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Integrating Complex Business Processes for Knowledge-driven Clinical Decision Support Systems

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Abstract— **This paper presents in detail the component of the Complex Business Process for Stream Processing framework that is responsible for integrating complex business processes to enable knowledge-driven Clinical Decision Support System (CDSS) recommendations. CDSSs aid the clinician in supporting the care of patients by providing accurate data analysis and evidence-based recommendations. However, the incorporation of a dynamic knowledge-management system that supports the definition and enactment of complex business processes and real-time data streams has not been researched. In this paper we discuss the process web service as an innovative method of providing contextual information to a real-time data stream processing CDSS.**

I. Introduction

Critical and complex care is performed in data intensive environments that host a variety of medical devices, along with large repositories of clinical information. Clinicians who work in these environments are actively capturing, aggregating and processing information generated by those heterogeneous data sources in real-time. These processes are performed while they are actively delivering well-planned and evidence-informed care management plans. However, the rapid pace at which data is generated is a challenge for the clinician, who as a human being is limited by the amount of variables she is able to compute simultaneously [1]. For instance, the Clinical Information Management Systems (CIMSs) contains large volumes of progressively updated biomedical and demographic data, while modern medical devices such as the Phillips Intellivue series of patient monitors generate sensor-based data streams at rates over 500 hertz. The sheer volume of data acquired for a patient is overwhelming and impractical to analyze thoroughly.

Evidence-informed practices are constantly being updated as new research findings are published and adapted into clinical practice guidelines (CPGs). In order to make evidence-informed decisions, the clinician is required to be familiar with the latest guidelines, while collecting, aggregating, and processing real-time biomedical information. The clinical decision support system (CDSS), has been used over the decades to aid the clinician in performing some of the low level aggregation and processing to convert the abundant raw facts to information. Modern and sophisticated CDSSs are able to incorporate CPGs for analysing raw data by using business process. However, these systems support a user-derived form of knowledge management that must be updated regularly as new CPGs are made available.

Business processes serve as building-blocks of larger workflows. They capture the activities in sequences which must occur in order to achieve some business result. The essential components of CPGs, are indeed independent business processes which serve to specify both the type and duration of medical care. The knowledge contained within these guidelines provides a means through which intelligent systems can capture and contextualize the medical activity, duration, and priority. In addition to being essential components that characterize various inputs and output parameters of a care management process, these three elements also serve to provide CDSS with the awareness of the activity's complexity. This awareness is of significant benefit to dynamic systems whose internal processing engines are capable of performing in a technology-rich, unpredictable, and rapidly changing critical care environment [2].

Modern intensive care CDSS are being required to become increasingly aware of the environment in which they operate. Studies have shown that while effective tools for care management, the effect on positive patient outcomes have been minimal [3]. Consensus about the need for systems that minimize false alarms, while increasing clinical relevant alarms has been consistently published for over a decade [4]. A way forward to provide CDSS with the ability to recognize their operational environment is through the representation of behaviours and processes that are relevant to the patient care management. Representing business processes in the framework of CDSSs, especially those found within CPGs is an important step towards improving the intelligence and workflow management in critical care environments. In this paper we present the component of the Complex Business Process for Stream Processing (CBP_{sp}) that supports the definition, enactment, and post-enactment analysis of business processes to support critical care. The paper is structured as follows; section two presents related work in the area, section three presents the architecture, section four presents a discussion of the framework, and section five concludes with future work.

II. Related Works

Biomedical data is increasingly available in greater quantities and at shorter frequencies, reciprocating this trend, medical knowledge has also increased substantially over the past few decades [5]. Through research findings and

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perpetual improvements in the delivery of care, medical knowledge continues to be an area of active change. CDSS traditionally were designed with focus on prevention and screening, particularly in the outpatient environments. However as knowledge evolves and practices change, the CDSS must be able to adapt seamlessly to the change through architectural support for knowledge versioning for continued evidence-informed recommendations. Research in the area of versioning, particularly for medical knowledge has been limited, with the majority of work in the areas of ontologies and medical vocabulary [6]. There has also been limited research in CDSS frameworks which support an active knowledge management and versioning to maintain an up-to-date medical knowledge repository [7].

