

From Medical Guidelines to Personalized Careflows: the iCareflow Ontological Framework

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Abstract

Computer-Interpretable Guidelines (CIG) are Clinical Guidelines described in a language that can be interpreted by computers. They are often used to support physicians in a single point in time to design and test guidelines. The next steps are the application of CIGs to determine careflows, the personalization of careflows and their execution. This paper presents the iCareflow ontological framework which intends to support the adaptation of guidelines during the design phase in order to obtain personalized careflows. The proposed framework explores how guidelines, policies of the care institution, patient preferences, terminologies and other knowledge sources interact with each other to determine a patient-centric careflow. Scenarios and further applications of the framework are also provided.

1. Introduction

Clinical Guidelines (CG) are systematically developed statements to assist practitioner and patient decisions about appropriate healthcare for specific clinical circumstances [1]. It has shown to be a valuable tool for sharing good practices and to improve the quality of care [2]. The content of a guideline is based on a systematic review of clinical evidence and its utilization moves clinical practices from informal consensus (or personal experience) to evidence-based practices.

Various methodologies have been used to elaborate guidelines and to integrate specific adaptations. There is no consensus about the best methodology to use, about the criteria to declare information as evidence [3] or about how the information has to be presented. However, the importance of clinical guidelines has

increasingly been recognized by the healthcare sector thanks to the benefits of this practice, including benefits for healthcare professionals, patients and communities (of patients or professionals).

Despite the significant effort invested in guideline authoring, the quality of individual guidelines varies considerably. In order to improve it and facilitate the review of the contents of guidelines, some organizations are working on the formalization of guidelines description [4, 5]. The increasing utilization of informatics tools in clinical practices may be an opportunity to generalize the use of CG and to improve the quality of knowledge description. For instance, workflow technologies associated to CG knowledge can be used to support physicians to determine the most appropriated treatment plan (named careflow) for a patient [6, 7].

Regardless of the strength of evidence (in a guideline), clinicians have to interpret their application taking into account the needs and wishes of individual patients [8]. Although literature presents some alternatives to adapt guidelines according to local constraints [9], approaches for employing guidelines in a personalized patient treatment are still missing.

This paper focuses on how Computer-Interpretable Guideline (CIG) approaches can be used in a multiple-tier framework, to promote adaptations and refinements of (inter)national guidelines in order to produce personalized careflows. Here a personalized careflow is considered as a treatment plan that takes into account national constraints, institutional constraints (only the institutions that are supposed to provide care to the patient), physicians' preferences and patients' health records, preferences and constraints. This paper introduces the iCareflow approach. It is a framework based on an explicitly ontological description, which associates the main aspects of the guideline adaptation and personalization, such as: policies of the care institution, patient preferences, terminologies, drugs

interactions, etc. Even if iCareflow is a CG description language independent approach, we will use SAGE specifications [10] to illustrate our concepts.

This paper is structured as follows: Section 2 presents the properties of computer-interpretable guidelines and careflows; Section 3 presents the iCareflow framework including the design strategy, the description of the ontology and an illustrative example; Section 4 concludes this paper and outlines future works.

2. Computer-interpretable guidelines and careflows

Although several international organizations create and maintain repositories with CGs in different domains, they are not being widely used in daily practice [11]. Several reasons were identified, such as: lack of familiarity with the use of guidelines, lack of awareness of the guideline's existence, lack of agreement with a specific guideline or with the principle of using it, lack of physicians' self-efficacy, lack of outcome expectancy, lack of motivation or inertia to change habits, or external factors [12].

To promote the use of CG, it is necessary to integrate decision support systems into daily used medical information systems (e.g., Practice Management System and Hospital Information Systems). CIGs were proposed to improve clinical guideline description. According to [13], it has a significant potential to achieve compliance of Health professionals and improve the quality of care.

