Designing Guideline-based Workflow-enabled Electronic Health Records

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Abstract

With the rising prevalence of chronic illness, there is a growing pressure to develop systems that engender evidence-based care. The potential for workflow support to coordinate services and improve communication in the context of chronic disease management is intuitively appealing, but is still a challenging (and hence rarely seen) accomplishment in practice. We examine the problem of achieving a close relationship of Electronic Health Record (EHR) content to other components of a clinical information system (guidelines, decision support and workflow), with particular emphasis on integrating the EHR with workflow. We use the open*EHR architecture, which allows extension of a core Reference Model via Archetypes, to refine the detailed information recording options for specific points in the workflow and to represent the chain of instructions that is the workflow itself. We illustrate the use of* open*EHR for tracking the relationship of a series of clinical services or events to a guideline-based workflow via a case study of an Early Supported Discharge (ESD) program for Post-Stroke Rehabilitation. This case study shows the contribution guideline content and its derived workflow can have on problem-specific EHR structure and demonstrates the potential for a constructive interaction of workflow support and the EHR. We conclude with a discussion of the practical boundary of applicability of workflow approaches versus decision support system approaches in supporting guideline-based care.*

1. Introduction

> Our world is in transition. Societies all over the world are becoming more urbanized. Populations are ageing. Physical activity levels are declining as people adapt to more sedentary lifestyles. We see a major shift away from traditional diets, and the increased consumption of energy-dense diets with high levels of fats and sugars, as well as salt. The consumption of fruit and vegetables is also going down. All these factors, as well as tobacco use, have dramatically changed the global profile of disease. Non-communicable conditions now account for approximately 60 per cent of the 56.5 million global deaths annually.
>
> *- Dr Gro Harlem Brundtland, Director-General of the World Health Organization, Geneva, 16 May 2003.*

In light of increasing prevalence of chronic illness, a key element of health strategies for developed countries must be to increase the effectiveness of Chronic Disease Management (CDM) activities, including chronic disease prevention, where possible. It is generally accepted that, when properly contextualised and deployed, clinical practice guidelines systematically developed from the best available evidence can lead to improved outcomes across a wide spectrum of healthcare activities [1]. Moreover, there is a widely held optimism (at least in the medical informatics community) that the use of clinical decision support systems – i.e., systems that provide patient-specific advice – can facilitate the practice of evidence-based medicine and thereby substantially improve health care quality [2]. The empirical record shows that many clinical decision support systems do appear to be effective [3], however, the record of successes in CDM is patchy. In fact, a recent evaluation of primary care decision support for asthma and angina in the UK found the system to have no influence on healthcare process or outcomes [4]. There is still much to be learned about successful development and deployment of information technology to improve CDM outcomes.

Current guideline models vary depending on the type of processes they try to express. A typology of four modeling formalisms used by guideline models is iden-

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tified in [5]: (1) flowcharts for algorithmic problem-solving processes; (2) disease-state maps to relate decisions made during the course of patient care; (3) sequencing of activities in care plans that aim to meet goals; and (4) workflows to model care processes in an organisation. We take the position that in general, engineering of a given guideline for use in a clinical information system with electronic decision support produces a number of artefacts [6]. In particular: (1) guidelines allow us to specify what needs to be recorded (EHR content), when to record; (2) how to evaluate/make decisions (computer interpretable clinical guidelines (CIGs)); (3) specify what needs to be done (workflow schemas/definitions that may include a combination of clinician and system dependent actions); and (4) produce a human-readable electronic version of the guideline as hypermedia. Maintaining a clear relationship among these artefacts during the execution of the system is key to successful computer support in CDM.

Panzarasa et al. report the successful representation of evidence-based post-stroke rehabilitation guidelines as a workflow model from which a 'careflow' management system is implemented using Oracle Workflow tools [7]. This system illustrates that at least in some cases, a very significant aspect of the knowledge from an evidence-based guideline for CDM can be expressed through the design of a patient-centred workflow. However, this workflow remains disconnected from the EHR, which effectively makes it difficult to build integrated clinical information systems that provide *patient-specific* decision-support seamlessly with the provider's workflow, and providing support for what needs to be captured at a given point in time. A particular focus of this paper will be on the design of EHRs as an approach to help ensure that the appropriate information is collected within the EHR for specific points in the workflow.

With respect to health policy for CDM, the Australian Commonwealth (federal) Government has taken a significant step through its Enhanced Primary Care (EPC) framework, which introduces a variety of new reimbursement items for health care providers through the Medical Benefits Schedule (MBS). In particular, healthcare providers can be reimbursed through the MBS for care planning and discharge planning activities [8]. As an administrative system, the EPC MBS items allow General Practitioners (GPs, family physicians) and others to make claims *if* they perform the right set of activities at the right time *and* properly document those activities. This has given rise to localised guidebooks that are an interesting blend of evidence-based medicine and administrative how-to manual (e.g., [9]).

