A Framework for Multidimensional Real-Time Data Analysis: A Case Study for the Detection of Apnoea of Prematurity

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ABSTRACT

In this paper, the authors present a framework to support multidimensional analysis of real-time physiological data streams and clinical data. The clinical context for the case study demonstration is neonatal intensive care, focusing specifically on the detection of episodes of central apnoea, a clinically significant problem. The model accounts for the multidimensional and real-time nature of apnoea of prematurity and the associated clinical rules. The framework demonstration includes: 1) defining rules that quantify concurrent behaviours between multiple synchronous data streams and asynchronous data values; 2) designing UML models to define present practice event processing for episodes of apnoea; 3) translating the model in SPADE to enable the deployment within the real-time processing layer of the Artemis platform, which utilizes IBM’s InfoSphere Streams; 4) demonstrating knowledge discovery with simple and complex temporal abstractions of the data streams; and 5) presenting results for early detection of episodes of apnoea across multiple physiological data streams.

Keywords: Apnoea, Frameworks, Neonatal Intensive Care, Physiological Monitoring, Real-Time Data, Streaming Data

INTRODUCTION

Increasingly real-time clinical monitoring systems must be capable of processing multidimensional data where multiple elements, each representing a dimension that can vary in value, characterize an item of interest. Real-time monitoring of multiple physiological time series data streams and the interactions between these streams, as well as including clinical informa-
tion from diverse patient information systems, represents an important but non-trivial problem.

We have developed a framework to support multidimensional real-time data analysis of both physiological time series data streams and clinical data, such as that obtained from hospital Clinical Information Management Systems (CIMS) or laboratory information systems. Such a framework is relevant to clinical environments associated with real-time monitoring, such as intensive care and post-operative care, obstetrics, and cardiology. Drawing on the authors’ experience, we demonstrate the framework within the context of neonatal intensive care, presenting a case study for the detection and classification of episodes of apnoea, based on analyzing the interactions between multiple physiological signals in association with other relevant clinical information.

Patient support in the Neonatal Intensive Care Unit (NICU) includes obtaining real-time physiological data from bedside medical devices to support the diagnosis and treatment of critically ill newborn infants. NICU clinical monitoring systems must be capable of handling multidimensional data; examples of varying dimensions include the number of data streams collected, the length and behaviour of the streams, and the number of events present or to be detected in the streams. While current medical devices provide the ability to output and display high speed data streams; in general, NICUs lack frameworks to use this information to facilitate real-time clinical care and clinical research (Stacey, McGregor, & Tracy, 2007). Significant challenges exist when supporting complex real-time clinical management of high frequency, multidimensional streaming data, including the ability to apply clinical rules to: 1) more than one physiological data stream, including coordinating activities between streams; 2) both synchronous data in the form of physiological data streams and asynchronous data available from hospital CIMSs; 3) real-time data; and 4) environments where clinical rules are updated frequently and possibly dynamically.

These challenges are not unique to NICUs but apply to any environment that must process and analyze high-frequency streaming data in real-time. This framework provides a structured approach to representing, modeling, translating and abstracting clinical knowledge sources together with the clinical rules required to support the processing of multiple physiological data streams, clinical data, and real-time analysis of the data. The framework has been instantiated within the Artemis platform; Artemis provides a flexible environment for real-time online analysis of physiological data streams that provides both an interface to multiple medical devices and the ability to store the raw data from multiple infants at the rate they are generated (Blount, Ebling, et al., 2010).

Real-time modeling of clinical data streams and clinical rules is performed using Universal Modeling Language (UML 2.0) (Object Management Group, 2010). Knowledge discovery is based on applying temporal abstractions (TA) to both incoming data streams and on newly abstracted streams. Knowledge translation and data processing is supported by IBM’s recently developed Stream Processing Application Declarative Engine (SPADE) language. SPADE is the programming language for IBM’s InfoSphere Streams middleware that supports stream processing applications. From a clinical perspective, the framework demonstration involves progressing from: 1) defining apnoea rules that quantify concurrent behaviours between multiple synchronous data streams and asynchronous data values; to 2) designing relevant UML models to define present practice event processing for clinically significant episodes of apnoea; to 3) deploying a programmatic representation capable of interfacing with IBM’s InfoSphere Streams, this involves translating UML event processing models into SPADE code; to 4) demonstrating real-time knowledge discovery based on TAs of the incoming physiological data streams; to 5) demonstrating the applicability of the SPADE modeling language to support early detection of episodes of apnoea across multiple physiological data streams.

Previous work presented preliminary results using this approach to model and
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