

# A Method for Reporting of Variance in Informal Care Pathways

John J Chelsom<sup>a,b</sup>, Conceição Granja<sup>c</sup>

<sup>a</sup>Seven Informatics Ltd, Banbury, United Kingdom

<sup>b</sup>Health Information Science, University of Victoria, Victoria, Canada

<sup>c</sup>Norwegian Centre for E-health Research, Tromsø, Norway

## Abstract

Care pathways are commonly used as a means to ensure the implementation of proven best practice in clinical care. They can be defined in an Electronic Health Record system using formal representations of template pathways which are then instantiated for specific patients, to guide clinical users through a sequence of tasks and actions. The open source cityEHR system uses HL7 CDA documents for the formal pathway definitions, but in practice we have found that some care pathways, and clinical protocols, can be implemented effectively using less formal mechanisms. In addition to the shared patient record itself, we find that the most important of these mechanisms are notification on recording of patient events, support for care teams, annotation of the record, and the clinician-centred 'In-Tray'. One important feature lost in this approach is the ability to report on the variance of the care provided to the patient from the best practice encapsulated in a more formally defined pathway. To address this, we describe a method for transforming a formally defined care pathway to a finite state machine representation and querying the patient record to generate a retrospective report on the variance of states recorded in the patient record.

## Keywords:

Care pathways, Clinical communication, Patient-centred EHR, HL7 CDA, Finite State Machine, Variance Report.

## Introduction

A care pathway is a step-by-step guide for the care or treatment of a patient, in a defined clinical context, usually following an evidence-based recommendation of best clinical practice in that context. The implementations of care pathways in Electronic Health Record (EHR) systems generally adopt a formal approach to the definition of template pathways, which are then instantiated with data from an individual patient record to create specific instances that guide the care of that patient [1].

The open source cityEHR system uses HL7 CDA documents [2] to provide the formal definition of care pathways and records the progress of the pathway as a series of CDA documents stored in the patient record [3]. For some implemen-

tations of the cityEHR we have observed that alternative, and less formal, methods are more effective in managing the care pathways. We define an informal care pathway as being a set of mechanisms, configured in the EHR, which guide clinical users in following a sequence of actions, without a predetermined or prescribed specification of that sequence.

These mechanisms use the patient centred record as the hub for communication between the care team and the patient, in the ways described by Ueckert et al [4] and White & Danis [5]. The use of the EHR as the facilitator for communications has been identified as one of the key issues in the patient-centred medical home (PCMH) model in the United States [6].

As an example, we refer in this paper to an implementation of cityEHR which supports the activities of a Fracture Prevention Service (FPS) in the UK. This system, called Elfin, has been developed at the Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences at the University of Oxford. Elfin has been running in Oxford since March 2015, and has seen live operation at two other NHS sites in England. The system is built on the cityEHR platform, with an information model developed specifically to address the requirements of the Fracture Liaison Service.

The first implementation of Elfin was designed with a formal representation of the care pathway, using HL7 CDA as the underlying data representation. The advantage of using HL7 CDA is that the care pathways are stored in the record in the same form as all other clinical documents [3]. The Care Pathway engine in cityEHR then uses the formal definitions to drive the sequence of actions undertaken by clinical users, where the outcome of each action is itself recorded as an HL7 CDA document (e.g., a form, letter, order, prescription, etc.).

After the first implementation, we discovered that a more flexible, less formal, approach could be used; it is this version that was adopted for live use and its key features are described in the following section. One consequence of this alternative approach is that there is no inherent mechanism for reporting on variance (or compliance) with the formally defined pathway. Reporting of variance has been identified by Wakamiya and Yamauchi as one of the key features of a conventional care pathway implementation [7], and hence is an important issue to address.

Our objective, therefore, was to define and implement a method for reporting on the variance between actions recorded in the patient record and the set of actions defined formally in a care pathway, where that pathway is applied retrospectively, rather than being used to prescribe the sequence of actions as they are performed. This method is based on the transformation of the pathway into a finite state machine, as proposed by Eshuis [8], followed by pattern matching and temporal analysis as proposed by Awad et al [9].