We believe that the power of workflow to represent evidence-based CDM has been under-emphasised vis-à-vis algorithmic decision support (e.g., CIGs); and furthermore that there has been insufficient exploration of the role of the electronic health record (EHR) to integrate with such workflow, and in fact to play a significant part in its implementation. In this paper, we present a model and architecture aimed at facilitating the development of EHRs and associated clinical information systems to incorporate guideline-based workflow for CDM. The model and architecture exploits the *open*EHR approach to allow extension of the Reference Architecture for specific EHR refinement as requirements are identified. The next section of this paper describes the workflows derived from an Early Supported Discharge (ESD) case study – in terms of clinical domain, this is very closely related to the post-stroke rehabilitation system reported by Panzarasa et al., [7], however, we have a greater focus on the re-integration to the community. Section 3 describes the *open*EHR framework with particular attention to its representation of instructions and associated activities and activity states. Section 4 presents our approach, including the associated system architecture, for representing evidence-based workflow, such as that required for the ESD, in the *open*EHR framework. Section 5 completes the illustration of our approach with a walk-through of part of the lifecycle of an instance of ESD workflow, with the associated EHR instance content. We conclude with discussion of the boundary between workflow and computer-interpretable guideline representations for CDM decision support and by identifying associated future research directions.

2. Early Supported Discharge Case Study

There are particular opportunities for coordinating and supporting the flow of information as a patient is being prepared for discharge from hospital, at which time it is vital to correctly identify and service the needs related to sustaining the patient in the community. We illustrate our proposed EHR architecture and workflow interaction in the context of an ESD based on a hospital in suburban South Australia, and the Scottish Intercollegiate Guidelines Network's post-stroke rehabilitation, prevention and management of complications and discharge planning guideline [10]. ESD requires coordination of the hospital discharge planner, occupational therapists (OTs), domiciliary care nurses (through the Royal District Nursing Service (RDNS)), general practitioners (GPs), long-term domiciliary care organisation, and various local government services. Such discharge processes require intensive hands-on approach and comprehensive knowledge of how to access services available in the community,

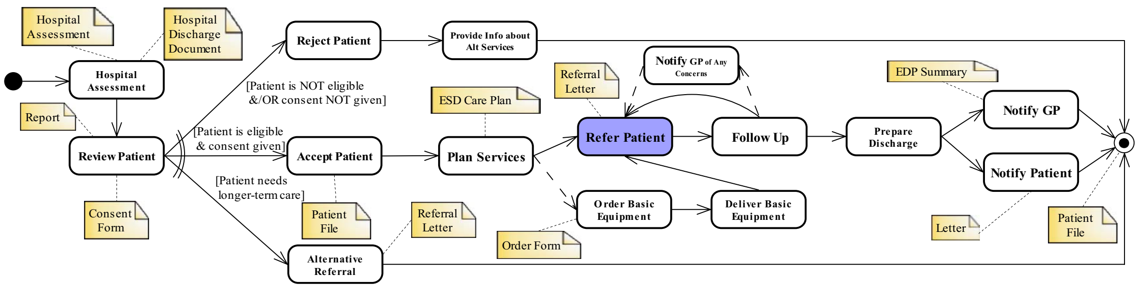

Figure 1. ESD workflow with document to activity mapping

allowing about 100 cases per year to be managed through a two-week post-hospital-discharge period. A clinical information system that supported the coordination would allow significant expansion of the program.

We derive a set of workflows, and the set of documents (i.e., data to be recorded) required in specific points in the workflows from the guideline. The ESD workflow and associated documents is as shown in figure 1. (Notations used are as follows: double arcs crossing multiple arcs from one activity denote exclusive choice; multiple arcs with no double arcs from one activity denote parallel execution of activities; single arc crossing multiple arcs from one activity denote inclusive choice; and dotted arc denotes an inclusive optional activity. Shaded activities represent sub-workflows). Figure 2 illustrates the sub-workflow for the referral to one or more types of care providers. Figure 3 describes the sub-workflow of the OT.

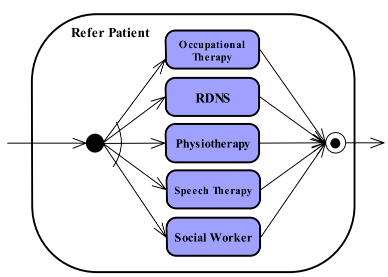

Figure 2. Refer Patient sub-workflow

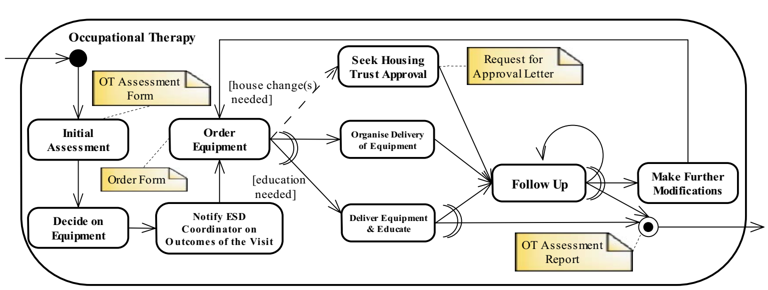

Figure 3. OT sub-workflow with document to activity mapping

3. EHR Architecture

A record architecture is defined as a "set of principles governing the logical structure and behaviour of healthcare record systems to enable communication of the whole or part of a healthcare record" [11]. We use the *open*EHR [12] architecture as the basis for our EHR approach. *open*EHR evolved from the Australian Good Electronic Health Record (GEHR) [13] and provides a method of implementing the clinical content of records through a two-level model framework: (1) a Reference Model, and (2) the Archetype Model.

