InfoSphere Stream Technology in Healthcare Analytics

Myla P. Brooks, Richard W. Cogger and Janet L. Grennell
Public Sector, Strategy & Change
Healthcare Practice

and

Maria R. Ebling, Archan Misra and Daby M. Sow
IBM T. J. Watson Research Center

IBM Global Business Services

Table of Contents

Executive Summary

Today's healthcare organizations face unprecedented business demands. They are striving to improve patient safety, provide better clinical outcomes, improve overall patient satisfaction, slow the growth of costs, and anticipate and respond to lost revenue streams.

Some of these challenges have been met with improved technologies that have given doctors better tools to monitor and treat their patients. Such advancements have the potential to drastically change how healthcare practitioners and organizations can access and analyze data to not only improve quality of care but also reduce financial costs. However, these advancements have also created new challenges.

Today's medical devices generate copious amounts of data. The volume of data produced by these devices prove challenging to medical staff to comprehend in a timely and efficient manner. Consequently, the risk exists that important clinical information is being overlooked.

This problem exists in other industries as well, including financial services, manufacturing, and scientific research. To address this problem, IBM has built an advanced stream computing platform, called InfoSphere Streams. InfoSphere Streams provides an underlying infrastructure for near-real time processing of large volumes of streaming data coming at a high rate, such as video, audio, and sensor data. InfoSphere Streams has been successfully applied in domains as varied as financial services, manufacturing, and radio astronomy.

Healthcare is another promising candidate application domain for InfoSphere Streams, as stream computing can enable healthcare delivery organizations to connect and rapidly analyze large volumes of medical data. It holds the potential to help medical practitioners make better decisions by observing, collecting, and combining physiological data streams (e.g., respiration, heart rate, electrocardiogram and body temperature) with environmental data collected from sensors, and data from traditional paper-based methods. This scalable and open stream computing platform provides a means by which medical practitioners can enhance patient care by applying sophisticated medical analytics; the development of such analytic algorithms is itself witnessing rapid growth, due to both the availability of larger volumes of physiological data from increasingly sophisticated sensors and the development of better offline data mining technology. In many instances, more accurate diagnosis or predictions of medical conditions can be obtained through correlation of multiple physiological streams, a capability that cannot be embedded into individual medical devices. InfoSphere Streams holds particular promise for such multiple-stream based analytic applications, as it enables the deployment of new or experimental medical analytical algorithms and their application in patient care environments.

The goal of the Artemis project is to specialize InfoSphere Streams for healthcare applications. It aims at improving quality of patient care while increasing productivity of healthcare providers. Artemis is intended to supplement current methods employed by many medical practitioners and enable analytics results to alert practitioners of critical situations. Using Artemis, healthcare organizations can streamline their delivery and monitoring practices without incurring a linear increase in monitoring personnel. Artemis enables detection of rare medical condition that even trained medical staff might miss readily on a standard medical device.

In this white paper, we examine InfoSphere Streams' foundational components and how Streams can be leveraged in real-life healthcare scenarios to improve the decisions made by healthcare practitioners. We outlined three use-cases that focus on how sensor-based technology can be used to support medical practitioners and caregivers improve the quality of care and contain costs. The

application of this type of technology in the healthcare industry and the recognition of its potential have only begun to be realized. IBM has the opportunity to be the leader in this emerging area.

1. Introduction

Today's healthcare organizations face unprecedented business demands. They are striving to improve patient safety, provide better clinical outcomes, improve overall patient satisfaction, slow the growth of costs, and anticipate and respond to lost revenue streams. InfoSphere Stream Technology can position IBM to address these significant business challenges.

Healthcare organizations (HCO's) today face a difficult environment with mounting demands in providing quality care and unrelenting pressures related to cost and access. HCO's will need to become more effective, agile, and resilient by incorporating analysis and intelligence in all levels of business processing. For example, HCO's should be able to mine the data being generated by today's medical devices to find opportunities for process improvement. Healthcare practitioners today collect millions of pieces of data every year with the intention of using this information to improve the quality of patient care and overall performance.

