Step-Guided Clinical Workflow Fulfilment Measure for Clinical Guidelines*

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Abstract. Health-care quality control is a challenge that medical services and their information systems will deal with in the following years. Clinical Practice Guidelines are a structured set of recommendations for physicians to solve a medical problem. The correct fulfilment of a guideline seems to be a good indicator of health-care quality. However, the guideline fulfilment checking is an open clinical problem that requires collaborative efforts. In this sense, clinical workflows have demonstrated to be an effective approach to partially model a clinical guideline. Moreover, some efforts have been done in consistency checking and debugging management in order to obtain a correct description of the clinical processes. However, the clinical practice not always strictly fulfils clinical workflows, since patients require personalised care and unexpected situations occur. Therefore, in order to obtain a workflow fulfilment degree, it seems reasonable to compare *a posteriori* the evolution of the patient records and the clinical workflow, providing a flexible fulfilment measure. In this work we present a general framework to classify and study the development of these measures, and we propose a workflow fulfilment function, illustrating its suitability in the clinical domain by an example of a real medical problem.

1 Introduction

A Clinical Practise Guideline (CPG) is a set of recommendations/rules developed in some systematic way in order to help professionals and patients during the decision-making process concerning an appropriate health-care pathway, by means of opportune diagnosis and therapy choices, on specific health problems or clinical conditions [4]. The common use of CPG has demonstrated to improve the health-care processes and to reduce their cost [1].

Moreover, the correct use of CPG for each patient can be considered a good quality indicator for health-care processes. The key question is how to check and quantify the correct application of the CPG. Despite the efforts done in the medical field to check the CPG fulfilment [1], this is still an open clinical problem that requires collaborative efforts. In this sense, advancements in medical computer-based systems have meant a sounded impact in the medical activity, such as the Health Information System (HIS),

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the Electronic Health Records (EHRs), but also CPGs. Therefore, it seems reasonable to consider that this task (to measure health-care quality) could be partially solved by computer methods, providing quality indicators based only in the recorded data within EHRs and the HIS.

Main efforts on Computerized CPG are focused on the quality improvement and the optimisation of financial and human resources, and patients' care. The basic principles for the assitential quality through such tools consist of 1) reducing the variability during resources utilization, 2) improving the efficiency of such resources, and 3) reducing the cost of the whole process. The first step in order to produce Computerized CPG is the modelling process. On one hand, specific languages have been proposed for modelling CPG such as GLIF3, ASBRU or GLARE.

On the other hand, workflow models are useful formalisms to model some aspects of the CPG. Workflows are collections of organised tasks to carry out some process made by software systems, groups of people, or the combination of both [8]. Workflow Management Systems (WfMS) provide support for modelling, executing and monitoring the workflows. Traditional WfMS states an effective strategy to assist information processes driven by the workflow, especially in industry. Few efforts have been done in checking the workflow consistency on modelling and handling unexpected actions [5,6]. These proposals can be considered and *a priori* approach for checking the correct execution of the workflow, since any kind of variation from the standard information process must be specified. However, due to the complexity of the medical knowledge (imprecise, incomplete, and multidisciplinary), clinical environments must allow a flexible performance of the workflow (when represents a CPG). For instance, physicians must solve unexpected medical problems of a patient daily. In other words, the activities done by physicians (registered in the EHR) could not strictly follow the workflow. Therefore, it seems reasonable to consider that the difference between the workflow and the activities executed can be measured *a posteriori*, quantifying the accomplishment of the CPG for a patient.

This paper is a preliminary work on the analysis of the fulfilment of CPGs represented by Clinical Workflows based on *retrospective* checking of the EHR. The remainder of this paper is organized as follows. In Section 2 we address the clinical workflow principles. In Section 3 we present a general framework to classify workflow fulfilment approaches, we propose a workflow fulfilment measure and we present a practical example in the medical domain. Section 4 draws a conclusion and future works.

