial Intelligence, Rovira i Virgili University, Tarragona, Spain
[2]CAD RM B, Rome, Italy
[3]Department of Geriatrics, University of Perugia, Perugia, Italy
[4]IRCCS S. Lucia, Rome, Italy

Abstract. The care of the elder at home is highly demanded in modern societies. It is based on the difficult task of coordinating multiple professionals and procedures acting on the same patient. K4CARE is a project aiming at implementing and testing a technology-based incremental and adaptable model to assist health care systems in home care. One of the key components of this model is the Case Profile Ontology (CPO) that is used to support the activities in the life-cycle of home care. These activities define a path that goes from assessing the problem to deploying a care plan. Along this path several CPO-based tools have been implemented to ease the assessment step, to manage care plans as State-Decision-Action diagrams, to combine care plans for comorbid patients, and to personalize care plans. The use of these tools significantly reduces the complexity of dealing with patients at home.

1 INTRODUCTION

K4CARE (www.k4care.net) is the join effort of thirteen European institutional partners to construct a technology-based model for the care of the elder at home that could not only be deployed in European Health-Care Systems, but also be adapted to other Health-Care Systems worldwide. This construction is divided into three consecutive steps: propose an adaptable model, develop the technologies and computer-based tools to implement the model, and validate the model in the health care system of the town of Pollenza, Italy.

The health-care model [1] is defined to have two dimensions: human resources and services. Human resources concern the *actors* involved in the care of patients at home: health-care professionals, social assistants, care providers, patients, relatives, etc.; and the *actions* these actors are allowed to perform in the model. The dimension of services defines the *services* that the health-care model is able to offer to the final users (i.e., actors). Each service is represented by a *procedure* which is the formal representation of how one or more actions provided by actors are combined to implement that service. Actions can be related to *documents*. Read-only access to documents is also possible during the execution of actions. These are the structured forms in which actors register the data that are required or produced during the performance of actions. This model is formalized in what is called the Agent Profile Ontology (APO) [2, 3].

This health-care model is *incremental* in the sense that actors, actions, services, procedures, and documents are organized in modules that can be combined into greater modules. K4CARE has a basic module called Home Care Nuclear Structure (HCNS) and an additional module on Rehabilitation. Additional modules are called Home Care Accessory Services (HCAS) and they can be developed and integrated into the model as plug-ins of the HCNS.

The model is also *adaptable* to the particularities of the Health-Care System it is given support to. This adaptation can be achieved with the redistribution of actions among the actors in the APO [2], and also with the redefinition of the K4CARE procedures with the *SDA Lab* tool [4, 6].

Besides the APO that is devoted to formalize the management issues of home care in a health-care system, K4CARE provides a Case Profile Ontology (CPO) that gathers, provides structure to, and relates the concepts required to assess, to diagnose, and to treat patients at home. Unlike the APO, this new ontology is not concerned with the management of patients at home, but with the clinical, medical and social levels of the treatment, exclusively. In K4CARE, the CPO is finally used to support home care decisions, and also to personalize the treatment of patients.

In this paper, we describe the Case Profile Ontology and how this ontology is used to provide support to health-care professionals (i.e., physicians, nurses, social workers, etc.) in the care of patients at home.

2 The Case Profile Ontology

The average home care patient is an elderly patient, with co-morbid conditions and diseases, cognitive and/or physical impairment, functional loss from multiple disabilities, and impaired self-dependency [1].

The care of this sort of patient requires complex health-care management policies to be integrated with expert supervision and online adaptation of the care plan to the patient evolving condition. In this sense, the American Medical Association (AMA) indicates that the management of home care patients is a function of the physician's skills in optimizing the patient's independence while utilizing medical and social resources to minimize the effects of illness and disability in the patient's daily life [7], according to an evolving care plan.

The *care plans*, together with the *assessment tools*, are the final components of the life-cycle in the management of home care patients. This *life-cycle* starts with the admission of the patient to the home care service. Then the patient condition is assessed in order to propose a care plan. This plan must be adapted to the medical and social particularities of that patient before it is performed and the results evaluated. Depending on the evaluation, the care plan can be adjusted or a new care plan proposed and the process repeated.