3.1. *open*EHR Reference Model and Archetype Model

The *open*EHR reference model (RM) represents the generic types and structures for record management, whilst the archetype model (AM) provides the formal structured constraint definitions of clinical concepts (expressed using constraints on instances of an underlying reference model). Archetypes are validation rules that are used to define the particular configuration or desired composition of instances of those concepts. For example, an archetype may be for the concept "blood pressure", and constrains the particular arrangement of instances underneath that entry object as having two content item children for the systolic and diastolic values, and further constrains the valid range of their values and unit type. Such archetypes then serve as building blocks for producing instances of EHRs (see figure 4 in [14]). These archetypes can be used to allow for guideline-specific and case-specific information to be recorded in a general and extensible EHR framework.

3.2. *open*EHR Reference Model Concepts

As illustrated in figure 4, the *open*EHR reference model consists of a number of basic concepts: EHR, folder, transactions, organiser and entry. The *open*EHR *transaction* is defined as a unit of information that corresponds to the interaction of healthcare agent with the EHR. A transaction is very similar to a notion of a "document" and is sub-classed into two types of information: *event* transactions, and *persistent* transactions. An event transaction records data pertaining to a clinical event at a moment time such as a physician encounter or pathology test, whereas a persistent transaction records stateful clinical data that have much longer-term significance such as family history, current medications, care plan, or patient problem list. These transactions are organised within event and persistent *folders* via reference links, and these folders are archetyped similarly to *organisers* described later.

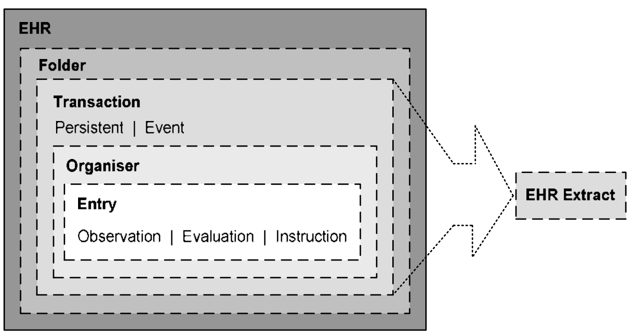

Figure 4. openEHR Reference Model

Using *open*EHR's structural components, such as *organisers*, we then define overall structure of the transaction, in much the same way headings are used to structure a document. In the case of patient-provider encounters, for example, we can define an organiser archetype that allows content entries within the EHR to be organised under Problem-SOAP headings (i.e., Subjective, Objective, Assessment, Plan). Further constraints can be made on entries under the "subjective" and "objective" organisers to be of type observation, under "assessment" organiser to be evaluation, and finally, entries under the "plan" organiser as instructions.

The *open*EHR RM defines the content of all information (recorded in transactions) that occurs in the "clinical statement" context as *entry* instances, subtyped into three classes: *observation*, *evaluation* and *instruction.* Observations are clinical statements due to observation of a phenomenon and may be measurable or subjective statements. Evaluations are clinical statements created as a result of interpretation or analysis of observations, hypotheses, diagnoses, goals, etc; and instructions are statements of actions to be carried out. Our focus will be on plans and instructions as they play a specific role in supporting workflow (to be discussed in the following sections).

3.3. *open*EHR Instructions

We have designed our model (figure 5) to align with the Workflow Management Coalition's (WfMC) workflow reference model [15] as it is widely used by a number of commercial workflow systems. The *open*EHR instruction is divided into *instruction definition* entries that specify the workflow schema / process definition, and *instruction execution* entries that describe the workflow instance.

Event transactions contain instruction definition entries that actuate the creation and updates to instruction execution entries within persistent transactions. That is, they indicate that some "activity(ies)" needs to be undertaken. Instruction definitions may refer to a *guideline_id* that uniquely identifies the guideline from which the instruction originates. The *data, reasoning* and *protocol* detail additional notes the care provider has about the instruction, and are of type STRUCTURE, which is a class for *open*EHR's logical data structures, namely - trees, lists, tables and single data structure. The data items within the structures are represented as compounds or elements, where an element contains a single value, and a compound allows groupings of data items, which may consist of further compounds and/or elements. The subject state pre- and post-conditions of activities refer to the patient state conditions such as "age > 65" and "smoker = true".