In this paper we describe our approach to implementing care pathways using informal mechanisms of patient-centred clinical communication within the cityEHR, the feedback we have gathered after experience with an operational EHR and a method for retrospective reporting of variance from a formally specified pathway.

## Methods

### The Formally Defined Care Pathway

An example care pathway is shown in Figure 1, depicted as an Activity Diagram, following the conventions of the Unified Modelling Language (UML). This example is a simplified version of the Fracture Liaison Service pathway implemented in the Elfin system.

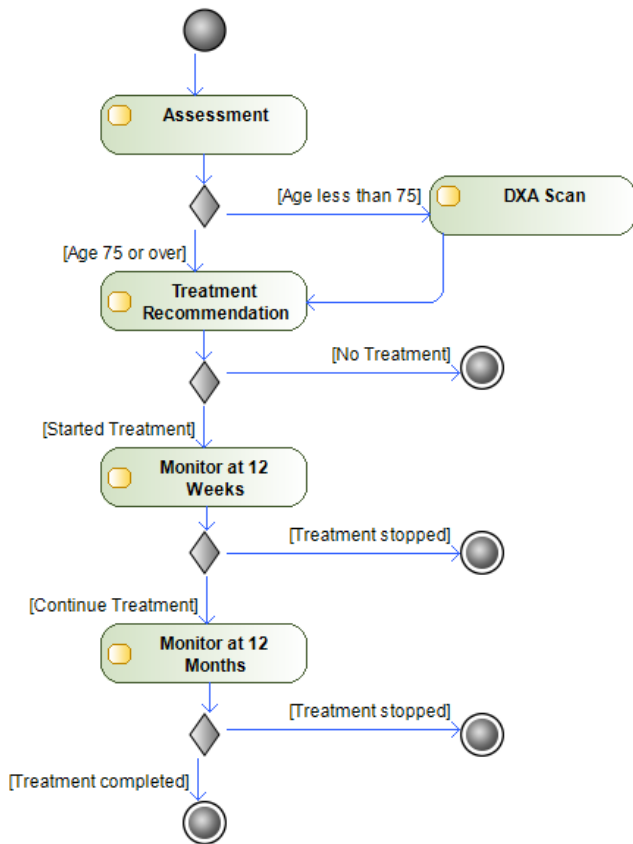


Figure 1- Simple Care Pathway for Fracture Liaison Service.

The pathway starts when patients are identified by the service, following hospital admission with a diagnosed fragility fracture (a fracture caused by a fall or minor trauma that would not normally result in a fracture, unless the bones had been weakened). The identified patient is assessed and sent for a bone density scan (DXA) if they are under the age of 75 (patients aged 75 and over are assumed to have some degree of age-related bone weakness, so the bone density scan is not deemed necessary). In most cases, a recommendation is made for treatment, but if not, the pathway ends. Patients who do have treatment are monitored after 12 weeks and then again at 12 months, to check compliance to the treatment, recommend possible alternatives or to acknowledge the patient's decision to stop treatment.

The cityEHR stores all clinical data as HL7 CDA documents, which follow the hierarchical structure of a health record specified in the ISO-13606 standard [7]; folder, composition, section, entry and element, where the elements record the actual recorded data values and the entries that contain elements are the lowest level of atomic clinical context.

All clinical data gathered in the example pathway shown in Figure 1, and any clinical decisions made, are recorded in the patient record in CDA documents for the Assessment, DXA Scan Results, Treatment Recommendation and Monitoring. The Monitoring documents are completed based on the answers to a questionnaire sent to patients in a letter, prior to the 12 week and 12 month monitoring dates; these letters are also stored in the patient record as CDA documents.

A formal specification of the pathway is created in cityEHR as a CDA document, which can then be instantiated for a specific patient and saved in the record in a series of versions that record progress through the sequence of actions in the pathway and prompt users (through their In-Tray) for the next action(s) to perform [3]. Once the pathway is completed, the CDA document is committed to the patient record as evidence of the actions performed.

### Informal Implementation of Care Pathways

The same core features of cityEHR that enable the formal execution of care pathways, as described above, can be used in a more loosely coupled way to achieve a similar control over the sequence of clinical activities. These features are:

- [1] support for care teams;
- [2] triggers and notification when documents are committed to the record;
- [3] annotation of the historic record, with associated notifications;
- [4] a clinician-centred In-Tray for handling of notifications.

