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Technically Representing Clinical Knowledge for Rehabilitation Care

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Abstract. Providing a suitable rehabilitation after an acute episode or a chronic disease helps people to live independently and enhance their quality of life. However, the continuity of care is often interrupted in the transition from hospital to home. Virtual coaches (VCs) could help these patients to engage in personalized home rehabilitation programs. These coaching systems need also to be fed with procedural precepts in order to work as intended. This, in turn, relates both to properly represent the clinical knowledge (as the VC somehow replaces the formal caregivers that cannot be fully present) as well guide the patient correctly (in order to follow the medically desired procedures given the need for personalisation according to individual needs). Therefore, we outline our technical approach to deal with this. In particular, clinical pathways in terms of semi-formal procedure models in combination with machine learning components processing and powerful user interfaces providing these pathway information and feeding the VC are presented. The system is currently under testing in a participatory design phase called Living Lab. Thus, initial user feedback for further improvements is about to come.

Keywords. Virtual Coaching, Clinical pathways, Machine learning

1. Introduction

Providing a suitable rehabilitation after an acute episode or a chronic disease helps people to live independently and enhance their quality of life. However, the continuity of care is often interrupted in the transition from hospital to home. Virtual coaches (VCs) could help these patients to engage in personalized home rehabilitation programs. The purpose of home rehabilitation is to reestablish independency of the patient, so that they can readily take part in different activities to pursue life and be a productive member of the society [1]. The use case is, in particular, embedded in the EU-funded project *vCare*[2] that addresses the rehabilitation after an acute severe episode causing chronic disabilities (restricting the patient's abilities of movement and physical resilience).

These coaching systems need also to be fed with procedural precepts in order to work as intended. This, in turn, relates both to properly represent the clinical knowledge

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[2] See: https://vcare-project.eu/

(as the VC somehow replaces the formal caregivers that cannot be fully present) as well guide the patient correctly (in order to follow the medically desired procedures). Still, also some degree of flexibility or personalization is desirable in order to cope with individual characteristics, preferences and habits. The lack of (formal) structure, consistency and ambiguity of clinical knowledge regarding foreseen or advisable procedures in particular clinical configurations [2] shall be managed by automated systems to improve the clinical practice. Current systems often fail with regard to combine a clinically indicated treatment schema with a still necessary degree of freedom. This is needed to smoothly align the execution of the plan with the individual situation. Otherwise, it is too dangerous to allow machine learning algorithms to be trained in a real-world scenario. Clinical pathways in terms of semi-formal procedure models deal with the needed formalization. These are a still easily understandable representation of clinical procedure knowledge [3,4]. Overall, from the technical point of view, the core issues to be dealt with, building the cornerstones of the present article are: the modelling of clinical procedural information (clinical pathways) as the basic controlling precepts in a formal format and the further processing, adaptation and personalization of this clinical knowledge (machine learning) feeding a VC system to support patient recovery.

The remainder of the article is structured as follows: Section 2 provides some methodical and approach-wise background. In section 3, we outline the technical architecture of our solution in order to address the outlined needs to feed a VC solution. In section 4, we provide some conclusions and outline further to-dos.

2. Methods

Within the vCare project, it is aimed to design an applicable VC that provides guidance within the rehabilitation phase. The home patients' rehabilitation shall be amended by advices for a healthy behavior and monitoring and motivating the execution of distinct (physical) exercises such as serious games. The project intends to demonstrate how the specific challenge of empowering and motivating works given the clinical setting. Due to the foreseen real-life context proof of the efficacy of prediction of intelligent algorithms, the reasoning capabilities of autonomous learning and the adaptation to personal needs are central. Based on these prerequisites, a participatory design approach foresees a high involvement of a joint multidisciplinary clinical-technical team both in the design and in the evaluation phase. This ensures a safe and reliable solution.