CIGs have been proposed in diverse areas as part of decision support systems. The idea of having a CIG is not new, for example, "*HELP hospital information system (Health Evaluation through Logical Processing)*" had been operational at LDS Hospital since 1967 [14]. Nowadays, many approaches exist for designing, testing and executing CIGs, a comparison work can be found in [15]. But, there still do not have a standard language to describe guidelines (Arden Syntax is an ANSI standard but it is not adequate to describe complex guidelines [16]) resulting in a miss of interoperability between the existing CIGs' description languages. Another aspect to be considered is that some approaches rather focus on guideline description and visualization (designing phase), while others stress the guideline implementation and the integration with care systems (performing phase). These different objectives have their implications for the representation and utilization of CIGs.

The scope of a guideline has also an impact on the CIG's description languages. For example, a clinical

guideline can be defined to be a general framework that is applicable only after some adaptations (i.e. considering national, local or personal constraints) or it can represent precise treatments where no adaptations are recommended. In the former case, if the potential adaptations for the general framework are not included in the guidelines (e.g. as multiple choices), the description language needs to support extensions of the guideline at run-time. In [11] some criteria are proposed to evaluate the quality of CIGs designing and execution tools, such as: representation language, acquisition, verification and execution. The first three criteria concern the authors of the guideline, whereas the last one is related to practitioners. In this paper two additional quality indications are highlighted: *Adaptation* and *Merging*. But we also propose to consider the *Selection* and the *Monitoring* criteria.

Adaptation. Guideline adaptations can be considered as a process in which existing guidelines are modified to reflect local constraints. Adaptations can be implemented in the design phase (focus of this paper), when the constraints are known and the data is available. Typically, it consists of informing about duration, dose, or procedure, suited to the local context and this was intentionally omitted in the general framework (original guideline) in order to produce a Clinical Protocol [9]. Adaptations can also be implemented in the performing phase and modify the careflow. This is the case when the available information is insufficient to take a decision during the design phase or when unexpected situations occur.

Merging clinical guidelines. When several guidelines are applied to one patient, the tool needs to check mutual exclusion (e.g., drug-drug interaction), deadlocks, availability of resources, etc. in order to define the personalized careflow.

Selection is the capacity of the system to select a subset of CG according to some predefined rules.

Monitoring is the capacity to identify (during the performing phase) when critical steps of the CG are reached.

In parallel, the *business process modeling* research field and the software industry have developed languages (e.g., Business Process Modelling Notation) and tools to notate and execute workflows. Some investigations are trying to adapt these tools in order to apply them to the CIG area. As pointed out by [6], guidelines and workflows offer complementary views of the clinical process and the integration of these views is a key research challenge for careflows. Combining CG to workflow methods, technical tools,

local and patient constraints, etc. in a progressive way is the basis to the iCareflow approach.

3. The iCareflow framework

This section presents the iCareflow framework for refining CIGs into personalized careflows. Section 3.1 describes the design strategy to define personalized careflows, section 3.2 presents the ontology that supports the personalization process, and section 3.3 presents a scenario that illustrates the framework.

3.1. Personalization strategy

Standardized guidelines are defined to be applied to many institutions and patients. In this work, we consider these CGs to contain general processes and/or goals to be reached in a clinical scenario. As emphasized on [17], the procedural knowledge in the guidelines has to be complemented by declarative medical knowledge.

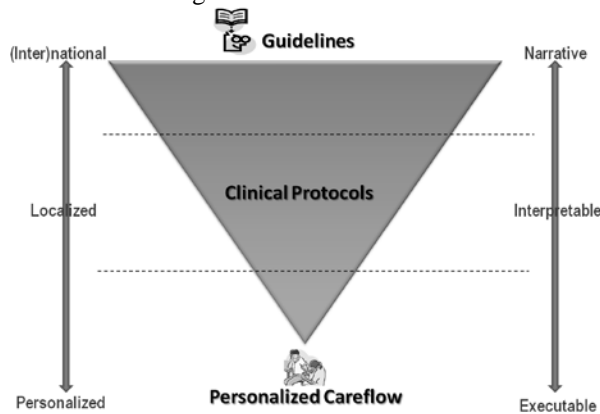


Figure 1. Guideline personalization strategy

On the left side of Figure 1, from top to bottom, guidelines are specified in the most general way without distinguishing local's and patient's aspects up to personalized guidelines. We assume that local policies, constrains and data are not part of the standardized guideline. They are defined by local authorities who can be governmental authorities or members of an institution (e.g. a hospital). An example for organization is presented in Figure 2, where the roles of the different actors are defined.

