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Synthesizing Analytic Evidence to Refine Care Pathways

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Abstract. Care pathways play significant roles in delivering evidence-based and coordinated care to patients with specific conditions. In order to put care pathways into practice, clinical institutions always need to adapt them based on local care settings so that the best local practices can be incorporated and used to develop refined pathways. However, it is knowledge-intensive and error-prone to incorporate various analytic insights from local data sets. In order to assist care pathway developers in working effectively and efficiently, we propose to automatically synthesize the analytical evidences derived from multiple analysis methods, and recommend modelling operations accordingly to derive a refined care pathway for a specific patient cohort. We validated our method by adapting a Congestive Heart Failure (CHF) Ambulatory Care Pathway for patients with additional condition of COPD through synthesizing the results of variation analysis and frequent pattern mining against patient records.

Keywords. Critical pathways, Data analysis, Knowledge management

Introduction

A care pathway (or critical pathway, clinical pathway) is a complex intervention for the mutual decision-making and organization of care processes for a well-defined group of patients during a well-defined period [1]. It usually consists of multiple phases corresponding to different disease progress conditions where each phase can have sub-phases or care activities performed by care givers. It has been widely used by care managers to create evidence-based care plans for individual patients with specific clinical conditions in order to improve care quality. As the clinical evidence that forms the basis for care pathways has a surprisingly short shelf life, it is not unusual that a care pathway could fail to address the clinical needs of a specific patient cohort due to the absence of required clinical knowledge or the evidence supporting a care pathway becoming obsolete. Thus, to successfully put a care pathway into practice and better adapt it to a local care setting, clinical institutions must revise the care pathway based on the discovered best practice from their own patient records.

To address the above issue, our previous work [2] has developed a care pathway workbench that allow users to develop care pathways by integrating evidences identified from clinical guidelines and patient data. However, integration of various evidences is done manually and relies on the personal knowledge and experience of the

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pathway developer. This integration process becomes time-consuming and error prone when the care pathway is complex and multiple analytic tools are used to identify the best practices from clinical data sets. The task is particularly challenging if these multiple analytic tools may employ different methods, emphasize on different patterns, and even are performed on different data sets (A care pathway may involve collaboration among different departments and/or institutions).

Therefore in this paper we aim to propose an intelligent method to streamline the process of synthesizing different pathway evidences produced from various analytic methods and recommend the appropriate modelling operations (add, delete, update pathway elements) based on the synthesized evidences. The method was validated on a Congestive Heart Failure (CHF) Ambulatory Care Pathway and two analytical methods working on a real data set for patients with CHF and COPD. We believe that it could greatly improve the effectiveness and efficiency of care pathway developers who aim to refine a care pathway for a specific patient cohort using analytics.

1. Methods

We formally represent a care pathway (CP) as CP = (A_M, S, Δ, C, D), where $A_M \subset A$ is a set of CP activities, S is a set of care phases/subphases, Δ: $A_M \rightarrow S$ is a many-to-many mapping between activities and phases, C is a set of temporal constraints between pairs of activities or phases (For example, an activity of testing blood lipids must be performed before an activity of prescribing ACEI), D is the set of information elements (an information element can be either a clinical document or a specific data item) used throughout the CP. Our goal is to refine such a CP based on analytic insights from local data sets. Figure 1 illustrates our approach.

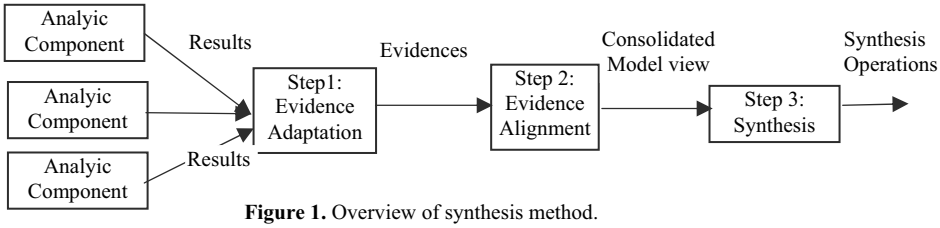

Figure 1. Overview of synthesis method.

Step 1: Adapting various analytic results as modelling evidences. Though different analytic components may employ different analysis methods working on different sources (including clinical guidelines and clinical data sets), we can generalize their results as pathway modelling evidences. Each evidence states the presence strength of a piece of pathway element, e.g., an activity and a temporal constraint (for simplicity, we do not consider the evidences related to phases and sub-phases as the phases are seldom changed for a pathway). Depending on the semantics of results from particular analytic components, we classify evidences into voting evidences and vetoing evidences. For example, additional activities (which are not defined in the original CP) identified from a pathway variation analysis are considered as voting evidences. In the subsequent sections, we use $E_i^+(a_j)$ to represent a voting evidence derived from analytic component i towards activity a_j , $E_i^-(a_j)$ to represent such a vetoing evidence against a_j , $E_i^+(a_j, a_k)$ to represent a voting evidence derived from

analytic component i towards a precedence constraint (a_j must be performed before a_k) , and $E_i^-(a_j, a_k)$ to represent a vetoing evidence towards such a constraint. The strength of an evidence could be measured using its support degree in a data set or correlation with some expected outcome.