On the one hand, the clinical expertise is used to derive the basic rehabilitation needs as well as the foreseen in- and outpatient clinical pathways. On the other hand, the technicians ensure that the VC solution properly works and is adapted to the patients' needs and pathways. To in turn ensure this overall ambition, an iterative, tripartite testing strategy is in place: First, within the *TechLab phase* the sole functioning of the technical components and their interplay have been tested having the therapists substituting the patient behaviors. Second, the *Living Lab* simulates the homes by research apartments providing a protected environment and support for the patients trying out the VC solution. Third, within the *Pilot phase* the patients use the solution in their real home setting. The present paper reports on the technical developments as result of the TechLab implementation, specifically on the connection between clinical pathways and a VC system for home rehabilitation. These are currently under test during the Living Lab.

3. Results

The clinical needs led to the technical architecture and function range for the representation of the pathway information as outlined in Figure 1. The primary ambition was to integrate the care plan repository with the professional portal to allow physicians to define the templates. These pathway templates are used to prescribe a specific care plan for a patient via a professional portal. Using this care plan, the VC can be initialized and the home-based rehabilitation can be started. Details on this are described in the following.

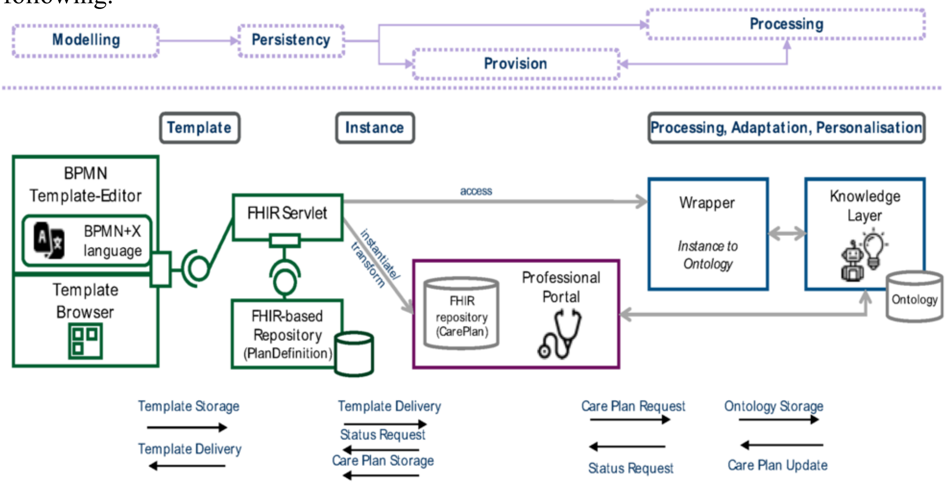

Figure 1: Architectural outline

The first question is how the *modelling* of the clinical procedural knowledge/pathways takes place. In general, clinical pathways are integrated as templates in the system. To grasp the clinical procedural information, a template editor making use of the BPMN [5] (including some additions as required given the project context) is employed in order to graphically model the patients' desired process flows. With the help of this model-based graphical representation, medical knowledge is represented and made accessible to the technical layers of the system building the basis for the VC's activities supporting the (procedure-wise) proper set up of the rehabilitation.

Secondly, the *persistency* of this pathway information needs to be ensured. Here, the HL7 FHIR[3] standard comes into play to exchange data between software systems in healthcare. FHIR describes data formats and elements as so-called "resources" and provides an interface to exchange them. The overall question is then how to represent the medical content in terms of the subject-specific pathways given the choice for BPMN as the modelling language for the rehabilitation care pathway templates. After analysing the available FHIR resources, PlanDefinition[4] (for the patient-independent rehabilitation care pathway template) and CarePlan[5] (mapped to after the physician has assigned a rehabilitation care pathway template to a particular patient generating the patient-specific instance of the template) have been chosen.