### Support for Care Teams

The cityEHR supports the formation of care teams, which are composed of both clinical and administrative system users. Subject to access control permissions, any user can create a care team and then assign users to it. The care teams act as user groups for the purposes of clinical communication. Any

such communication (initiated through the notification or annotation mechanisms described below) can be directed to an individual (named) user, to a user role or to a care team.

### ***Triggers and Notifications***

Triggers can be configured to watch for the committal of specific compositions, entries and elements to the record. There are two types of trigger:

- for immediate navigation/action by the current user
- to notify future actions that may be performed by any (specified) user

Triggers are defined so that when a specific combination of composition, entry and element is committed to the record, and other pre-set conditions are satisfied, the trigger is activated.

For navigation triggers, the user is immediately prompted for the choice of navigation to other parts of the patient record. These choices can include viewing the clinical dashboard, viewing summaries of the record for the individual patient or creation of a new clinical document for the patient; for example a form, letter, order or prescription.

For notification triggers, a new notification composition is instantiated and added to the patient record. Notifications are stored as HL7 CDA documents, in the same way as all other clinical data, and contain information about the source of the notification, the system users to be notified and the actions (if any) that are required in response.

### ***Annotation of the Historic Record***

The mechanism of triggers and notification described above, implements pre-configured pathways of clinical actions. For more ad-hoc communication between members of the care team, the annotation features can be used. Once data have been committed to the record (in the form of an HL7 CDA composition), users can annotate any document in the record and address notifications to other users, roles of user or members of a care team. It is not possible to send ad-hoc notifications without reference to a document in the record. This ensures that all communication is centred around the patient record; there is no support for communication between system users that is not related to an individual patient.

### ***Clinician-Centred In-Tray***

The In-Tray acts as the hub for communication, whereby a system user can view and act upon all the notifications that have been addressed to them by other users. These notifications may have been addressed to the individual user, to one of their assigned user roles or to one of the care teams of which they are a member.

The In-Tray is a cross-patient feature, which looks and feels similar to a standard email facility. However, it is fundamentally different, in the sense that the list of notifications seen in a user's In-Tray is formed by a dynamic query across the records stored in the cityEHR. Each notification then provides a link directly through to the record of the individual patient about which it concerns. Hence, there is no stored 'in-box' of notifications for each user, instead there is a display

of the virtual in-box created each time the user accesses the In-Tray. Similarly, although the user accesses specific documents, or actions, in the patient record through the In-Tray, no part of the patient record is transmitted; the notification merely contains a pointer to the patient record, which remains stored in the database and subject to the usual access controls.

## **Results**

### **Reporting of Variance from Formal Pathway**

Using the methods described in the previous section, a care pathway can be implemented using informal mechanisms to guide the actions of system users. As these actions are completed, the EHR provides a history of the results of each action in the form of HL7 CDA documents stored in the record for the patient. To the system user, this process seems similar to the more formal implementation, but unlike the formal implementation there is no underlying 'engine' to ensure that the sequence of actions follows the pre-defined pathway.

Instead the user is guided by a series of notifications or annotations, each of which is triggered independently, based on the current state of the patient record. As a result, since no predetermined sequence of actions is being followed, it is not possible to determine at any specific time, whether a particular pathway has been completed, or whether a pathway is in progress and partially completed.

However, we may wish to analyse the sequence of actions completed, to assess whether they follow the steps in a formally specified pathway which has been applied retrospectively.

To achieve this, the pathway is defined as an HL7 CDA document, in the same way that it would be defined to drive the formal execution of the pathway. The CDA document (in XML) is then transformed using XSLT into a representation of the finite states in the pathway. This representation uses the State Chart Extensible Markup Language (SCXML) which was published as a W3C standard in 2015 [10]. SCXML was based, in part, on the STATEMATE graphical process representation language, first described by Harel et al [11].

Using the SCXML representation, a set of database queries is generated to interrogate the state of the patient record along a set of time lines, derived from the set of possible initial states found in the record. The queries are expressed in XQuery, the W3C standard for representing queries for XML databases, since the EHR is stored as a collection of HL7 CDA (XML) documents.