Step 2: Aligning evidences with the base care pathway. With the adapted modelling evidences from various sources, we need to synthesize them together in order to recommend refinement operations against the base care pathway. Because an activity can be defined in multiple phases and data sets usually do not include explicit phase labels for each activity, the evidences resulted from analytical components may not have labelling information either. Thus, a critical task is to assign those evidences with unknown phase labels into appropriate phases. We adopt a K-means clustering method to solve the problem where we cluster activity evidences relying on their context attributes including performer role, information required, information updated, temporal relationships with other activities, and K is the number of phases, and the members of one cluster are assigned into the same phase. We represent the alignment result as a Consolidated Model View (CMV) where the original CP is a tree and aligned evidences are put into appropriate branches. Figure 2 depicts an example of CMV where the CP has 3 phases and 3 activities a1, a2 and a3, and 5 evidences are aligned with the CP. Note that multiple evidence from different sources may target to the same CP element. We call them *peer evidences*, and $E1^+(a4)$ and $E2^+(a4)$ are such examples as they both target to a4 (which is actually a newly discovered activity from the data). Other three evidences are noted as *unique evidences.*

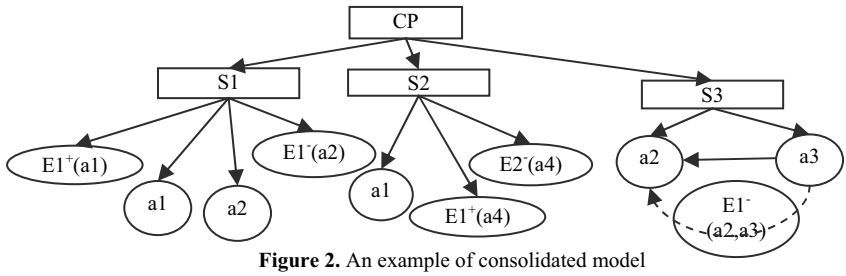

Figure 2. An example of consolidated model

Step 3: Recommend synthesis operations. After a consolidate model view is formed, we recommend three types of synthesis operations for a given CP as follows:

- ADD(Tx): Adding a newly discovered element Tx to the CP where Tx can either be an activity or a precedence constraint between two existing activities in the CP.
- DEL(Tx): Deleting an existing pathway element Tx in the CP.
- UPD(Tx, Mandatory): Changing behaviour of activity Tx from optional to mandatory (the default execution behaviour of an activity in a CP is optional)

Figure 3 depicts the sketch of our algorithm of recommending synthesis operations. The main idea is that (1) for an unique evidence the algorithm recommends an ADD or DEL operation depending on whether it is a voting or vetoing evidence and whether its strength exceeds the predefined thresholds (which can be proportion of patients with a voting evidence or without a vetoing evidence); (UPD operation is generated if strong voting evidence is associated with an existing activity) (2) for peer evidences targeting to the same element, it firstly merges them to a virtual unique evidence and then applies the same rule as (1) to recommend operations accordingly. The merging process determines if the virtual unique evidence is voting or vetoing depending on the

strength of each peer, and assigns a reconciled strength with it. Note that because the strength of evidences from different analytic sources may be measured using different metrics and each source may have different power in reconciliation, our algorithm allows to set different source weights for evidences when reconciling the conflicts among peers.

```
For each evidence Ei with target Tx and a strength of Pi  in evidence set E
If Ei is unique :L1(Treating an unique evidence)
        If Tx is already defined in CP
              If Ei is a voting evience
                  If (Pi > Threshold_mandatory)
                          Then generate an update operation UPD(Tx, mandatory)
              Else     If (Pi > Threshold_delete)
                          Then generate a delete operation DEL(Tx)
        Else
             If Ei is a voting evidence with a strenth of Pi
                  If (Pi > Threshold_add) Then generate an add operation ADD(Tx)
Else :L2(Treating peer evidences)
         Remove Ei's peer evidence with the same target Tx from E
         Merge peers and construct a virtual unique evidence Ev
         Call :L1
```

Figure 3. Algorithm of recommending synthesis operations.