In response to an event transaction being posted, an instruction execution entry within a persistent transaction is created – specifying that some "activity/ies" needs to be performed. A persistent transaction's instruction is then regularly amended as the state(s) of its "activity(ies)" progresses. These changes are the result of new event transactions being added to the system. Instruction execution entries refer to the event transaction's instruction definition entries. The state machine for instructions is illustrated in figure 6.

In general, instructions may contain one or more activities (which can either be atomic or composite (i.e., containing two or more activities)). Activities are linked via *connectors*. (Due to limited space, the subtypes of connector are not shown – these include: *sequence*, *split*, *conditional_loop*, *and_join*, and *choice_join*). These connectors specify the pre- and post-conditions for the valid ordering and execution of activities (i.e., conditions pertaining to the workflow execution state rather than the patient state).

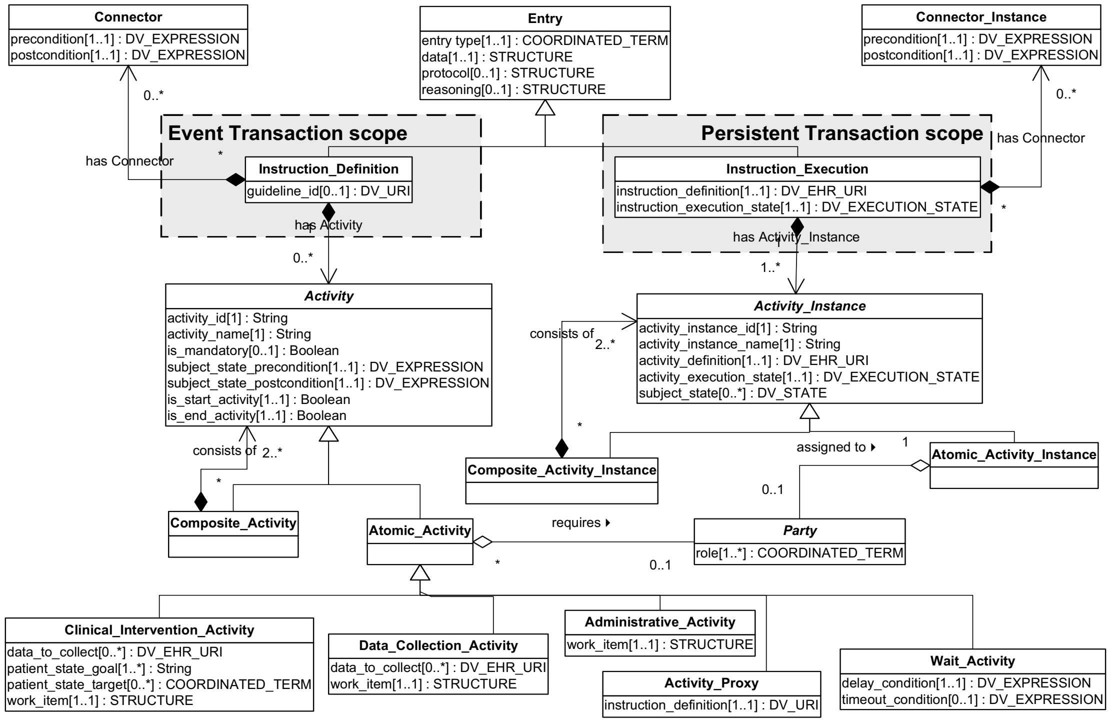

Figure 5. Partial Model for *open*EHR Instruction

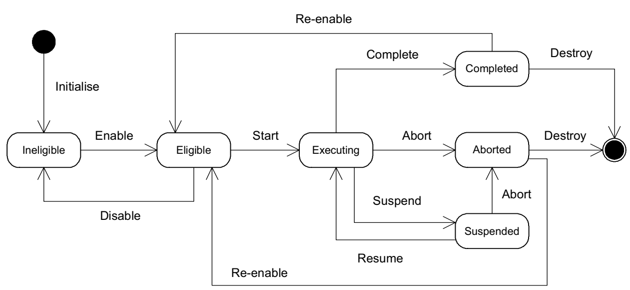

Figure 6. State Machine

A number of types of atomic activities are defined including:

(1) *Clinical_Intervention*: a clinical act or fact of interfering with the intention to modify (i.e., to change somewhat the form or qualities of) the patient's health [16]. E.g., "administer antihypertensive drug". The activity allows one to state the goal or desired patient health outcome for the intervention, as well as possibly setting a specific patient variable target such as a blood pressure target of 130/80 mmHg;

(2) *Data_Collection*: the activity of collecting of observations only rather than an act intended to influence the patient state;

(3) *Administrative*: class of administrative activities such as system/manual notification and reminders;

(4) *Activity_Proxy*: an activity that refers to another instruction definition generally used when referring to another clinical guideline; and

(5) *Wait*: an explicit activity to delay before the next activity takes place. This is generally used for specifying relatively long waiting periods, such as recalls for immunisation.