2 Clinical Workflow

Workflows are traditionally dedicated to the representation of business tasks, but there is an increasing interest in the medical field to represent CPG by workflow models, named Clinical Workflows [9,3].

In short, we define a workflow as:

$$W =< \mathbb{T}, \mathbb{C}, \mathbb{E} > \tag{1}$$

$$\mathbb{T} = \{< taskname, id >\} \tag{2}$$

$$\mathbb{C} \in \wp(\zeta) \tag{3}$$

$$\mathbb{E} \subseteq (\mathbb{T} \times \mathbb{T}) \cup (\mathbb{T} \times \mathbb{C}) \cup (\mathbb{C} \times \mathbb{T}) \cup (\mathbb{C} \times \mathbb{C}) \tag{4}$$

where $\mathbb{T}$ is the set of task that can be performed, $\wp$ is the power set, $\mathbb{C}$ is the set of control nodes (characterized by $\zeta = \{BE, EN, XORs, XORj, ORs, ORj, ANDs, ANDj\}$) and $\mathbb{E}$ is the set of edges that state the precedence between tasks, control nodes or both.

In medicine, another key concept is the pathway, a set of the taken care of plans characterized by a procedure applied to a clinical scenario in the time [7]. In other words, a pathway is the subset of tasks and split-paths in the Clinical Workflow followed by the medical team for a concrete patient. When a pathway is selected, the workflow can be executed.

A workflow case (C), the execution of a workflow, is the set of performed tasks of a workflow (named case tasks, $ct \in CT$). A case task is a tuple $< taskName, temp\_exec >$ where $taskName$ is a task label, and $temp\_exec$ is defined by the timestamps t_b, t_e, describing the beginning and ending time of when the performed task occurred.

3 Measuring Fulfilment of Clinical Workflows

From a methodological perspective, the workflow fulfilment checking is a complex issue that could be interpreted by several ways and it could be composed of different tasks. In this section we propose a framework to analyse the possible alternatives to develop a workflow fulfilment checking. Then, we propose a fulfilment measure for clinical workflows and we illustrate it with a real piece of CPG represented by a workflow schema.

3.1 Strategies of Workflow Fulfilment Measures

There is not a consensus about the meaning of the concept *fulfilment measure* since it could indicate if a case fulfils workflow or not (classification), it could identify the concrete parts of workflow that is being fulfilled (to diagnose), or it could establish a measurement of the fulfilment degree (quantification). Moreover, different methods could be applied to solve this tasks and the workflow languages play an essential role since they state the flow control of the tasks (e.g. control nodes or edges).

In order to characterise the alternatives for the development of workflow fulfilment measures, we identify three dimensions (see Figure 1): technique, problem and task.

Technique Dimension establishes the different ways to solve the problem. *Step-Guided* approach attempts to find the decisions made for each condition when the workflow case was performed, checking step by step the path of the workflow schema followed by the case. Unlike *Step-Guided*, *Pathway* approach requires a pre-processing step that calculates all possible (without loops) pathways of the workflow schema. Then, the fulfilment checking means to find the pathway followed by the case. *Brute-force* is similar to pathway approach but considering even the execution of tasks in loops (useful only when the number of loops is known beforehand).

Problem Dimension raises the different elements that we are going to find in workflow and how treat them, depending on the workflow language.

In this work, we chose YAWL (Yet Another Workflow Language) [11]. This workflow language is based on the patterns of workflow with high level Petri Nets, but it