Garg and colleagues, in a systematic review, researched the effectiveness of process-oriented CDSSs in a wide range of medical areas from 1973 to 2004 [3]. A total of 100 studies met the criteria and were tested for effectiveness. An interesting finding of that review was that in 47% of the studies the CDSS was integrated with existing electronic systems. However only 30% of these systems actually allowed for automated data feeds from CIMS. Of that figure, the research further finds that 98% of these studies required some form of input from physician or trainee physicians (38%), other health care staff (29%), or staff paid by research funds (21%). Toth-Pal, Wardh, Strender, & Nilsson, 2008, provide research findings to support the beneficial effects of a process-oriented CDSS which use evidence-based CPGs, on general practitioners [8]. Their CDSS was tested by five general practitioners and the results studied determining that the confidence of physicians when a CDSS is based on CPG is higher. The level of automation is reported to be an important aspect of a physician's likelihood for its continued use, and improved overall physician outcome [3]. Those systems which provided complete automations, and required physician input only when performing clinically significant decisions tend to have better physician outcomes on adoptability and improved the overall patient outcome [3]. Moreover, while it is important to provide control over the output mechanisms for improved physician outcomes, there must be a good balance between components that the physician can control with particular respect to alerting mechanisms of the system. A study by Tamblyn et al, found that when physicians were allowed to customize the alerts for a prescription safety CDSS, it resulted in over 88% of the alerts being ignored because clinicians did not see clinical and situational relevance in the output [9]. The study however presents several limitations in the depth of analysis and classification of existing and new drugs used to product the alerts. Even so, the results can be used to illustrate that systems which produce significant amount of alerts can largely become ignored if the context and environment are not carefully considered.

Although knowledge management has been a persistent theme in modern CDSSs [7], a framework incorporating the automated definition, enactment, and post-analysis of business processes has not been conceived. The ability to define and enact a business process must include the ability to (1) automatically acquire analytical metrics from clinical guidelines, while providing flexibility to enhance this definition in an on-going basis as new evidence is produced. The enactments must (2) incorporate new forms of high frequency data streams, and asynchronous slow streams such as: age or temperature using services-oriented architecture (SOA) principles. Finally, the post-analysis stage must allow the clinician or organization (3) the ability to view in context, the journey of a patient through the critical care environment to support resource management and quality improvement. These three requirements have not been fully exploited in existing CDSS architectures and warrants research. We have developed a framework introduced in [10] called the Complex Business Processes for stream processing (CBP_{sp}) which supports the definition, enactment, and analysis of complex business processes to support critical care. In this paper we present in detail the Process Web Service which allows for the CBP representation.

III. ARCHITECTURE

The CBP_{sp} framework is an on-demand real-time service-oriented architecture (SOA), that allows for the processing of complex business processes in high frequency data intensive environments. Moreover, the framework abstracts critical detail from the business processes and incorporates this rule-set at run-time to aid data analysis [10]. This framework is significant for critical care environments in which complex care is performed using clinical practice guidelines representing the critical business processes.

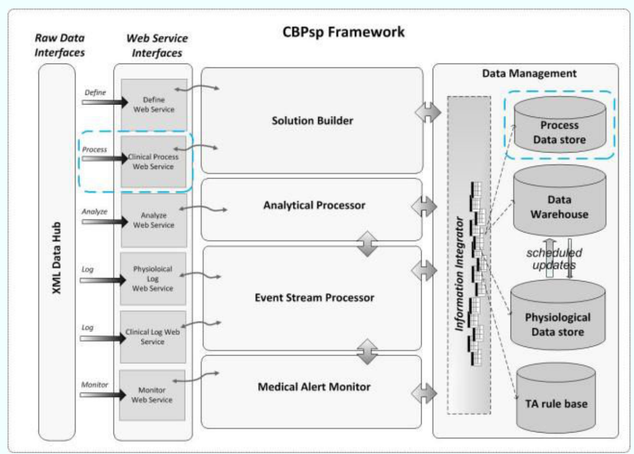

Figure 1 Complex Business Process for Stream Processing System Architecture with Process Web Service highlighted.