Hence, the first query finds any documents recorded in the patient record which match the initial state for the pathway. Each of these documents is a candidate initial state and the effective time of the document (i.e. the time it was committed to the record) sets the base time for the pathway. The next queries find candidates for the second state in the path-

way and advance the timeline to the effective time of those states.

The sequence of XQuery submissions to the database is continued until a sequence of states has been found which validates the pathway. Alternatively, the submission of searches continues until all the set of possible valid sequences has been exhausted. The results for the searches are then collated and returned as the variance report, which is generated as an HL7 CDA document (which can then be stored in the patient record, if required).

The overall method of reporting variance is summarised in Figure 2.

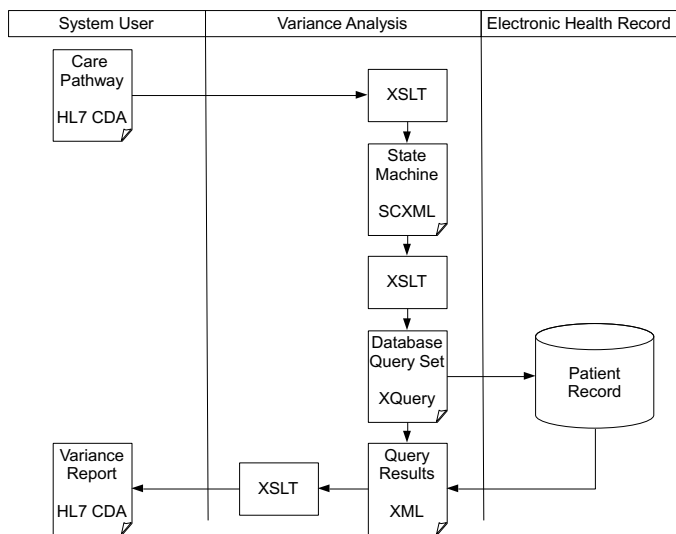


Figure 2-Reporting Variance Using SCXML.

Returning to the example pathway from Figure 1, it can be seen that there is a single initial node in the pathway and four possible end nodes. The state transition from the initial node to one of the end nodes can be defined by a sequence of CDA documents, as shown in Figure 3.

The state transitions are shown for patients under the age of 75 years, who have a DXA scan; there is a similar set of transitions for patients aged 75 and over, without the DXA Results document. The set of XQueries generated from the pathway definition search for patterns of documents that match the state transitions. So in this example, the first query searches for Assessment documents, then DXA Results, then Treatment Recommendations, in the correct time order. Within the documents, the queries test for Age < 75 and the type of Treatment (Started or None). The next queries search for Monitoring documents, with tests for the Monitoring Phase (12 weeks or 12 months) and the Treatment (Ongoing, Stopped or Completed).

Collating the results of these queries allows a report of variance to be generated, which shows:

- potential pathways that were started but then deviated from the definition (had one or more valid transitions from the start state, but then had an invalid transition)

- pathways that have started, with valid transitions, but which are not complete (are missing states to the end node, but have no invalid transitions)
- pathways which are complete (have a set of valid transitions from a start node to and end node)