The Case Profile Ontology (CPO) whose root concepts are shown in figure 1 was conceived to support professional decisions in the life-cycle of home care treatments. It is based on the peripheral concepts of Problem Assessment (i.e., assessment tools) and Intervention (i.e., actions of the care plans), and how these two concepts are related

through intermediate (but relevant) concepts as Signs & Symptoms and Care Problems as Social Issues, Syndromes, or Diseases.

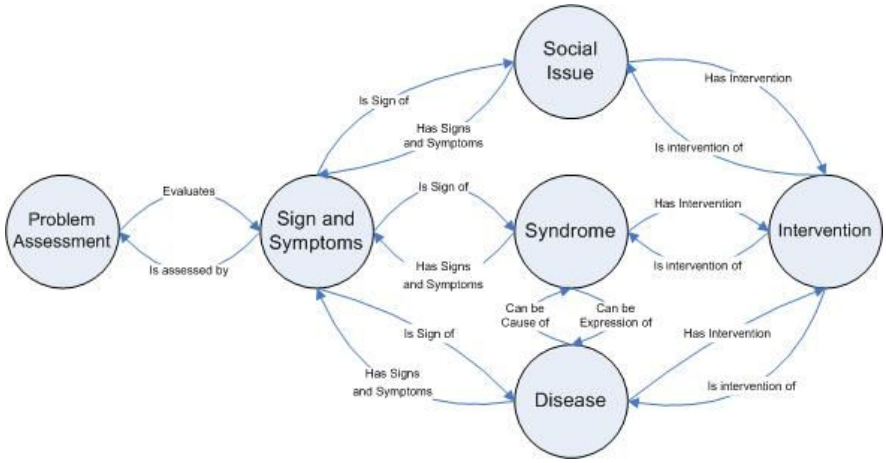

Fig. 1. Case Profile Ontology: main classes and properties.

Social Issues in the CPO comprise the concepts of lack of family support, low income, lack of social network, bad environment, and insanity. The concept Syndrome represents a complex health situation in which a combination of Signs and Symptoms co-occur more frequently than would be expected on the basis of chance alone, generating a functional decline. The CPO includes the syndromes of cognitive impairment [8, 9] and immobility [9, 10], and the diseases contained in figure 2 as explicit concepts.

The number of concepts in the CPO and their codification system are provided in table 1. Moreover, the ontology has other complementary concepts: 28 routes of administration and 177 ATC [11] codes for the pharmacological interventions, and 270 ICD10 [12] codes for the diseases.

	CODE	**CPO v3**
Disease	DIxx.x	21
Intervention	INxx.x.x	174
ProblemAssessment	several	214
SignAndSymptom	SSxx.xx	317
SocialIssue	SIxx	5
Syndrome	SYx.x	2
Remaining concepts	-	475
Total number of classes	-	**1,208**

Table 1. Number of classes of the CPO

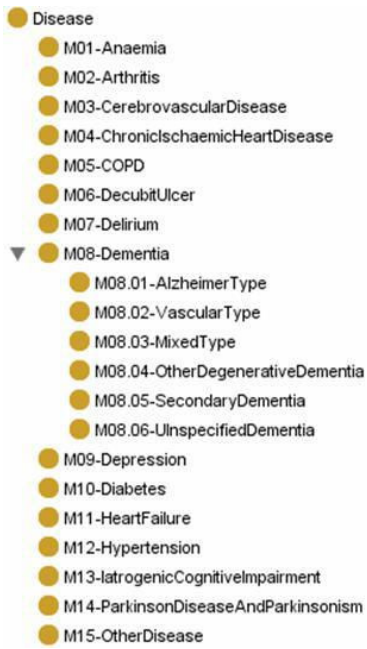

Fig. 2. Hierarchy of diseases in the CPO

We have developed this ontology in OWL [13] using the ontology manager Protégé [14].

Figure 1 also shows as arrows the properties that relate the concepts in the CPO. In the life-cycle of home care, these properties can be used to support the following sorts of health-care reasoning:

- *Forward reasoning*: Provided the assessments of some signs and symptoms of a patient, determine what are the feasible social issues, syndromes, and diseases (*isSignOf* property) of this patient, the set of interventions he or she requires (*hasIntervention* property), and the way they are applied (*hasFIP* property).
- *Backward reasoning*: Knowing the interventions a patient is receiving, determine the social issues, syndromes, and diseases of this patient (*isInterventionOf* property) and the signs and symptoms this patient should present (*hasSignsAndSymptoms* property), and finally get some recommendations on the appropriate assessments of the health and social conditions of this patient (*IsAssessedBy* property).
- *Inward reasoning*: Observing the diseases of a patient, foresee the possible syndromes the patient can develop (*CanBeCauseOf* property) and suggest proper interventions (*hasIntervention* property).