In Figure 1, the CBP_{SP} is shown to include several compartments designed to define, and support the enactment and analysis of business processes. The Raw Data Interface (RDI) component serves as a gateway which formats and structures the incoming data and routes appropriate packages to their corresponding components. This component is in constant communication with the inner components of CBP_{SP} to direct required data as it is made available.

The Process Web Service is a web service which performs the initial invokes, packet acquisition, and then routes the packet from the knowledge management system to the Solution Builder. The Define Web Service collects enactment specific data, such as identification and feeds this information to the Solution Builder. The Solution Builder allows for the definition and modeling of the business process. In the solution builder, data from both process and define web services are collected and a model of the enactment is created.

This model is translated into the Spade Programming Language (SPL) in which we implement the InfoSphere Streams engine as the event stream processor. The SPL is submitted to the event stream processor for enactment. While the Event Stream Processor supports the actual enactment, and the Analytical Processor supports the retrospective analysis of each enactment. The basic component of the framework which allows for the definition and enactment of business processes is the Process Web Service. This component is highlighted in Figure 1, and exists as an interface to source business process messages from an external knowledge management system. The external system acts as a client that initiates an independent connection with the service, to begin initial exchange of acknowledgements to register a new process change or addition to the existing run-time. This exchange of information is facilitated by the RDI which ensures the incoming stream of information meets a set of minimal criteria in data standard and business process information. Figure 2 illustrates the sequences of activities starting with the RDI sending and invoke to the process web service to inform of it newly received processes.

The Process Web Service then performs a desired level of data capture according to the requirements of the business process and stores the meta-data in the Process Data Store. Then the service submits parametric information about the business process to the Solution Builder. The six key data fields required before it is sent to the solution builder are:

1. **EventID:** Each process is associated with an ID. The PWS uses this ID to keep track of client-client, client-service, and service-service relationships.
2. **EventType:** The class of the event is recorded. For instances, 'Read Glucose Level' is translated into 'Lab Order' event.
3. **SequenceNumber:** The sequence number is determined by the exact order in which the process appears in the clinical guideline. For instance, after a newborn is admitted to the NICU, the process which is represented by the decision point ''Baby is unwell?' receives a sequence number of two.
4. **isDecision**: A Boolean element denoting whether the process needs to be represented as a decision point.
5. **Value**: Extraction of numerical values.
6. **Critical Value**: This element is a Boolean field representing the importance of a specific process and value. Processes containing True supersedes other processes of the same level.

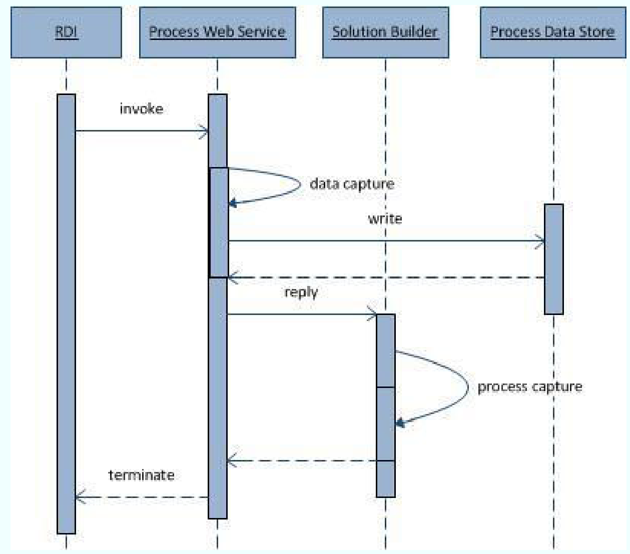

Figure 2 The Process Web Service interacts with services to capture and store definition and enactment details.

The *EventID* will serve as the primary key by which other related information will be referred. This table is stored in the process data store database found in the data management layer. The translation required to populate these tables are performed by parsing the Extended Markup Language (XML) elements to simple automatons. This information is then supplied to the solution builder to populate the Operator Configuration Agent as shown in Figure 3. The solution builder uses the message, and instruction about the process to construct a model of the activity that is translated to SPL, and enacted in real-time.