IBM Corporation has the potential to be a leader in this industry. IBM understands the evolution of healthcare and recognizes that development of a bold new technology will create a revolution in healthcare efficiency and overall value (see Figure 1).

Two early IBM Research projects have examined the use of this new InfoSphere Streams technology in the healthcare domain. These projects are the Century and Artemis projects:

- The Century Project used InfoSphere Streams to monitor patients recoving from cardiac surgery. Century was a joint project between IBM Research and IBM Korea's Ubiquitous Computing Laboratory and was sponsored by the Korean Government. A small pilot study was done in collaboration with doctors at Gil Medical Center in mid-2008.
- The Artemis Project is currently using InfoSphere Streams to monitor premature infants in a neonatal intensive care unit (NICU). Artemis is a First-of-a-Kind (FOAK) project with the University of Ontario Institute of Technology. It will be experimenting with two NICU scenarios: early onset detecting of nosocomial infection ("sepsis") and early detecting of infant "crashing". The early onset detection of nosocomial infection will identify a decrease in the heart rate variability as one indicator while the early detection of an infant "crashing" will look at pulse oxygen saturation falling below 85% and blood pressure falling below the gestational age of the infant in weeks for a minimum of 20 continuous seconds. The Artemis Project expects to have a pilot solution deployed in the NICU at the Hospital for Sick Kids in Toronto sometime during 2Q09. Further information on the Artemis Project is available from the Research co-authors.

The potential of this technology in the healthcare domain goes well beyond application to cardiac and neonatal scenarios. The purpose of this white paper is to make the case for the application of InfoSphere Streams to a more general set of healthcare scenarios. Toward this purpose, we examine how the technology can be leveraged in real-life healthcare scenarios to improve the decision-making of healthcare providers. We describe three clinical scenarios that focus on sensor-based patient monitoring using high rate, high volume data streams. During collection, these streams are analyzed to create an alert based on specific clinician criteria for timely intervention in patient's care.