[3] Fast Healthcare Interoperability Resources; see: https://www.hl7.org/fhir/
[4] See: http://hl7.org/fhir/r4/plandefinition.html
[5] See: https://www.hl7.org/fhir/careplan.html

Overall, the Pathway Template System is a combination of two interlinked components: the Pathways editor and Template management using a HL7 FHIR-based repository[6]. For the professional user, a web-based model editor is provided that allows graphical work on the rehabilitation program (using the bpmn.io[7] library). The template repository browser provides an overview of available templates and basic functionalities to create new or edit existing template models together with their metadata. This also enables the database *persistence* and a REST-based access to the developed templates. To underpin the project specifics, a particular profile[8] was defined somehow refraining from the too generic standard FHIR data schema using the PlanDefinition as base resource. The profile also introduces refinements in order to map the templates modelled using the editor (BPMN-XML) to the corresponding persisted FHIR resource (FHIR-XML). The endpoint for the REST-based access is provided by a web servlet providing the basic CRUD-operations for the pathway templates.

Thirdly, the FHIR resources are also to allow the *provision* of the pathway information to the clinicians, further used within the *professional portal* [6]. This is to prescribe particular activities for a patient and to overview him/her allocating particular coaching services. In particular, the professional portal is a web-based application providing health care professionals with the possibility to enrol new patients who are going to use the virtual coach. Here, the healthcare professional can choose and adapt an appropriate pathway for patients, can review vital parameters (e.g., blood pressure or daily physical activity) and make continuous adjustments during therapy. Moreover, it provides FHIR application programming interfaces for the knowledge layer for semi-automatic update of the care plan.

A standardised way to access pathway information for a wrapper of clinical pathways is provided to store them into the pathway ontology. This allows inference activities by performing reasoning queries and reinforcement learning on the pathway information. The particular pathway instance can then finally automatically be updated to adapt to the patient's needs, status, performance or preferences.

Fourthly, the pathways are to be *processed* with the aim of personalization. For this purpose, the wrapper converts instances of the pathways into Resource Description Framework formats (RDF) as shown in Figure 1. The information representation in serialized form enables data integration, semantic validation and systematic processing via semantic SPARQL queries[9]. Processed information about assigned CarePlans can easily be linked to structured vocabularies (e.g., medical ontologies, such as RadLex[10], universal HealthMeasurement[11] or Human Disease Ontology[12]).

The semantic processing also facilitates the identification of personalization points. The SPARQL queries serve to specifically identify those activities within a care plan that leave room for personalization. The RDF schema in FHIR standard provides attributes such as *duration* and *durationMax*, which define a range for the final realization. Attributes such as the *selectionBehavior* offer additional points of reference for optimally selecting and parameterizing activities for an individual patient.

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[6] See: https://hapifhir.io
[7] https://github.com/bpmn-io
[8] https://www.hl7.org/fhir/profiling.html
[9] See: https://www.hl7.org/fhir/rdf.html
[10] See: https://bioportal.bioontology.org/ontologies/RADLEX
[11] See: http://ontology.universaal.org/HealthMeasurement.owl
[12] See: https://bioportal.bioontology.org/ontologies/DOID

Considering an overall framework in which additional information on the individual clinical development of a patient is incorporated into the knowledge database, the knowledge layer presented here provides a well-founded basis for decisions on the further personalization of a care plan.

4. Discussion & Conclusions

Virtual coaches may help patients to engage in a personalized rehabilitation program that complies with age-related conditions. These coaches could be a key technology for empowering patients towards increasing their adherence to the care plan and to improve their secondary prevention measures. In this paper, we presented the technical core of a novel virtual coaching system in terms of transferring the clinical procedural pathway information to the distant home-based rehabilitation sphere. We address the challenges by combining recent technological advances with clinical pathways, machine learning and convenient but still powerful user interfaces, based on joint research and validation activities from researchers from the medical and ICT domains.

Operatively, the current Living Lab phase is divided in a number of test waves to test the single pathways and components more fine grained. This transfers the overall iterative approach to the testing phase by incrementally adding additional functionalities. A first basic pathway representing the VC's core features (reminders, pain assessment, serious motor games) is just tested. After completing the whole test procedure, all the feedback from professionals will be incorporated into the solution what is essential to safely start the Pilot Phase's VC application in its full extent in the patients' homes.

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A test system tour can be accessed here: https://pathways.vcare-project.eu/

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