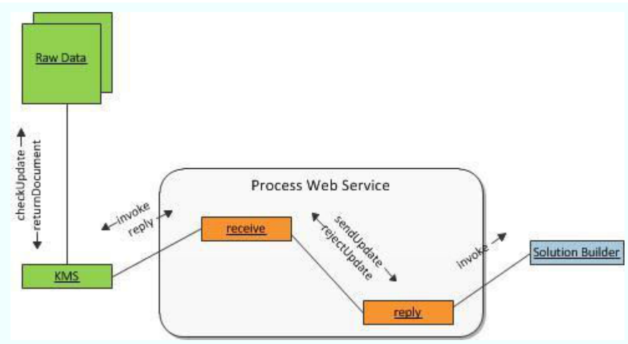

Figure 3 This diagram illustrates the functions involved in a typical initiation of a process definition and enactment.

As illustrated in Figure 3, the XML derived parameters of business processes are sent to the solution manager's operator configuration agent by the invoking the reply function. The agent upon receiving the complete model begins the translation of the business process into SPL components. The SPL script is enacted in real-time and alerts are sent to the Monitoring Web Service. The clinician can interact with that service in real-time to make adjustments regarding frequencies or false alarms. One important point to note is that, in the translation of the business process to the execution script, the EventType is an important factor in determining the class of functions necessary to perform that activity. The classes of activities are: source, filter, aggregate, join, split, or sink. Additionally, the *IsDecision* value is very useful in determining whether an operation will require the join of multiple data streams arriving via the Clinical Log Web Services and Physiological Log Web Service (Figure 1). This feature allows the CBP_{sp} to determine the frequency of the input variables, and make necessary changes in the SPL script if there is a join required between high frequency data streams, and slower asynchronous streams.

IV. Discussion

The CBPsp framework is novel in the sense that it introduces a structured method of integrating complex business processes and by that means, an ability to represent explicit knowledge acquired from electronic clinical guidelines within a real-time event processing engine. We present an application of this framework for a neonatal hypoglycaemia case study in a previous publication [10]. In the case study we create an electronic representation of the clinical practice guideline in the *Guideline Embedded Model (GEM)* a standard that represents the business process and attributes in a structured XML format. Using that electronic representation as an input, we translate the GEM guideline to an activity model in UML 2.0 at an agent in the Solution Builder. The new dynamic model is then converted activity by activity to its corresponding SPL component, to generate a final ESP script which is executed in in the real-time engine. The six fields generated by the Process Web Service is used to construct the SPL code. Each business process outlined in the GEM guideline is assigned an EventID, and if the event is associated with two or more inputs and one output, the isDecision field is populated designating that process as a potential join or split operator in SPL. Using high level natural language processing, keywords specifying mathematical operations are categories by their function and the field EventType is populated with the activity class the business process is determined to be. For instance, if a business process involves check glucose, this the event would be picked up as a *Source* gluclose operator. We fed the engine with retrospective physiological data from 60 patients for whom we had earlier collected data. The script when executed produces alerts to identify infants at risk of neonatal hypoglycaemia and proposes a simple care management output.

That case study illustrates an example of how this framework can be applied to a simple CDSS model that monitors slow changing data streams and performs simple forms of natural processing to identify diagnosis that increase the risk of an infant to neonatal hypoglycaemia. The potential for this framework is vast due to its flexible architecture built on

V. Conclusion

This paper has presented a demonstration of the Complex Business Process for Stream Processing (CBP_{SP}) framework, which incorporates the clinical guideline, clinician care plan, and event stream processing. The Process Web Service was detailed, and detail was provided to illustrate the methods involved in representing complex business processes in a real-time CDSS framework. It was found that although some forms of knowledge-management have been attempted, a framework incorporating the automated definition, enactment, and post-analysis of business processes does not currently exist. We have stated that the ability of a modern CDSS to define and enact a business process must include the ability to (1) automatically acquire analytical metrics from clinical guidelines, (2) incorporate new forms of streaming data, and allow for (3) the ability to view post-enactment analysis of business processes, to support resource management and quality improvement. Our future work would involve applying this framework produce rules to detect instances of Apnoea in the neonatal infant.

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