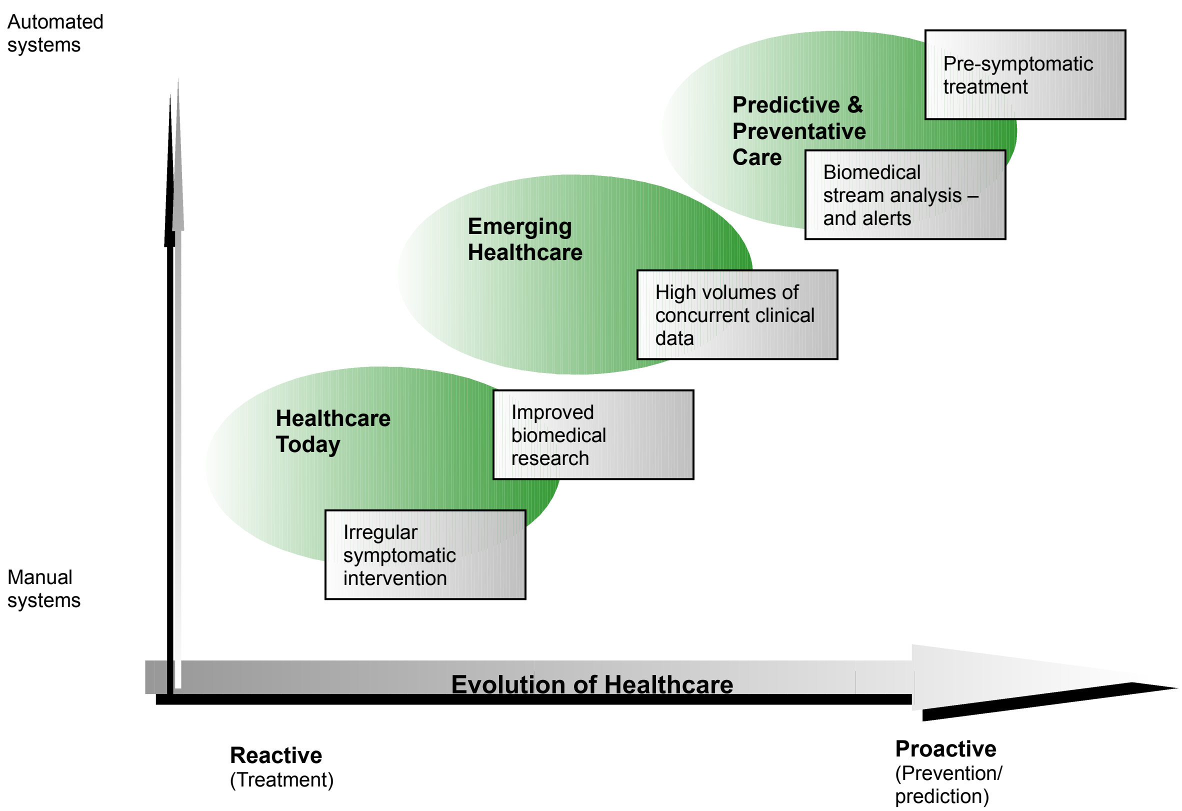


Figure1. Revolutionary technologies and evolutionary practices

2. Data Streaming Processing Technology Overview

Streaming analytics is a new processing paradigm that focuses on processing and analyzing data from streams as they arrive, without requiring that they be stored or replayed. With the proliferation of network communication technologies, information is increasingly made available as data streams of time-ordered sequences of events or readings, and delivered to interested applications across a network. Traditional information processing systems that apply a "store-then-process" paradigm have difficulty coping with the higher rates of data that they must ingest from an expanding number of data streams. An additional challenge arises from the need to provide near-real time support for sophisticated analysis algorithms that extract important higher-layer events or features by correlating multiple heterogeneous 'real world' data streams, such as video camera feeds, audio streams or medical sensor data.

At IBM Research, years of investment in stream computing have resulted in the development of System S, a large-scale distributed stream processing system which supports the development, deployment, and execution of stream processing applications. The System S software is now being transitioned into a new IBM Software Group offering called **InfoSphere Streams**, which is expected to have limited availability in the first half of 2009. InfoSphere Streams provides a new application execution environment for user-developed processing elements that consume, filter, and, most importantly, analyze data streams. The system runtime infrastructure allows stream processing graphs that can be created on the fly, mapped to a variety of different hardware and sensors resources, and adapted as requests come and go, and relative priorities shift. InfoSphere Streams is designed to support a large number of long-running jobs executing on from one to thousands of compute nodes.

To provide authors of analytics applications a higher-level of programming abstraction, the InfoSphere Streams platform introduces a higher-level programming language called **SPADE**. SPADE facilitates the development of streaming applications without the need for understanding low level details of InfoSphere Streams. The SPADE language constructs can be viewed as intermediate between higher-level programming tools like Stream SQL and lower-level system programming APIs. SPADE provides a toolkit of built-in stream-relational operators that can implement any relational query on data streams. SPADE is also extensible; it supports the definition of user-defined operators that integrate seamlessly with built-in operators. An application specified in SPADE's intermediate language is compiled into a stream processing graph, which can then be instantiated on the system runtime.

InfoSphere Streams has been used in numerous application domains. These domains include financial services, manufacturing (IBM's Burlington facility), and radio astronomy. The Century project, a predecessor to Artemis, and the Artemis project are the first to leverage InfoSphere Streams in the domain of Healthcare. In the next section, we will describe three additional healthcare scenarios that can benefit from the application of InfoSphere Streams.

3. Healthcare Monitoring Scenarios

We now describe three different medically relevant scenarios, where online analytics can be applied to detect and alert medical professionals of serious medical conditions. The three scenarios help establish two different points;

a) Many sophisticated and medically relevant analytics exist that require management and interpretation due to the diverse set and volume of these specific medical data streams.
b) The SPADE programming language can be used to express these analytics logic, such that the analytic application is then implemented on the Artemis infrastructure.