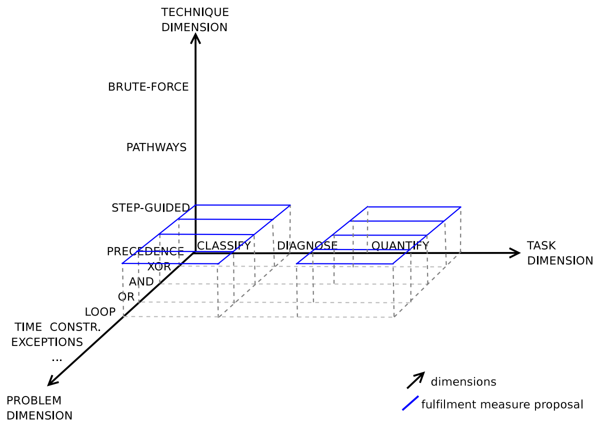

Fig. 1. Framework

extends this type of networks with additional characteristics for a better representation of workflows. Therefore, we enumerate (but not limited to) some of the most commonly used flow-control components: begin, end, or, xor, and, precedence edge, loops, temporal constraints and exceptions.

Task Dimension concerns the nature of the fulfilment measure. We consider three possible tasks. *Classify* is the process of deciding if the case belongs to the set of cases that strictly fulfils the workflow schema. A more general approach could state the pertenence degree to this set, *quantifying* the degree of fulfilment. Finally, other approach could not only obtain a fulfilment degree, but also to diagnose it, that is, to identify which elements of the workflow schema are not fulfilled by the case.

3.2 Fulfilment Measure Proposal for Clinical Workflows

In this work, we present a workflow fulfilment measure based on similarity techniques. Our proposal uses different similarity functions, depending on the connector nodes of the workflow, to quantify the fulfilment degree.

In order to simplify the computational model, we assume that workflow schema does not have nested connectors. However its extension for more complex schemata could be obtained using recursive calls of the functions proposed.

Similarity Measures. Similarity, taken from the cognitive psychology idea, is a key concept of many Artificial Intelligence approaches (e.g. case-based reasoning). In general, a similarity function is a normalised binary function that tries to quantify how similar two elements are. Therefore, it seems reasonable to think that the fulfilment measure of a workflow could be based on the similarity degree between parts of the workflow schema (composed by tasks) and the workflow case (composed by executed tasks).

In the following, we propose some basic functions (named SIM) to measure the degree of similarity between a workflow case and primitive subworkflow schemata.

For the sake of simplicity, we describe these functions in incrementally complexity, describing how to obtain the similarity degree depending on the control nodes.

Firstly, we define how a case task ($ct \in CT$) and the tasks of a workflow schema ($t \in \mathbb{T}$) are compared.

$$SIM_{task}(ct, w) = \begin{cases} 1 \text{ if } ct \in \mathbb{T} \\ 0 \text{ if } ct \notin \mathbb{T} \end{cases} \tag{5}$$

That is, $SIM_{task} = 1$ if ct is a task of w that was executed.

The following expression defines how to check fulfilment of a sequential workflow (i.e. no control nodes but begin and end).

$$SIM_{tot}(c, w) = \frac{2 * \sum_{i=1}^{|c|} SIM_{task}(ct_i, w)}{|\mathbb{T}| + |c|} \tag{6}$$

where $|c|$ and $|\mathbb{T}|$ are the cardinalities of the case and the workflow task set respectively and ct_i is the i-th task of the case.

In the following, we describe how to measure the fulfilment of a and-branched workflow.

$$SIM_{and}(c, w) = \frac{\sum_{i=1}^{n} SIM_{part}(c, w_i)}{n} \tag{7}$$

$$SIM_{part}(c, w_i) = \frac{\sum_{j=1}^{|c|} SIM_{task}(ct_{i,j}, w_i)}{|\mathbb{T}_i|} \tag{8}$$

where n is the number of subworkflow branches of the and control node, $|\mathbb{T}_i|$ is the task cardinality of a subworkflow branch w_i, and $ct_{i,j}$ is its j-th case task.

In order to check the fulfilment of xor split, we define:

$$SIM_{xor}(c, w) = MAX(\{SIM_{tot}(c, w_n), \forall w_n\}) \tag{9}$$

where w_n is the n-th subworkflow branch of the xor control node.