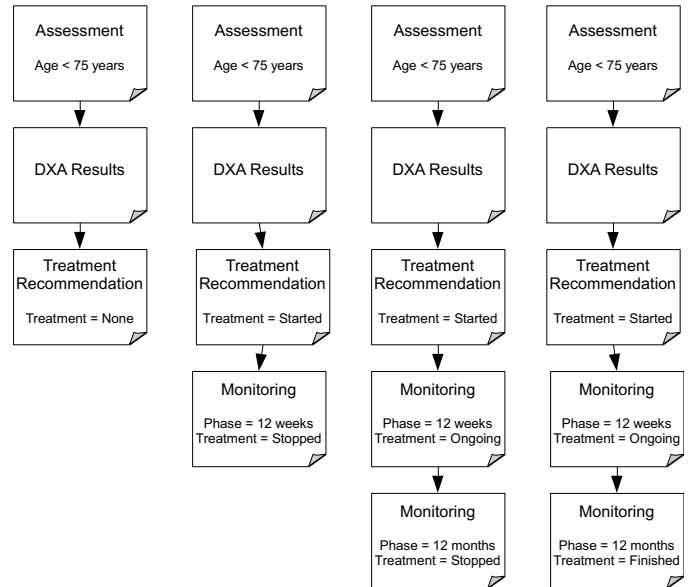


Figure 3: Pathway State Transition

## Discussion and Conclusion

Care pathways in cityEHR are modelled as HL7 CDA documents. The XML structure of an HL7 CDA document is ideal for representing the hierarchical decomposition of tasks in a pathway, and processing of the pathway can take advantage of some general properties of XML as a hierarchy of document nodes. We have demonstrated how the same methodology can be used in the implementation of informal care pathways. However, by describing care pathways using informal mechanisms it becomes a requirement to determine the completion of a particular pathway according to the actions recorded in the patient record.

We propose a method to report on the variance from a formally defined pathway, using the information set recorded for the patient. This method uses the same representation of the pathway that would be used in the formal implementation but, transforms it first into a finite state machine representation (SCXML), and then into a set of (XQuery) database queries that are used to find patterns of information in the record and report on variance of the recorded data from the pathway.

One key advantage of the method we propose is that any pathway can be formulated retrospectively, and then applied against the patient record to report variance.

The implementation of this method has been validated with simple example pathways, such as the one presented in this paper, and has been shown to function correctly. Future work

will be to validate the method with more complex pathways and real patient data.

### Acknowledgements

John Chelsom would like to thank the members of the Elfin project team and the Oxfordshire Fracture Liaison Service at the Nuffield Orthopaedic Centre, Oxford.

Conceição Granja would like to thank the regional health authority Helse-Nord for funding the research project HST1304-16.

### References

- [1] Gooch P, Roudsari A. Computerization of workflows, guidelines, and care pathways: a review of implementation challenges for process-oriented health information systems. *Journal of the American Medical Informatics Association*. 2011;18(6):738-748.
- [2] Dolin RH, Alschuler L, Boyer S, Beebe C, Behlen FM, Biron PV, et al. HL7 clinical document architecture, release 2. *Journal of the American Medical Informatics Association*. 2006;13(1):30-39.
- [3] Chelsom J, Pande I, Gaywood I, Granja C, Bolle SR. Document-Driven Care Pathways Using HL7 CDA. In: *Proceedings of the Seventh International Conference on eHealth T, and Social Medicine*. International Academy, Research and Industry Association; 2015 Presented at: eTelemed February 22-27, 2015; Lisbon, Portugal p. 118-123.
- [4] Ueckert F, Goerz M, Ataian M, Tessmann S, Prokosch H-U. Empowerment of patients and communication with health care professionals through an electronic health record. *International journal of medical informatics*. 2003;70(2-3):99-108.
- [5] White A, Danis M. Enhancing patient-centered communication and collaboration by using the electronic health record in the examination room. *Jama*. 2013;309(22):2327-2328.
- [6] Bitton A. Who is on the home team? Redefining the relationship between primary and specialty care in the patient-centered medical home. *LWW*; 2011.
- [7] Wakamiya S, Yamauchi K. What are the standard functions of electronic clinical pathways? *International journal of medical informatics*. 2009;78(8):543-550.
- [8] Eshuis R. Symbolic model checking of UML activity diagrams. *ACM Transactions on Software Engineering and Methodology (TOSEM)*. 2006;15(1):1-38.
- [9] Awad A, Decker G, Weske M. Efficient compliance checking using BPMN-Q and temporal logic. In: *Proceedings of the Springer*; Presented at: *International Conference on Business Process Management*, 2008; p. 326-341.
- [10] Barnett J, Akolkar R, Auburn R, Bodell M, Burnett D, Carter J, et al. State chart XML (SCXML) state

machine notation for control abstraction. *W3C Recommendation*. 2015.

- [11] Harel D, Lachover H, Naamad A, Pnueli A, Politi M, Sherman R, et al. Statemate: A working environment for the development of complex reactive systems. *IEEE Transactions on software engineering*. 1990;16(4):403-414.

### Address for correspondence

Dr John Chelsom, Seven Informatics, 16a North Bar Street, Banbury, Oxon, UK. [john.chelsom@seveninformatics.com](mailto:john.chelsom@seveninformatics.com)