3.1 *Scenario 1 Labor with Fetal Late Decelerations*

Labor is a unique challenge for everyone involved, including and especially the unborn fetus. During labor, the fetus is stressed as labor progresses and moves the fetus through a narrow pelvis. While most of the time this journey goes well, sometimes the stress of labor is too difficult for the fetus. In a troubled delivery, the fetus may respond with decelerations in heart rate or other signs of distress. Periodically assessing how the fetus is handling labor is vital to a successful delivery outcome and a safe and happy birth experience for all.

Usually intermittent fetal heart checks using a Doppler or fetal monitor are effective ways to assess fetal condition. Higher risk pregnancies including induction of labor, epidural anesthesia, multiple fetuses and the like require a fetal monitor, probably throughout the entire labor. There are three types of continuous fetal monitoring:

External monitoring: An ultrasound transducer (Appendix A) is strapped over the mother's abdomen to pick up the fetus' heartbeat. A second detector is strapped to the top of the abdomen to record the frequency and power of the contractions. Both are connected to a monitor, and the measurements are printed on paper readout.

Internal monitoring: If the cervix is sufficiently dilated (one to three centimeters), the amniotic sac is no longer intact, and more accurate results are required (such as when there is reason to suspect fetal distress), an internal monitor is indicated. A tiny electrode is attached to the fetus' scalp and a catheter may be placed in the uterus. In addition, an external pressure gauge may be strapped to the abdomen to measure the strength of the contractions.

Telemetry monitoring: Available only in some hospitals, this type of monitoring uses a transmitter on the thigh to transmit the fetus heart tones (via radio waves) to the nurse's station. The benefit to this type of monitoring is that the mother maintains her mobility while still having constant monitoring.

With fetal monitoring, false alarms are common. The machine can start beeping loudly if the transducer has slipped out of place, if the fetus has shifted positions, if the monitor is not working correctly, or if contractions have suddenly picked up in intensity. A practitioner will take all these factors and others into account before concluding that the fetus is in distress. If the fetus does seem to be in danger, further tests will be run or a cesarean will be performed[1].

Labor and delivery practitioners and clinicians alike know the agony of an fetal death (or other less than optimal birth outcome) to everyone involved in the delivery. One of many examples of a poor outcome is a fetus that has experienced low oxygen levels during birth with resultant brain damage. The child may not die during or immediately after delivery, but instead may have long-term costly physical or mental disabilities. Low oxygen levels during birth, although less common with today's improved technology, better prenatal care, screening and assessment, require immediate recognition and intervention if we are to have a successful delivery, avoiding brain damage.

Another aspect of a successful delivery is managing both the mother's and the infant's length of stay. The increasing pressure from insurance companies to limit extended hospital stay creates an increased challenge to prevent untoward outcomes. If a patient stays beyond the predefined length of stay related to a preventable hospital incident then insurance companies are less likely to reimburse that overage. Therefore, if a Caesarean section is required it is advantageous to have quantitative evidence of the threat to that fetus and the vital need for the invasive procedure. The very real danger of a fetal demise or hypoxia (lack of oxygen) with late decelerations in labor underscores the need for early recognition, documentation and intervention especially when that intervention requires a longer and more costly length of stay. The overall cost for both mother and child must be analyzed. Whereas a caesarian section might be more costly for the mother than a vaginal delivery, the cost – both in length of stay and in human suffering – is less for a healthy baby than that of an oxygen deprived baby who may wind up in a Neonatal Intensive Care Unit.

Ms. Adams is a 25 year old female who is 40 weeks pregnant and in active labor. Due to several low fetal heart rate spot check readings noted during transport to the hospital and the gestational age of the fetus, which is right at full term, Ms. Adams baby is at risk for "late decelerations". Late decelerations are a specific pattern of decrease in fetal heart rate during the second half of a uterine contraction. This is a very ominous sign for a fetus during labor and there is a very real risk of fetal deterioration and demise if emergency intervention is not established. Typically, oxygen is placed on the mother to improve the oxygen flow to the fetus, a change in maternal position to the left side improves blood flow to the infant and if there is no improvement with these interventions, an emergency cesarean section is likely.