The work item of activities describes the work to be done once an atomic activity instance has been assigned to a *party* or role. Furthermore, an important aspect considered is being able to explicitly specify the "data_to_collect" for clinical intervention and data collection activities. This might specify the archetype ID from which the required EHR form needs to be instantiated from and made available for data entry when that activity is eligible to be undertaken (e.g., an assessment form for an OT home assessment activity), and only completes when that record has committed.

4. Workflow-based EHR Design

The aforementioned *open*EHR constructs have a direct relationship to components of workflows. While the workflow informs facets of the EHR, existence of these components in the EHR can allow the point-of-care application to better promote the guideline with workflow and decision support (i.e., what is to be done, when, how, by and for whom, and precisely what to record at specific points of care in the workflow). While many workflow-based systems allow data access and updates to domain-based databases, the *open*EHR architecture allows us to establish a close and structured correspondence between the workflow and the EHR. We view workflow as having direct correlation with a care plan instruction within an EHR, and where each workflow activity is an EHR instruction activity with subject/patient state pre- and post-conditions for its execution. Just as conditions may be placed on workflow activities to occur and complete, and transitions to fire, similar conditions are placed on EHR instruction activities to be performed (for example, the instruction to order and administer a particular drug for a patient can be performed on the condition that the patient has no known adverse reactions to that drug). Furthermore, such conditions are evaluated using data from the system (known as workflow parameters in workflow, and activity states and data collection items for EHR), and where workflow activities can result in production (or domain-related) data, EHR activity execution would typically result in EHR data recording (i.e., EHR event and persistent transactions).

4.1. System Architecture

We propose to implement a system that facilitates guideline-based workflow using our EHR framework. Figure 7 shows a diagrammatical view of the system architecture followed by a description of its components.

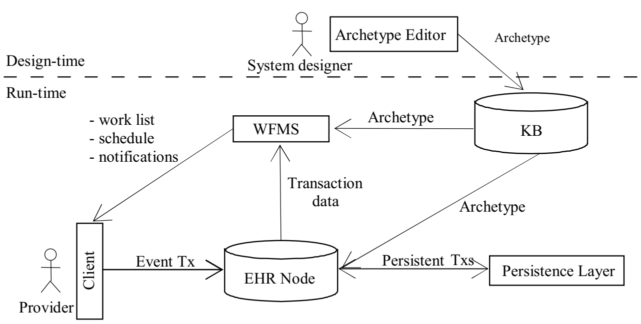

Figure 7. System architecture

EHR Node: is the database/storage repository for the EHRs. It is responsible for recording details about events and the current state of a workflow.

Persistence Layer: Updates the persistent plan transactions that are affected by the event transaction recorded. For example, posting of an event transaction "Hospital Assessment" that contains an instruction definition "Recommended ESD post-stroke rehabilitation, guideline ID = 1240" would add a new plan persistent transaction in the care plans folder that is specific to the guideline in the EHR. Similarly, a new encounter event transaction that has the entry "Evaluation: problem = hypertension, and instruction definition: recommendation = ACE Inhibitor" would update the "Current Problem List", and "Current Medications" persistent transactions to include the new problem diagnosed and the new drug therapy.

Work List Manager: simply identifies the "work list" that specifies the list of activities, which are either currently executing (i.e., set of activities whose state is currently executing) or able to be started (i.e., the set of activities whose preconditions have been satisfied). It also updates the states of activities by monitoring to see if actions to be undertaken within activities are performed / cancelled and using that information to update the activities' state machines. Such work lists may be specific to a particular human or application participating in the workflow, or it may be a work list shared by a number of participants. Work lists are generated via a query to all instruction activity states relevant to the one / group participant. The work list manager allows mechanisms for participants to select activities to be performed, reassign activities, abort activities, suspend activities, and confirm that an activity has been completed. It may also invoke any applications that are assigned to do particular activities.

WfMS: this is the Workflow Management System, which is defined by WfMC as a "system that completely defines, manages, and executes workflows through the execution of software whose order of execution is driven by a computer representation of the workflow logic". In addition to having the functionalities of a work list manager, it provides mechanisms for resource allocation (i.e., assigning activities to users), scheduling activities, prioritisation, optimisation, audit trails, notifications, automatic system action invocation and execution, etc. The WfMS serves as an optional extension to the work list manager.

Client: is the provider application itself, and provides an interface for viewing event and persistent transactions, and allows event transactions to be recorded. The client also offers a view to the work list and schedule generated by the Workflow Management System (WfMS), as well as any notifications.

KB: is a knowledge base that stores all standard archetypes authored by the system designer via an archetype editor including additional customised archetypes that is specific to the domain of the clinical information system being considered such as a "referral to the OT from the ESD coordinator". That is, it stores the knowledge about the EHR, and guideline-based workflows. Furthermore, simple ad hoc specialisations of archetype instances are created from existing archetypes in the KB. We are currently using an open source Java-based graphical workflow editor called JaWE [17] to create workflow schemas specified as WPDL (the WfMC's Workflow Process Definition Language). The WPDL specifications are then transformed into XML-based instruction definition archetypes using XSL (W3C's eXtensible Stylesheet Language).