Once described, the constraints and preferences are stored locally and are used by the system to adapt the guideline. The order that the guidelines have to be modified (e.g., first local constraints, then patient constraints, then physician preferences) can be varied according to the strategy of the physician, but the final result needs to be a consistent careflow.

As illustrated in Figure 1, on its right side, standardized guidelines can be described in narrative format which, usually, is not interpretable by computers. But this information serves as basis for a more refined guideline that can be translated to a language that is interpretable by computers. This translation has as advantage that some inferences can be applied in order to get (with the participation of the physician) a computer executable careflow. The definition of the careflow language is beyond the scope of this paper, but we can suppose that it will be selected according to some technical criteria (e.g. interoperability with the clinical information system) which are defined by the care institution committee (see Figure 2).

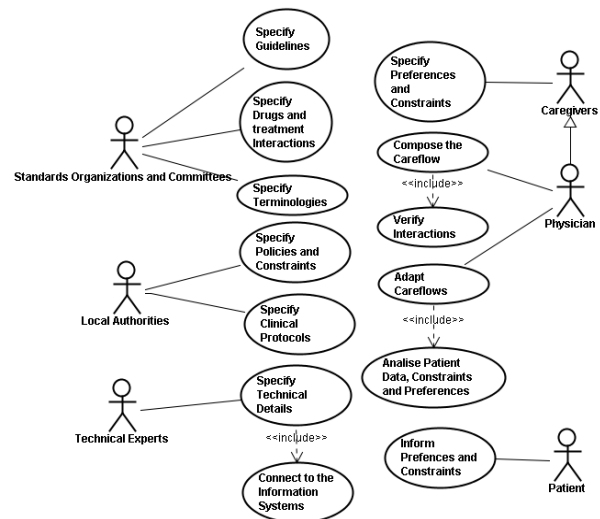


Figure 2. iCareflow specification authors

As illustrated at the bottom of Figure 1, the outcome of our approach is to get a careflow which is consistent to the original guideline, considers specific caregivers and patients' constraints, includes physicians' preferences and takes institutional policies into account.

Additionally, the careflow definition process can include some extra steps related to the functionalities that are provided by external decision support system tools. It includes, for instance, the verification of treatments' interactions (when merging guidelines) as well as drugs interactions, resource availability, etc.

3.2. Framework description

Figure 3 presents the overview of the ontology framework that associates the main aspects of the guideline adaptation and personalization strategy. From top to bottom, Figure 3 shows that CIG follows one

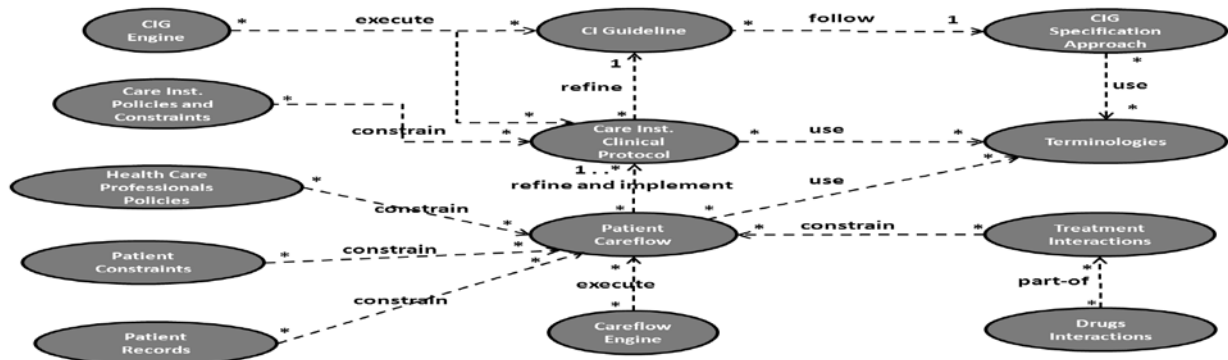


Figure 3. Overview of the iCareflow ontology framework

particular specification approach (e.g. SAGE). The CIG can also be executed by a CIG Engine. The choice of the CIG engine depends on the description language used.