The following expression defines how to check fulfilment of a or-branched workflow.

$$SIM_{or}(c, w) = \begin{cases} 1 & \text{if } (\exists |w_n| = |c|) \wedge (SIM_{tot}(c, w_n) = 1) \\ SIM_{AND}(c, w) & \text{other case} \end{cases} \tag{10}$$

where w_n is the n-th subworkflow branch of the *or* control node.

Finally, the following definition states how to measure the fulfilment of a $loop$ in a workflow.

$$SIM_{loop} = \frac{\sum_{i=1}^{n} SIM_{tot}(c_i, w)}{n} \tag{11}$$

where n is the number of loops performed, while c_i are the tasks performed in the i-th iteration of the loop.

Fulfilment Measure Proposal. We propose a fulfilment measure that can be characterised as: guided (technique dimension), quantifier (dimension task), and covers precedence, or, and, xor, and loop control nodes (problem dimension). Figure 1 depicts the dimensions covered by our proposal.

We present $FULFIL{-}CHECK$ (see Algorithm 2), a workflow fulfilment measure based on the $NEXT$ (see Algorithm 1) function that obtains the pieces of the workflow schema that the case followed (guided strategy).

Algorithm 1. NEXT function

Function *NEXT*(c, w) **return** $(C \times W)$
  $con_i = firstControl(w)$
  $\{$Copy tasks and edges from w until the next connector$\}$
  $w' = copy(\forall task_i, E_i)\ until\ con_{i+1}$ $\{$built a subworkflow of w$\}$
  $\{$built a subcase of C$\}$
  last $task_j \in \mathbb{T}_{w'}$ that $mach(c, task_j)$
  $ct_j = match(C, task_j)$
  $c' =< ct_1, \ldots, ct_j > \ ct_i \in c$
  return (c', w')

Given $w =< \mathbb{T}, \mathbb{C}, \mathbb{E} >$, $firstTask$ and $firstControl$ functions returns the first elements of $\mathbb{T}$ and $\mathbb{C}$ respectively. Given a workflow task $task_i$ and a case c, $match$ function returns the case task $ct \in c$ as the result of the execution of $task_i$.

Algorithm 2. The fulfilment measure proposed

Function *FULFIL-CHECK*(c, w) **return** $[0, 1]$
  $c' = \emptyset, \ w' = \emptyset$
  $overall = 0, \ n = 0$
  while $NEXT(c, w) \neq \emptyset$ **do**
    $(c', w') = NEXT(c, w)$
    $con' = firstControl(w')$
    if $con' = \emptyset$ **then**
      $tot = SIM_{tot}(c', w')$
    else
      case of (con') $\{$depending on connector type$\}$
      AND: $tot = SIM_{and}(c', w')$
      OR: $tot = SIM_{or}(c', w')$
      XOR: $tot = SIM_{xor}(c', w')$
      $LOOP$: $tot = SIM_{loop}(c', w')$
    end if
    $c = c \backslash c'$
    $w = w \backslash w'$
    $n++$
    $overall = overall + tot$
  end while
  return $(overall/n)$

This work is a preliminary study focused on the methodological and the similarity aspects. Note that $NEXT$ function is a simplistic approach only suitable for simple executions, and real situations require a more sophisticated version. Nevertheless, modifications on function $NEXT$ do not affect the rest of the proposal.

3.3 Example in the Medical Domain

We ilustrate the application in the medical domain of the fulfilment measure proposed for a real CPG. In particular, a portion of a real CPG have been modelled (see Figure 2) for the treatment of cerebral vasoespasms of patients affected by Subarachnoid Haemorrhage (SAH) [10].