4.2. Example of Affecting Workflow with Instructions

Figure 8 shows a fragment of a Hospital Assessment event transaction archetype. Its content is constrained to archetypes, which are of type ENTRY (i.e., archetypes that have archetype IDs that match the pattern "openehr.entry-*.v1"), and has an organiser containing the headings "Patient Details" through to "Recommendations" in an ordered list structure. An example of a valid entry archetype instance that can be used as part of the transaction's content is an instruction definition entry named "Early Supported Discharge" (figure 8).

c_transaction: ARCHETYPE_FRAGMENT	
c_archetype_id	openehr.transaction-event.hospital_assessment.v1
c_name: C_DV_TEXT	Hospital Assessment
meaning: DV_TEXT	Hospital Assessment Event Transaction Archetype
c_content: ARCHETYPE_PROXY_C_ORGANISER	
constrainer: C_ARCHETYPE_ID	"openehr.entry-*.v1"
target: C_ORGANISER	
c_name: C_DV_TEXT	hospital assessment organiser
meaning: C_DV_TEXT	hospital assessment event transaction organiser
c_items: C_LIST_C_CONTENT_ITEM	
occurrences: INTERVAL_INTEGER	1...1
is_ordered: BOOLEAN	TRUE
is_unique: BOOLEAN	TRUE
item: C_CONTENT_ITEM	Patient Details
item: C_CONTENT_ITEM	Hospital Details
item: C_CONTENT_ITEM	Diagnosis(es)
item: C_CONTENT_ITEM	Drugs
item: C_CONTENT_ITEM	Special Needs
item: C_CONTENT_ITEM	Further Hospital Attendances
item: C_CONTENT_ITEM	Details of transport arrangements
item: C_CONTENT_ITEM	Recommendations
c_context: C_CLINICAL_CONTEXT	
c_practice_setting: C_DV_TEXT	hospital
c_is_persistent: C_BOOLEAN	TRUE

c_instruction_definition: C_ENTRY	
c_archetype_id	openehr.entry-instruction-definition.ESD.v1
c_name: C_DV_TEXT	Early Supported Discharge
meaning: DV_TEXT	ESD Instruction Definition Entry Archetype
c_data: C_SINGLE_EVENT_C_STRUCTURE	
c_item: C_LIST_S	
c_name: C_DV_TEXT	Early Supported Discharge
meaning: DV_TEXT	ESD Instruction Definition Entry
occurrences: INTERVAL_INTEGER	1...1
items: C_LIST_C_ITEM	
item: C_ELEMENT	
c_name: C_DV_TEXT	ESD
meaning: DV_TEXT	Instruction definition
item: C_ELEMENT	
c_name: C_DV_TEXT	guideline_id
meaning: DV_TEXT	Guideline ID to use

Figure 8. Fragment of Hospital Assessment event transaction archetype

These archetypes constrain the configuration of data elements in the EHR's content. Once instantiated into EHR forms, and data entry has been made, and committed into the database (i.e., an event has occurred) – updates are made to the affected persistent transactions. E.g., posting of a Hospital Assessment event transaction with a recommendation for the patient to enrol in an ESD program, with a specified guideline_id, would result in an instantiation of an Early Supported Discharge instruction execution entry within a persistent transaction, and set its first activity instance execution state to "eligible".

5. Example ESD Workflow Instance Walkthrough

We use the petri-net execution approach to specify the instruction activity and connector conditions for modeling workflow. As such, we can define what states the previous and next instructions must be at according to the current placing of a given token, and take into account the typical workflow patterns such as sequential, conditional, branching, iteration and parallelism. Consider an example valid ESD workflow instance steps/sequence: [{Hospital Assessment}, {Patient Review}, {Accept Patient}, {Plan Services}, {Refer Patient}, {Follow Up}, {Prepare Discharge}]. The following will describe a portion of the instance's execution (from Hospital Assessment to the OT Initial Assessment activity) in terms of what occurs at the WfMS level and the EHR level to enact the workflow (via petri-net simulation) given the knowledge specified within the instruction archetypes:

1. A Hospital Assessment event transaction is recorded into the EHR containing the instruction "Early Supported Discharge for Post-stroke Rehabilitation; guideline ID = 1240" as a recommendation. This event causes the persistence layer to instantiate a new persistent ESD plan transaction into the EHR from the ESD plan archetype in the KB with the corresponding guideline ID. The WfMS initialises all the valid instruction activity instances' execution states (or their state machines) within that plan to "ineligible", except for the first valid activity instance Review Patient being set to "eligible".
2. Review Patient is "completed" as a result of receiving the "Report" event transaction, and the next direct set of valid activity instances in the persistent plan transaction is then updated to the "eligible" state (i.e., Accept Patient, Reject Patient, and Alternative Referral are eligible).
3. The subject state pre-conditions on the patient's eligibility for ESD in Accept Patient, Reject Patient, and Alternative Referral activities queries the EHR for the eligibility data item value in the

"Report" (in this case is equal to "true"), and receipt of a "Patient Consent" event transaction in the EHR with "patient consent given = true" consequently updates the state machine of Accept Patient directly to "completed" (as this is a simple activity instance), and Reject Patient, and Alternative Referral back to "ineligible". Plan Services is automatically set to "eligible". A "patient file" event transaction form may then be automatically recorded or presented for manual data entry. After the required form has been filled in and committed, Plan Services execution state is set to "completed".

