Unsupervised Clustering of Patient-Centric Models to Cluster-Centric Models for Ubiquitous Healthcare Environment

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***Abstract*—In this paper we present an approach based on data-driven clustering of patient-centric models for ubiquitous healthcare environments. The use of clusters of models instead of patient-specific models offers the advance of dynamic reconfiguration of the models according to upcoming healthcare events that appear for members of the cluster. The healthcare events are related to the patient's health condition.**

I. Introduction

NOWADAYS, the patient is considered to be the core entity in the provision of services at the healthcare domain. The main objective is to constitute a normal life for the patient keeping high his quality of daily living. To achieve that, the deterioration of patient's health condition should always be prevented. This patient-centric approach requires the provision of personalized healthcare services to the patient at the right time, right place and right manner without temporal and spatial limitations [1]. The continuous and uninterrupted provision of healthcare services is achieved via ubiquitous computing and networking technology. Moreover, the deployment of ubiquitous healthcare (UH) services makes the patient feel safer.

In the patient-centric model, the UH services are provided to the patient by a group of entities (medical personnel, relatives, friends, volunteers, etc.) which dynamically compose a dedicated service group. The provision of personalized UH services to the patient can be enabled by the use of the profiles of these entities participating in the UH environment [2]. The profiles of the involved entities will incorporate their preferences and the interests (e.g. patient, doctor, nurse) as well as contextual information and bio-information related to the user.

The profiles of the participating entities are exploited for the creation and management of a group profile that will be responsible to enable the appropriate entities to collaborate for the efficient provision of personalized ubiquitous healthcare services to the patient. The group profile facilitates the dynamic creation of the appropriate group of entities that should be rapidly provisioned and released with minimal management effort. The inception for the creation of a group profile is the patient's health condition [3]. We consider that the patient's health condition functions as the convener of a session and the participating entities as the participants of a session respectively [9].

In the patient-centric model, each patient is considered as a dedicated case in order to provide him a healthcare service of high quality. The patient-centric model should have dynamic and self adaptation abilities, i.e. dynamic and self re-configuration, in order the group profile to be updated based on new conditions and events. However, it is essential the provided healthcare services to accomplish the rising demand for the provision of low cost healthcare services to different population groups while keeping high the quality of patient's daily living.

In this paper, we propose the use of centric models for clusters of patients instead of one patient-centric model for each individual patient. These models, which in the rest of this paper will be denoted as cluster-centric models, will merge patient-centric models which were found to be similar according to a similarity criterion. The patients the models of whom belong to the same cluster will share the same centric-model.

Following the introduction, this paper is organized as follows. In Section II, related work is presented. In Section III, the ubiquitous healthcare environment concept is described. In section IV, the proposed concept for unsupervised clustering of the patient-centric models to cluster-centric models is described. In section V, a pilot scenario of operation of the cluster-centric based ubiquitous healthcare environment is presented. Finally, section VI concludes the paper.

II. Related Work

In the research area of healthcare domain, it is noticed that the whole research focuses on the improvement of accurate detection of emergent events and the improvement of patient's daily living. The provision of personalized healthcare services is achieved in different level in each work. These directions are found in several research activities.

HeartCycle system [4] represents a conceptual approach of a Personalized Health System (PHS). The proposed PHS system provides professional healthcare at home. The PHS is represented through two intervening closed loops corresponding to the patient and the healthcare provider. Essentially, the two closed loops are a patient-oriented platform in collaboration with a healthcare provider-oriented

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platform. The provided services are measurement, detection and prediction, analysis and decision, therapy and feedback. The continuous reconfiguration of optimal treatment plan for each patient is the major expression of personalization in this work.

In [5] the concept of personalized healthcare services is approached as a process of continuous estimation of the best treatment scheme given patient's health status and context. The utilized technology is based on ontology and rule-based techniques.

Within the context of CHRONIOUS project [6, 7], an enhanced model-platform was designed for forthcoming chronic disease management systems. The CHRONIOUS project aimed at the establishment of a personalized coaching healthcare system. CHRONIOUS system advises users on adjusting their lifestyle to their health status requirements. In CHRONIOUS system, it is defined that the use of profiles makes personalization feasible. Profiles' content is an accurate description of patient's health status. Profiles are used on identification of emergent conditions and on suggestion of proper treatment plans The feature of personalization is enhanced regarding therapeutic plans making decisions, since besides patient's vital signs, nutrition habits and drug intake are taken into consideration.

III. The Ubiquitous Healthcare Environment

We consider that a UH environment is composed, at least, by the following classes of UH entities:

Patient: individual receiving the UH services, to support independent living and/or using UH services for the care of his or her own health and wellbeing [8].

Medical professionals: professionals (e.g. clinicians, doctors, pharmacists) involved in the assessment of patient's health condition and delivery of more specialist care than the provided by carers [8].

Formal carers: professional providing care for the client (e.g. occupational therapist, social worker); involved in the assessment of patient's health condition delivering of one or more non-medical care roles [8].