Therefore, physicians could follow part of this Clinical Workflow (w_{SAH}) for patients affected by SAH. This could be represented by the following examples: $Case\_a$ = <(T1, (0,11)), (T2,(28,148)), (T3,(150,152)), (T4, (170,175))>, $Case\_b$ = <(T2, (0,121)), (T1,(125,138)), (T6, (142,148))>, and $Case\_c$ = <(T2, (0,124)), (T4,(128,134)), (T1, (139,145))>. Then, the $FULFIL - CHECK$ function is used to compute the fulfilment degree of w_{SAH} of cases. Table 1 summarizes the fulfilment calculi. Note that Algorithm 2 iterations depends on $NEXT$ function. For the sake of simplicity, in Figure 2 pointed rectangles (labeled $NEXT(i)$) represents the loops executed by Algorithm 2 (loops $NEXT(-)$ are not considered).

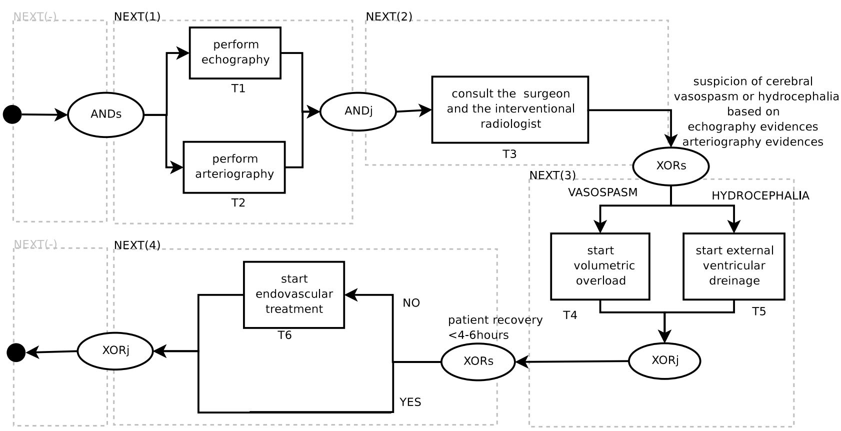

Fig. 2. Clinical Workflow for the treatment of SAH (w_{SAH})

Table 1. Fulfilment degree of w_{SAH}

$Case$	$NEXT_1$	$NEXT_2$	$NEXT_3$	$NEXT_4$	n	overall	Result
$Case\_a$	$SIM_{and} = 1$	$SIM_{tot} = 1$	$SIM_{xor} = 1$	$SIM_{xor} = 1$	4	4	1.0
$Case\_b$	$SIM_{and} = 1$	$SIM_{tot} = 0$	$SIM_{xor} = 0$	$SIM_{xor} = 1$	4	2	0.5
$Case\_c$	$SIM_{and} = 1$	$SIM_{tot} = 0$	$SIM_{xor} = 0$	$SIM_{xor} = 0$	4	1	0.25

4 Conclusions and Future Works

In this work we deal with the correct application of CPGs using Clinical Workflows, as a health-care quality indicator, by measuring the fulfilment of their tasks. Thus, the main results presented are: (1) to present a general workflow model, (2) to state a framework to classify and analyse the development of workflow fulfilment measures; and (3) to propose a method to quantify the fulfilment based on similarity techniques, illustrating its application by the use of part of the Subarachnoid Haemorrhage guideline.

As far as we are concerned, most efforts in workflow modelling focus on the consistent definition of the workflow schema. In [5] the authors states a set of correctness issues. The work described in [6] deals with the management of unexpected situations and handling exceptions. However, our workflow fulfilment measure assumes that Clinical Workflow represents a CPG, i.e. the set of recommendations to follow by the physician team, and therefore the workflow schema and the workflow case could differ. Inspired in the Case-Based Reasoning approach, in [2] a similarity measure is proposed to face the fulfilment of the temporal aspects of CPGs. Unlike that proposal, in this work we focus on the fulfilment of the alternative paths, instead of the temporal facet.

Future works focus on the development of methods for techniques proposed in the framework presented, the extension of the proposed checking method for real life cases (composed workflow schema, $NEXT$ function and weighted pathways).

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