4. WfMS then sets Refer Patient composite activity instance to "eligible", and subsequently, enables its sub-activity instances also. Observe that iteration of Refer Patient (i.e., re-enabling of state) is made allowable by also checking if the Follow Up state is "completed"). Figure 9 illustrates a fragment of the instruction definition. (Note that "$" appear as placeholders for the complete navigational path to the data/variable item being queried). The plan persistent transaction form is updated to have the check boxes eligible for selection of the available referral choices (i.e., "Occupational Therapy", "RDNS", "Physiotherapy", "Speech Therapy", and/or "Social Worker"). This inclusive choice within the composite activity instance (i.e., sub-workflow) is maintained by specifying the appropriate connector pre-conditions (in this case, we use a *split* connector type), and ensuring Refer Patient post-condition checks that all of its sub-activity instances' execution states are either set to "ineligible" (i.e., was not selected for execution) or "completed" (i.e., was executing and has successfully reached completion).
5. Posting of a "referral" event transaction to the OT causes the WfMS to set Refer Patient execution state to "executing" and a transition to the OT sub-workflow is made – enabling the OT Initial Assessment activity instance execution state. A condition exists in the instruction such that the OT Initial Assessment activity instance can be immediately set to "eligible" whilst its higher-level activity instance is still "executing". However, the higher-level activity instance Refer Patient cannot be set to "completed" until all of its running sub-activities have also "completed". The sub-activities that are not selected for execution are disabled back to the "ineligible" state. Any of the sub-activities may be made eligible at a later point so long as Refer Patient is still "executing" – allowing for asynchronous enabling or start up of activities with synchronous completion (or, in petri-net analogy – all tokens that were fired have been received by the output place).
6. OT Initial Assessment is "completed" once an event transaction is recorded into the EHR.

We assume this is the current position in the workflow instance execution and end our illustration here.

composite_activity		
	activity_id	
		v = "act_inst_007"
	activity_name	
		v = "Occupational_Therapy"
	is_mandatory	
		v = "false"
	subject_state_precondition	
		v = "$trans-event_v1.0_ESD-report.equipment-needed = true"
	subject_state_postcondition	
		v = "$trans-event_v1.0_ESD-report.equipment-installed = true"
	is_start_activity	
		v = "false"
	is_end_activity	
		v = "false"
composite_activity		
	activity_id	
		v = "act_inst_008"
	activity_name	
		v = "RDNS"
	is_mandatory	
		v = "false"
	subject_state_precondition	
		v = "$trans-event_v1.0_ESD-report.RDNS-needed = true"
	subject_state_postcondition	
		v = "$trans-event_v1.0_ESD-report.RDNS-visited = true"
	is_start_activity	
		v = "false"
	is_end_activity	
		v = "false"
composite_activity		
	activity_id	
		v = "act_inst_009"
	activity_name	
		v = "Physiotherapy"
	<continues similarly … >	
composite_activity		
	activity_id	
		v = "act_inst_011"
	activity_name	
		v = "Social_Worker"
	<continues similarly … >	
Split		
	Precondition	
		v = "($Plan_Services.activity_execution_state = completed" OR $Follow_Up.activity_execution_state = completed")
	postcondition	
		v = "[($Occupational_Therapy.activity_execution_state = completed OR $Occupational_Therapy.activity_execution_state = ineligible) AND ($RDNS.activity_execution_state = completed OR $RDNS. activity_execution_state = ineligible) AND ($Physiotherapy. activity_execution_state = completed OR $Physiotherapy.activity_execution_state = ineligible) AND ($Speech_Therapy. activity_execution_state = completed OR $Speech_Therapy. activity_execution_state = ineligible) AND ($Social_Worker. activity_execution_state = completed OR $Social_Worker.activity_execution_state = ineligible)]"
	Split_type	
		v = "OR_split"
	input_activity_id	
		v = "act_inst_006"
	output_activity_id	
		v = "act_inst_007"
	output_activity_id	
		v = "act_inst_008"
	output_activity_id	
		v = "act_inst_009"
	output_activity_id	
		v = "act_inst_010"
	output_activity_id	
		v = "act_inst_011"

Figure 9. Fragment of *Refer Patient* Composite Activity within the ESD Instruction Definition Entry