A cardiotocographic machine[2] monitors fetal heart rate in direct relation to uterine contractions. Currently, a patient is allowed to labor "for a while" and then these monitor strips are collected and reviewed manually by a nurse or physician to see how the fetus is tolerating labor.

With InfoSphere Streams, this monitoring could be performed continuously in order to measure this fetus's response to active labor, even when the nurse is out of the room. To support continuous, automatic monitoring, we first need to calculate the fetal baseline heart rate, measured in beats per minute. This is accomplished with data streamed from the cardiotocograph for the fetal heart rate and filtering out any aberrancies and artifact like loss of contact or fetal movement. With this baseline measurement, we can monitor for a decrease in the heart rate of the fetus (often seen visually in the data stream as an inverted bell curve) that occurs right after the peak of the contraction and then lingers on, only slowly recovering long after the contraction is finished. Once detected, an alert could then warn the nurse, who may not be in the room, that late decelerations have been detected. Further, fetal conditions of concern, such as a fast rhythm (tachycardia), a slow flat rhythm (bradycardia), a loss of contact (the monitor fell off) or a loss of signal (the fetus moved or potentially fetal death), can be similarly detected and alerted to healthcare personnel.

3.2 *Scenario 2 ST segment elevated on EKG*

Acute Myocardial Infarction (AMI), commonly known as heart attack, is a serious threat across the globe. More than one million Americans have new or recurrent heart attacks each year and an estimated 175,000 Americans will experience silent first heart attacks this year[3]. According to the American Heart Association's Heart Disease and Stroke Statistics[4] (the 2008 Update): 1,271,000 angioplasties were performed in the United States in 2005. 469,000 cardiac revascularizations (also known as coronary artery bypass graft (CABG)) were done in the United States in 2005. CABG was performed on 325,000 men and 145,000 women. Early intervention is key to an outcome that minimizes cardiac muscle injury and preserves the efficiency of the heart pump.

Often addressed in literature as “STEMI” or ST Elevation Myocardial Infarction, heart attacks with ST elevation (appendix B) on Electrocardiogram (EKG) can be deadly if intervention in the form of medication, surgery, intensive cardiac monitoring or other therapy is delayed even just a few minutes[5]. As soon as ST elevation is observed on a standard bedside EKG, the presence of new or ongoing heart damage should be vigorously investigated and documented with a more detailed 12 lead EKG. However, trained staff cannot be everywhere at once in order to continuously note these very small changes on a wave form. Early intervention – sometimes even before the patient mentions chest pain (or for those who cannot indicate pain due to anesthesia, coma, or intubation on a ventilator) could prevent heart muscle damage from lack of oxygen.

One such case of a serious threat to cardiac muscle is Mr. A., a 58 year old male with chest pain who presents to the emergency department. His pain, which began while he was at his desk working at 10 AM, radiates to the jaw and left arm with sweating and nausea. Initial 12 lead EKG shows ST elevation in 6 of the 12 “leads” or ways of looking at the electrical activity of the heart. “ST elevation” refers to a part of one single heart beat tracing between the QRS complex and the T wave called the “ST segment”. When this area of the tracing is elevated, heart damage is either happening or imminent. Mr. A is still having pain that he rates at 3 on a scale of 1-10 (10 being the highest on the scale). Because of secondary damage from simply being in pain, the standard of care is to make the patient pain free. Morphine relieved Mr. A’s pain and eventually he slept. While he slept, the nurse noted on the bedside monitor that the ST segment on the EKG had elevated again, despite initial resolution of the ST segment elevation.