In our approach, we advocate the use of standard terminologies in the CIG, such as UMLS (Unified Medical Language System), OBO (Open Biological and Biomedical Ontologies) and GO (Gene Ontology). This is an important aspect for guideline specification at the (inter)national level, since they must be properly interpreted by other systems that intend to use them. Undefined and ambiguous terms potentially lead to an erroneous interpretation of the guideline.

For many years the specification and classification of medical concepts and terms is a very active area in the medical field. Some specification approaches link the concepts used in guidelines with well accepted terminologies in order to make it unambiguous, and to promote reuse and interoperability. In consequence, the semantic interoperability is facilitated at careflow level by including terminologies at the guideline level. In other words, the terms used in the specification must be consistent with (or mapped to) the terms adopted in the medical information systems.

According to Figure 3, we defined a Care Institution Clinical Protocol as a refinement of a CIG. Those protocols must be consistent with the guideline specifications, so they should be checked to eliminate possible inconsistencies and to detect possible contradiction with the high level description of the guidelines. Protocols can be interpreted by engines and are also associated to standard terminologies. The Care Institution policies and constraints are used to refine CIG into protocols. They include aspects such as:

- **Local Resources:** A protocol is executed using local resources, like devices, drugs and human resources;
- **Local Procedures:** A care institution can have its own internal procedures in order to optimize its resources and improve its quality based on local context;

- **Local Constraints:** Some drugs are not recommended or allowed in some countries or states, but they can be recommended in others. Many local situations can influence the treatment (e.g., climate, social situation and geographical position).

Patient careflow specifications (see Figure 3) can be obtained by refining a set of clinical protocols. In this step, the careflows' specification takes the preferences and constraints of the health care professionals into account. Patients' constraints, preferences, consents and data are also considered in the design of the careflow. General patients' health conditions, their family history, and genetics can influence the construction of the most appropriate Careflow.

In the ontological framework, careflows are also constrained by treatment and drugs interactions. By using results of external tools, some risks can be detected, and the careflow can be adapted by physicians to eliminate them.

Finally, a careflow is determined and exported in a language that can be performed by a careflow engine. This engine is used to interpret the careflow requests, search the information into the data sources and perform the rules/inferences associated to the careflow.

3.3. Example

A simple example based on the SAGE specifications is used to explain the contributions of our approach. The scenario considers a patient presenting all symptoms of diabetes who consult doctors of a hospital to get some treatment. The paper based guideline that serves as basis to specify the CIG presents only evidences in the treatment of the disease. The SAGE specifications of the guideline implements ontologies to make guidelines machine interpretable. It provides a graphical notation to represent the guideline. In our example, the SAGE Primary Care Clinic Visit

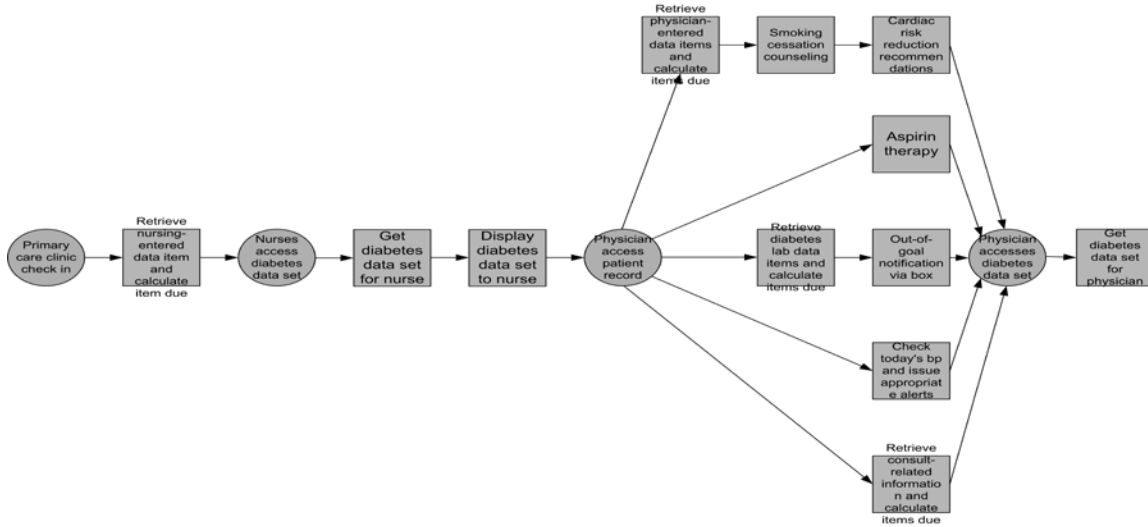


Figure 4. SAGE specifications for the primary care clinic visit guideline concerning diabetic patients