A relevant aspect of social issues, syndromes, and diseases is their datatype property *hasFIP* that is used to store a recommended Formal Intervention Plan to deal with these problems. A *Formal Intervention Plan* (FIP) is a computer-interpretable structure describing a care plan that relates signs, symptoms, social conditions, and secondary diseases with interventions.

There are several languages that can be used to represent FIPs: EON [15], GLIF [16], Prodigy [17], Proforma [18], SDA [4], etc. In K4CARE, FIPs are represented with the SDA language (see an example figure 3).

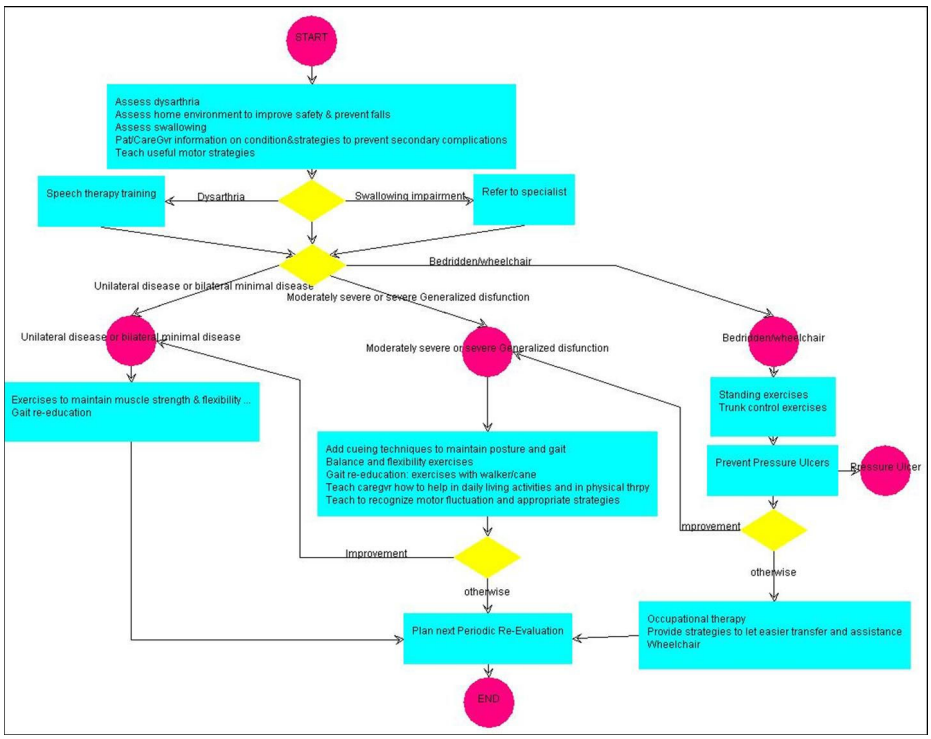

Fig. 3. FIP on Parkinson in the SDA formalism

SDA stands for State-Decision-Action which are the main elements that represent a formal intervention plan. *States* reflect the alternative conditions in which a patient can be incorporated in a treatment, each state acting as a starting point of different or alternative treatments. In figure 3, the arriving patient may start the treatment from the beginning (START state), or for example in state *Bedridden/wheelchair* if the patient has immobility problems. Different states represent different sorts of patients deserving different treatments, however the evolution of a patient over time may cause the treatment in the SDA to show an evolution from a state to another one and thus a change in the treatment, for example from the state wheelchair to the state moderately severe dysfunction.

Decisions are shown as yellow diamonds in the SDA and they capture the variabilities within the same treatment; for example, whether a referral to a specialist is required as a complement of the decided treatment. Finally, *actions* are the health care orders the FIP recommends in this point of the treatment of a patient.