2. Results

We applied the proposed method to refine a CHF care pathway so that a more specific care pathway for patients with both CHF and COPD (chronic obstructive pulmonary disease) can be generated. The original CHF pathway is defined based on a clinical guideline for the management of CHF [3], including 3 phases, 64 activities and 83 constraints between the activities. We employed two analytical components, namely, a variation analyser (VA) [4] and a frequent pattern miner (FPM) [5] to identify the best practices based on the records of a cohort of 430 CHF patients with COPD condition as well. In specific, VA computes the support degrees of CP elements and is used to identify (1) Additional activities, which are not defined in the CP but often occur in the patient records; (2) Absent activities, which are defined in the CP but seldom/never occur in the patient records; and (3) Violated constraints, which are defined in the CP but often violated in the patient records. FPM is to extract common sequences of clinical activites that are present in the patient records, and perform statistical analysis on how each sequence pattern correlates to patient outcome (in this case, the expected outcome is no-hospitalization within one year of diagnosis of COPD). We summarize the synthesis results of these two components as follows:

- Both agreed on the same voting evidences (having high support from VA and high outcome-correlation from FTM) and suggested to add the corresponding activities (e.g., Nonsteroidal Anti-inflammatory drugs, Bronchodilators which are useful for the treatment of CHF and COPD) to the derived CP. Likewise, in some cases both agreed on the same vetoing evidences and suggested to remove the corresponding activies from the derived CP. We did not get an update operation of existing activity which requires 100% support from VA.
- FTM identified a pattern with good outcome while VA had a low support to it. Tests of alkaline phosphatase and protein are such examples in our results. In this case, the synthesis method did not suggest adding operations.

- VA identified additional activities (e.g., Antianginal Agents) which however have negative correlation with the outcome (odds ratio < 1) based on FPM. In this case, the synthesis method did not suggest adding operations.
- VA identified absent activities which however were not supported by FPM. For example, though VA found that the baseline tests of BUN and glucose are seldom performed in phases 1 and 2, FPM identified them as good practice patterns in terms of clinical outcome in terms odds ratio. Thus, the synthesis method did not suggest removal of these activities.
- VA identified violated constraints which however were found having strong positive impact with the clinical outcome by FPM. For example, VA detected that the constraint of "a lipid measurement must be performed before prescribing diuretics at the phase 3" is often violated in patient records. However, FPM found that following this pattern may lead to better outcome in practice. Thus, the synthesis method kept this constraint in the derived CP.

The synthesis operations above were validated by a clinical expert and deemed useful to develop a specific pathway for patients with both CHF and COPD. However, we need to be cautious about the set of deleting operations where the majority are about the lab test activities. This reflects the non-compliance of clinicians in practice and may not be the real cases which we should delete from the CP definitions.

3. Discussion

Currently, elements of our care pathway do not include data related constraints between activities which in practice do exit. For example, "ensure serum potassium (k) ≤ 5.0 mmol/L before initiating angiotensin-converting enzyme inhibitors (ACEI)" is such a data constraint for using ACEI. In future, we would consider to synthesize evidences of data constraints where one critical issue is to reconcile the conflicts between different expressions, such as "serum potassium ≤ 5.0" and "serum potassium >4 and hba1c < 6.5". On the other hand, though we have proposed an automatic method to recommend refinement operations based on the analytic results, there is still a need to evaluate the resulted care pathway if taking recommended operations.We thus are also developing an outcome-oriented evaluation method to predict whether the derived care pathway could lead to a better outcome based on historic patient records.

References

[1] K. Vanhaecht, K. De Witte, and W. Sermeus. *The impact of clinical pathways on the organisation of care processes*. Belgium: KU Leuven (PhD dissertation), Katholieke Universiteit Leuven., 2007.

[2] Yiqin Yu, Haifeng Liu, Jing Li, Xiang Li, Jing Mei, Guotong Xie, Adam Perer, Fei Wang, and Jianying Hu. Care Pathway Workbench: Evidence Harmonization from Guideline and Data. *Studies in Health Technology and Informatics* **205** (2014), 23-27

[3] Hunt SA, Abraham WT, Chin MH, Feldman AM, Francis GS, Ganiats TG, et al. ACC/AHA 2005 guideline update for the diagnosis and management of chronic heart failure in the adult. *Circulation*. 2005; 112(12): 154-235.

[4] Xiang Li, Haifeng Liu, Shilei Zhang, Jing Mei, Guotong Xie, Yiqin Yu, Jing Li, and Geetika T. LAKSHMANAN. Automatic Variance Analysis of Multistage Care Pathway Workbench. *Studies in Health Technology and Informatics* **205** (2014), 715-9

[5] Adam Perer and Fei Wang. Frequence: Interactive Mining and Visualization of Temporal Frequent Event Sequences. *ACM Intelligent User Interfaces (IUI)* 2014. Haifa, Israel. (2014)