guideline¹ for diabetes is shown in Figure 4. SAGE indicates to treat this illness as explained on Figure 4 where circles denote context and boxes represent action. However, the proposed flow is still not tailored to a specific patient in a specific care institute. To overcome this drawback, we propose to distinguish the constraints provided by the local presuppositions (e.g. hospital policies) and the patients' specificities in order to personalize the treatment. To do so, we constrain the SAGE CIG using first-order logic rules. Two sets of rules must be defined for representing local constraints and expressing patients' characteristics.

Assume that the hospital implements the following policies and restrictions:

1. If possible to monitor a patient's blood glucose at least four times a day.
2. Check laboratory exam results for this patient

The above constraints can be expressed using first-order logic as:

- $$Patient(name) \wedge HasDiabetes(name)$$
1. $\rightarrow MonitorDiabetes(name, times) \wedge times \geq 4$
 $Patient(name) \wedge HasLabExamResults(name)$
 2. $\rightarrow GetDiabetesLabData(name)$

Relationship symbols used in the rules above have to respect the terminologies used in the SAGE specifications. Due to readability reasons, we keep the logical expressions here presented as close as possible to natural language. Then, the interpretation of the rules impacts on the refinement of the guideline into a clinical protocol. According to the results of the evaluation of the *hasLabExamResults* predicate, one (or several) action box(es) in the graph of Figure 4 can be performed (e.g. *retrieve diabetes lab data* and *out-*

of-goal notification). In some specification approaches, converging CIG into clinical protocols are not provided, thus it is not possible for the system to know in advance (and support the physician to decide), which health care institutions are able to provide the care to patients.

Patients also have some preferences and constraints concerning their health or treatment. These data must be integrated into the system to support the definition of the most appropriated careflow for this particular disease.

Assume, for example, that a patient is allergic to aspirin. In consequence, aspirin cannot be prescribed for this patient because it can cause irreversible damage to his health. Health care professionals therefore have to avoid this medication. Such constraint concerning the patients can be expressed using first-order logic. The corresponding rule can be the following:

$$Patient(name) \wedge IsAllergic(name, drug) \wedge Aspirin(drug) \rightarrow \neg Prescribe(name, drug)$$

The interpretation of the rule has as direct impact over the selection of the *Aspirin therapy* action. In the previous scenario, the resulting careflow alert the physician about the risk or it will not offer the possibility to apply the aspirin therapy to the patient.

In the original SAGE specification, the statements about allergy are part of each guideline specification. In iCareflow framework such constraints are general, thus, they can be associated to patients and can be applied to many guidelines and careflows.

4. Conclusion and perspectives

In this paper we have introduced a novel approach to converge computer interpretable guidelines into

¹ http://sage.wherever.org/cpgs/diabetes/diabetes_html/phtml.html

personalized careflows. The originality of our work consists in considering independently high level guidelines, local constraints, patients' characteristics and treatment interactions. This approach implements progressive personalization of careflow, improving conflicts' detection and the identification of their sources in order to support health care professionals. It therefore saves time in the management of patients which, in turn, can have an impact on the quality of care.

This approach splits the guideline execution into two phases: Designing and Performing. The focus of this paper is on the designing phase. By considering the various layers of abstraction it is able support the composition of careflows adapted for each patient.

Our future work will center on the specification of a prototype where the problem of interfaces between concepts will be studied. We are also working on the extension of the iCareflow framework in order to consider the performing phase. Finally, we evaluate how to monitor careflow execution and how to associate the feedback with the quality of guidelines, institutions and electronic health records.

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6. References

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