6. Conclusion

Based on our analysis herein, and other work in a closely related domain [7], we believe that workflow models with closely aligned EHR design provide a good representation of key guideline elements for evidence-based post-stroke rehabilitation and early supported discharge. Through extension of the *open*EHR plan and instruction archetype constructs, we uncover a feasible approach to incorporating the workflow (including representation of the associated assessment activities) with the EHR, which allows these elements to interact in a clinical information system. The linkage of workflow knowledge with the EHR enables a system to be aware of *what* needs to be recorded, by and for *whom*, and *when*. In addition, the availability of a WfMS, can make use of the workflow-enabled EHR to provide knowledge about *how* the workflow should be executed, and the resource allocation -- i.e., *who* should carry out the activities, and when (e.g., automated scheduling). As such, the system can run on the EHR itself, or in conjunction with a WfMS – in either case, a workflow-enabled EHR allows for a more active system than current traditional EHR systems. Such an approach could contribute to a substantial improvement in the management of chronic disease. Close EHR and workflow linkage allows information pertaining to the actual care process of the patient to be recorded and not just limiting it to the recording of the patient's state/health condition - thus, having medico-legal significance. While the workflow helps to ensure that the work is done, archetypes help ensure that the required data set is recorded at specific points in the workflow.

It has been pointed out in [1, 18] that, for proper and effective implementation of decision support, it is vital to provide *patient-specific* recommendations at the point of care, and in accordance with the physician's workflow. Hence, there needs to be substantial integration of the patient's EHR with CIGs. Our view is that a similar approach must be made when integrating the EHR with clinical workflows. Much research has been put towards designing workflow systems that provide flexibility and elegant exception handling [19, 20, 21] – application to a complex and ever-changing domain such as health care calls for sufficient support of relatively unstructured workflows. Since the EHR is a central component in many clinical information systems, our approach provides an EHR framework that allows for extensible EHR recording that is also directly *enabled* for workflow-support and decision-support. Thus, where workflow is too rigid for a particular clinical domain, the proposed EHR framework alone is still able to provide the information regarding what was done, and when, who it was done by, and what should be recorded next (via archetype definitions at the knowledge level). This approach is also open for use in decision support systems where tracking of decisions made is key to patient management, and suggestions of what should be recorded next effectively implies what the guideline-based recommendations are at that point in time.

While an approach heavily based on a patient-centred workflow model appears very appropriate for the post-stroke situation (and, in fact, we selected this scenario because of its goodness of fit), we are equally confident that workflow should *not* play a dominant role in the representation of guideline evidence in many other CDM contexts. If one looks at a guideline for treatment of hypertension in diabetes – the Texas Department of Health Hypertension Algorithm for Diabetes Mellitus in Adults is a nicely presented example [22] – it is suggestive of a type of workflow in that care progresses from non-pharmacologic approaches, to drug mono-therapy, then combination therapy, and (if blood pressure is still not controlled) to specialist referral. It is precisely this sort of 'disease-state' flow model that has been employed in the guidance for GP's in the UK's large-scale PRODIGY phase III project (see [5]). However, as discussed in the introduction, it is in fact a PRODIGY-based system that has recently been evaluated as ineffective [4]. A detailed qualitative analysis of user perceptions of this system revealed a wealth of problems; notably among these was difficulty in 'navigation' of the guideline and considerable perception by the GPs that the advice given was not worth the effort [23]. Looking back at the Texas Department of Health guideline [22], it is perhaps not surprising – in light of the eight explicit footnotes, sidebar table of supplementary considerations and many additional subtleties that are implied in word choices such as "preferred" versus "strongly recommended" options – that much of the important advice of the guideline is not explicit in the workflow of the algorithm or associated data collection (hence EHR) requirements. Panzarasa et al. [7] give considerable attention to the handling of exception in their careflow modeling approach – any successful workflow system in health must address this well – however, at some point the density and nature of exceptions renders the approach inappropriate. As pointed out in [23], for hypertension management, the exceptions will include the fact that the patient will very often receive treatment (and notably begin treatment) outside the scope of the system's record; this challenge is much less present in post-stroke rehabilitation / discharge planning, where the patient is apt to at least begin the care protocol in a relatively controlled environment.

We are currently engaged in the development of functional demonstration prototypes of post-stroke rehabilitation and community-based diabetes management implemented based on the evolving *open*EHR model and a prototype implementation architecture from the Titanium group of the Distributed Systems Technology Centre (DSTC, http://titanium.dstc.edu.au). In fact, we believe that detailed prototyping is an essential element in refining models such as *open*EHR – the *open*EHR representations of Instructions and Actions have been influenced by the case study presented herein. Among our near-term goals is to abstract from the post-stroke and diabetes prototypes a clearer articulation of the practical areas of applicability of workflow-based approaches vis-à-vis decision support systems in CDM. We believe this will provide valuable design guidance to health system designers whether or not they choose to work in the *open*EHR framework.

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