Terminology in states is restricted to the instances and classes of the sort Signs and Symptoms, Social Issue, Syndrome, and Disease of the CPO in figure 1. Terminology in decisions is restricted to CPO instances and classes of the sort Signs and Symptoms. For actions, the terminology is taken from the set of instances and classes of the sort Problem Assessment, and Intervention in the CPO.

3 CPO-Based Problem Assessment

In the CPO, problem assessment comprises some aspects that assess the condition of the patient during the first encounter and whenever a re-evaluation is required. We distinguish between:

- Comprehensive assessment: It is devoted to detect the whole series of the patient diseases, conditions, and difficulties, from both the medical and the social perspectives. It comprises Multi-Dimensional Evaluation (MDE), Clinical Assessment (CA), Physical Examination (PhE) and Social needs and network assessment (SNN).
- Consultation: It is a referral to a specialist physician. E.g., neurologist or endocrinologist.
- Diagnostic Examination (DE): Process by which physicians evaluate an area of the subject's body that is not externally visible, seeking to diagnose. E.g., hearing test or EEG.
- Laboratory Analysis (LA): Examination of several parameters in patient's fluids as blood, urine, etc. E.g., glucose tolerance test or INR.

All these problem assessments in the CPO are reported in documents that are defined in the APO, as table 2 summarizes. As an immediate consequence, every time a sign or symptom is observed in a patient, the physician is advised to start one or several assessments, and the documents to support these assessments are retrieved from the Electronic Health-Care Record of the system [19] if they exist; otherwise, the physician is asked either to confirm the request of new tests or to perform those tests that he or she is allowed to perform (i.e., they are actions related to the physician in the APO).

Document Code	Document Name	#	Sort of Assessment
D10.x	MDE Scales	23	MDE
D12.x	Clinical History	2	CA
D13	PhE Report	65	PhE
D18	Social Report	4	SNN
D17	Consultation Report	6	Consultation
*	*	12	DE
**	**	64	LA

* still not available; ** some of them available

Table 2. APO documents reporting on the CPO problem assessments

4 Care Plan Configuration

Care plans (or FIPs) are represented as SDA [4] diagrams converted to XML notation. See, for example, the simplified FIP for the treatment of Parkinson Disease provided in the K4CARE project in figure 3.

SDA diagrams contain states, decisions and actions interconnected. These are described with state, decision, and action terms, respectively. All these terms must appear in the CPO as instances or subclasses of the different concepts represented in figure 1: Signs and Symptoms for state and decision terms; Social Issues, Syndromes, and Diseases for state terms; Problem Assessment and Intervention for action terms. The physician is allowed to extend these sets of terms enlarging the CPO.

SDA diagrams may incorporate two sort of time constraints [5]: micro- and macro-temporalities. *Micro-temporality* represents a constraint on the time range and frequency of an action term. That is to say, the time the action must start, the time the action must finish, and the frequency of application. For example, the order take 5 g of Levodopa starting in three days, until the next visit in two months, and twice a day (i.e., every 12 hours), would have a micro-temporality [3d, 2M, 12h].

Macro-temporality is the way to represent delays in SDA. The connectors between states, decisions, and actions can have either a minimal delay, a maximal delay or both. For example in the treatment of Parkinson Disease, if we want to express that once Levodopa is prescribed (in action 1) the effects must not be assessed (in action 2) before 40 days and no later than in 2 months, then the arrow connecting action 1 and action 2 must have a macro-temporality [40d, 2M].

We have developed the *SDA Lab* [6], a tool for managing SDA diagrams, and have used it to develop SDAs for all the diseases in the CPO.

When a social issue, a syndrome or a disease is detected in a patient, then the related SDA in the CPO (*hasFIP* property) is activated as the current care plan. Unfortunately, the average home care patient is a comorbid case in which more than one social issue, syndrome, or disease co-occur. In this case, several SDAs are simultaneously activated for the patient. We consider that having several simultaneous care plans for the same patient is counterintuitive and source of medical errors. Therefore, we have started to develop merging techniques to combine several SDAs to form a single action plan [20].