Informal carers: trainee persons (e.g. relatives, neighbours, friends or volunteers) providing care for the client. This category provides care in a wide variety of situations in a non-professional capacity [8].

Each of the above participating entities in a UH environment has a profile. The profile may include information such as demographic data, preferences, contextual information, etc.

In the context of the patient-centric model, patient is the core entity of the UH environment, as shown in Figure 1. The state of the patient's health condition is the inception for the provision of healthcare services; it is continuously monitored using real time collected contextual and bio information, which is gathered by wearable or implanted biosensors as well as by environmental arrays of sensors.

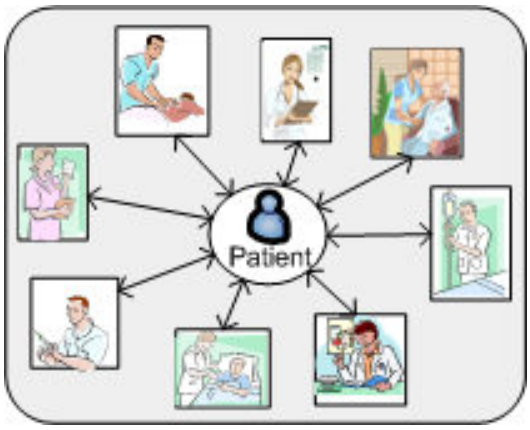

Fig. 1. Illustration of the patient-centric model [3].

The health condition is described at a high-level. It is not intended to give detailed information about the current health status of the person, but the health status to be used in the creation of rules or for informing other people such as relatives and friends. According to [8], the health condition can be characterized by four discrete states: well, mild-condition, stronger-condition and emergency. At a time, the patient's healthcare condition can be in only one state as depicted in Figure 2.

The transition from one state to another is triggered by

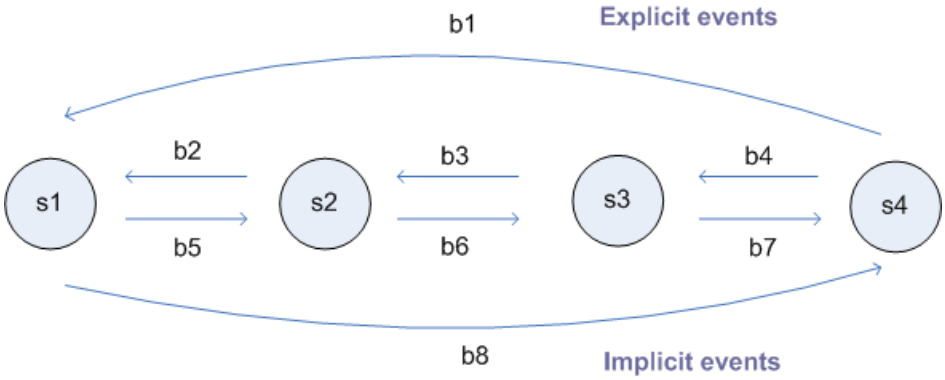

Fig. 2. The three potential states of patient's health condition; s1:well, s2:mild-condition, s3:stronger-condition, s4: emergency; {b1, b2, b3, b4}: positive/recovery transition, {b5, b6, b7, b8}: negative transition

certain events related to the patient's health condition. An event can be defined as a significant change in specific bio or contextual information captured by the objects or imported by the patients themselves. This transition can be either a positive transition e.g. b1 (amelioration of patient's health condition) or a negative transition e.g. b6 (deterioration of patient's health condition). Each transition is an event-driven operation. At each state, certain UH services are provided to the patient by certain entities.

In the patient-centric model, the selection of the entities that will be activated to dynamically form the appropriate group for each situation is of great importance for the provision of healthcare services and is determined for each patient. Each patient is studied as a separate case and the appropriate healthcare services are deployed.

In the context of ubiquitous healthcare environment we propose the use of cluster-centric models, instead of patient-specific centric models for the modeling of the healthcare of patients. The clustering of the patient-centric models to clusters of models will be performed using data-driven algorithms, as described in the following section, in contrast to rule-based [5] or expert's decision based approaches, followed in similar works.

IV. Unsupervised Clustering of Patient-Centric Models

The proposed methodology is based on the assumption that patient-centric models with similar group profiles will operate in a similar manner. Specifically, we assume that the ubiquitous healthcare system would build quite similar patient-centric models for patients with similar health status (types of diseases, monitored medical metrics, etc) and similar demographic characteristics (i.e. age, habits, family status, residence, etc) and health history. Moreover, we expect that similar patient-specific models will operate in similar sequences of upcoming events and subsequently should be adapted and/or re-configured to the new conditions and new data in the same way.

Under this assumption, the use of clusters of patients-centric models instead of individual patient-centric models, would result to several benefits. First of all, the training, and fine-tuning of the parameters of the models for a cluster of patients instead of individual ones can rely on larger amount of training data, and thus the determination of optimal values for the parameters of the model would be more precise (especially for those parameters that are statistically estimated) and result to more robust models. Moreover, the common use of the same cluster-centric model created from several patients with similar healthcare behavior offers the ability to re-configure the models according to information related to a subset of the patients of the cluster, and then be applied in the future for potential similar events that will be presented to other patients of the cluster.