Before a care plan is applied to a patient, it is transformed into an *individual care plan* (i.e., only valid for this patient) by simplifying all the decisions whose terms are known for the target patient. For example, if the Electronic Health-Care Record of a patient with Parkinson contains that the patient has dysarthria (i.e., motor speech disorder), then the upper condition in figure 3 will be removed and the upper action and the second condition connected. The alternative branches of the removed condition are considered for elimination together with all the non-reachable parts of the plan. Health care professionals are asked to validate the individual care plan before it is applied. During the validation process, these professionals can edit and modify the individual care plan in a restricted context that the CPO imposes: the CPO is used to (a) control the state, decision, and action terms of the individual intervention plan in order to avoid unknown terms or terms that are not of the appropriate sort; and (b) find inconsistencies of the individual care plan.

The inconsistencies that the CPO helps us to detect in individual care plans are:

- *Unjustified assessment orders*: the instances and the subclasses of the Problem Assessment class in the CPO are the available tests to confirm suspected signs of the treated patients (e.g., high blood pressure). The medical reason to order one of such tests is that the results of the test will provide some information that is relevant to the treatment of the patient. If an individual care plan contains an action of the sort Problem Assessment and the decisions following the action contain none of the signs and symptoms this problem assessment evaluates (*evaluates* property), this is a clear indication that the ordered assessment is not justified. So, the professional is warned to fix the individual care plan in order to avoid unjustified assessments.
- *Test omissions*: signs and symptoms come from professional observations and tests, mainly. If an individual care plan has a decision with a term of the sort sign and symptom, this value must come from a previous action that contains some of the tests that provide this information (*isAssessedBy* property). If this is not the case, the information can be the result of an observation of the health care professional, a consultation of the patient record, or an omission of the required test in the individual care plan. When the warning is raised, the professional must analyze the situation and correct the individual care plan if there is a test omission.
- *Unjustified interventions*: interventions deal with concrete problems. In the K4CARE project, there are three sorts of problems: social issues, syndromes, and diseases (see figure 1). Interventions are introduced in the individual care plan as actions, and they must be justified in terms of one or more of the problems these interventions try to solve (*isInterventionOf* property). If the problem does not appear in the states or decisions previous to the intervention, this is equivalent to order an intervention to solve a non-existing (or non-explicit) problem. This fact is communicated to the professional to correct the individual care plan.
- *Useless information*: individual care plans represent treatments to concrete problems. The introduction of a patient problem that is not related to the current treatment of the patient may be useless or confusing to the professionals participating in the execution of the individual care plan. If a social issue, syndrome or disease (i.e., patient problem) is found in a decision of an individual care plan and none intervention to this problem (*hasIntervention* property) is found in the list of actions after the decision, then the introduction of this problem is probably useless in the context of that concrete individual care plan. When this happens, the health care professional has to decide whether the useless information is removed or not.

In the K4CARE project, all these CPO-based techniques are used to support health care professionals in the process of determining the most appropriate individual care plan. The current users are the health care centers Azienda Unita Sanitaria Locale Roma B and Fondazione Santa Lucia in Italy, Ana Aslan International Academy of Aging in Romania, Szent Janos Hospital in Hungary, and the General University Hospital of Prague in the Czech Republic.

5 Conclusion

We have proposed an OWL ontology for the care of patients at home which is based on the concepts of assessment, sign and symptom, social issue, syndrome, disease, and

intervention. This ontology rules not only the way that the processes of problem assessment and care plan proposal are carried out in the life-cycle of home care, but also the sorts of health-care reasoning that goes from patient assessment to care plan proposal (i.e., problem-to-solution view or *forward reasoning*) and from the sorts of interventions a patient is receiving to the assessment of signs and symptoms (i.e., solution-to-problem view or *backward reasoning*). The first view helps the physician in the task of clinical decision, whereas the second view provides a way of detecting and reducing medical errors in the treatment of patients at home. The ontology is complemented with several tools to edit, merge, and personalize care plans. The tool to edit formal intervention plans is called *SDA Lab* and it is described in [6]. Merging care plans is far and away the most difficult of these tasks and it is still a topic of continuous research in the K4CARE project. This project also serves as the framework for testing the ontology-based forward and backward reasonings during the personalization of formal intervention plans. Unknown terms, inappropriate use of terms, unjustified assessment orders, test omissions, unjustified interventions, and useless information are the sort of inconsistencies that our tool to personalize care plans can detect with the help of the proposed ontology.

6 Acknowledgement

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