The clustering of the patient-centric models to groups can either be performed by setting some rules (decided by the clinical experts) or by unsupervised data-driven methods. The first option relies on the degree of knowledge and experience of the clinical experts, while the data-driven clustering relies on the amount of available bootstrap data and the degree of coverage they offer. The data-driven unsupervised clustering is based on powerful machine learning methods such as the k-means and the expectation-maximization algorithms [10], and uncover underlying information and correlations in the data, which a clinical expert may not be able to discover.

Let us define a set of N patient-centric models, P_n, with $1 \le n \le N$ where N is the number of individual patients. The unsupervised clustering f of the N models, will result to $M \le N$ cluster-centric models, C_m, with $1 \le m \le M$ where M is the number of clusters of patient-centric models, i.e.

$$\underset{\arg\min(V)}{f} : P_n \rightarrow C_m \qquad (1)$$

where the clustering is performed according to the minimization criterion V, i.e. a cluster variance threshold, for all patient-centric and cluster-centric models n and m, respectively. The concept of the clustering of the patient-centric models to cluster-centric models is illustrated in the following Figure, where patient-centric models which were found to be similar are grouped in the same cluster.

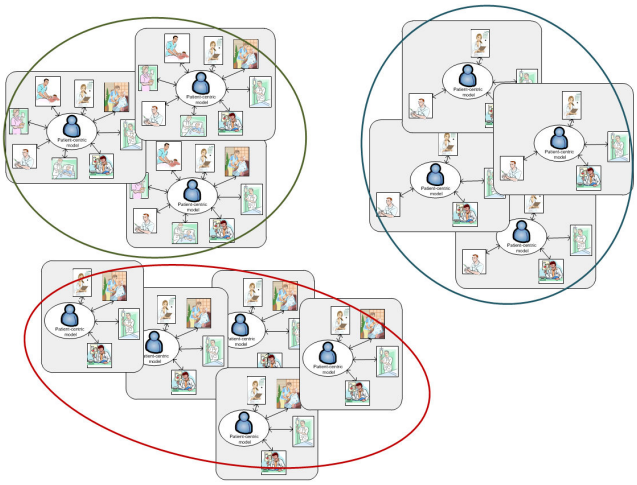

Fig. 3. Illustration of the concept of the cluster-centric models. Patient-centric models that are found to be close will be clustered to the same group of models.

The exploitation of new upcoming events and information related to the healthcare status of each patient will result to the adaptation/reconfiguration of the whole cluster-centric models, C_m, to the new conditions. Change of a cluster-centric model exceeding the predefined threshold, V, with respect to its initial parameter values would require re-clustering of the patient-centric models and estimation of new models of patient's groups. Thus, the grouping of the patient-centric models to clusters will be updated when

significant changes in the clusters are detected.

V. Pilot Scenario

We consider the case of Smart Homes equipped with the appropriate sensors for gathering context and bio-information as well as integrating the essential residential networks for supporting a UH system for providing monitoring services to cardiac patients remotely. The patients are being monitored by the system in order any critical event to be detected timely.

In the case of patient-centric models, one model would operate for each individual patient, thus reconfiguration of the model is performed purely from the logged history of the corresponding patient's activity. Thus, when an event appears in one patient, for example cardiac crisis due to a not predicted cause, this information will not be exploited to other patients with similar healthcare profile.

In the case of cluster-centric models all patients the models of which were found to be similar will share a common model, since they belong to the same cluster. In this case, when an event appears in one or more patients-members of the same group, the cluster-based model will be reconfigured/updated. By this way the adapted model will successfully handle similar healthcare events, when/if appear to other patients-members of the group.

When the appropriate cluster-centric model is selected, the group profile is created in the same manner as in the patient-centric model. The profiling mechanisms of the group profile management system [3] are enabled in order to the patient's profile to be accessed for acquiring the identities of the entities that are related to the patient and will participate in the group that supports the UH service. A request is sent to the patient's profile whose response returns the participating entities who are appropriate for this patient and are already subscribed to this service. Then, queries are sent to these participating entities' profiles in order to detect their availability and to bind one of them.

If the current state of the patient's health condition justifies the sharing of the emergency-related information from the patient's profile, this information may be necessary to be shared with a participating entity. The sharing will be based both on general policies that define what access the participating entity may have to the patient's profile and on the patient's haring preferences.

VI. Conclusion

In this paper we presented an approach based on data-driven clustering of patient-centric models for ubiquitous healthcare environments. We proposed the use of centric models for clusters of patients instead of one patient-centric model for each individual patient. These cluster-centric models will merge patient-centric models which are found to be similar according to a similarity criterion. The patients the models of whom belong to the same cluster will share the same centric-model.

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