Although the change in only one lead is not diagnostic of an MI (heart attack), a subtle change in the waveform might signal heart damage and an evolving silent MI[6]. Once other possible explanations have been explored – like a change in the patient position that has changed the EKG picture – then a 12 lead EKG should be completed to confirm or dispute the heart damage. In this case, the 12 lead did confirm that Mr. A was extending his initial heart attack to another area of his heart. Mr. A. received blood thinners (i.e.. Aspirin and Heparin) immediately and was prepared to go to the cardiac catheterization lab. A balloon and a stent (mesh tube used to hold the vessel open) will be inserted into his coronary arteries with the intention of locating and destroying the blood clot interfering with blood flow to his heart if the blood thinners have not already cleared the coronary artery blockage. If the blood thinners and the cardiac catheterization lab procedures do not clear the blockage then open-heart surgery is the next course of action. All this activity and intervention was initiated by a very slight rise in a waveform tracing by an observant nurse, who happened to be in his room during the critical moment.

But, what if the nurse isn't in the room? What if the elevation of the ST segment (appendix B) is only incidentally discovered on the routine 12 lead EKG completed each morning? Hours to save heart muscle may have already been lost. Early intervention of an elevated ST segment opens the opportunity for less overall invasive treatment if, in fact, early aggressive use of blood thinners results in successful opening of the vessel. This early intervention might prevent the need for cardiac catheterization, a balloon procedure or open heart surgery. By avoiding each of these invasive procedures, we decrease cost, decrease length of stay and avoid complications. Patients, overcrowded hospitals and insurance companies all win.

Used as a tool that generates an alert, interpretation of streamed data can make a difference in the outcome and recovery of a heart attack patient. Certainly, Artemis cannot replace the skill and interpretation of a trained professional, but Artemis could be used as an indicator to the staff of subtle changes noted within volumes of data, especially during periods when someone cannot stand by the monitoring equipment continuously. Even in light of the inevitable false alerts, every avenue for predictive analysis should be explored and refined to move us to the next generation of health care analysis and pro-active rather than reactive care.

3.3 *Scenario 3 Intracranial Pressure (ICP) Monitoring in Traumatic Brain Injury (TBI)*

Traumatic Brain Injury (TBI), also called acquired brain injury, occurs when a sudden trauma causes damage to the brain (appendix C). TBI can result when the head suddenly and violently hits an object, or when an object pierces the skull and enters brain tissue.

TBI is a leading cause of death and disability among children and young adults in the United States. Each year, an estimated 1.5 million Americans sustain TBI. That's 8 times the number of people diagnosed with breast cancer and 34 times the number of new cases of HIV/AIDS each year.

The incidence for traumatic brain injury is about 100 hospitalized cases per 100,000 populations (Kraus & McArthur, 1999). It is helpful to understand how TBI compares to the occurrence of other disorders. With spinal cord injury, the incidence rate is about 4 per 100,000 and for cerebral palsy it is about 10 per 100,000. While the incidence of stroke approaches that of TBI, it usually occurs in an older population.

TBI occurs twice as often in men as in women. Populations at a higher risk include:

- Individuals between the ages of 15 and 24 years
- Individuals age 75 and older

Half of all traumatic brain injuries involve alcohol use, either by the victim or the person causing the injury.

Children age five and younger are also at a higher-than-average risk. According to the National Pediatric Trauma Registry, more than 30,000 children are permanently disabled each year as a result of brain injuries. The greatest risk occurs from mid-afternoon to early evening, and during weekends and the summer months. Children are especially at risk after school. Nearly half (42.6%) of all children's injuries occur in roads, 34.3% occur at home and 6.6% occur in recreation areas.

The causes of TBI vary and are broken down in Table 1. Vehicle-related injuries involve people of all ages. Falls are most common among the elderly and the very young. Alcohol and medication use are common contributing factors in falls. Gunshot wounds account for a small proportion of TBIs (10%), but a high percentage of related fatalities (44%). Nine out of ten people who incur TBI from a firearm die[7].

Domestic abuse (including shaken baby syndrome) and sports injuries are common causes of TBI. Approximately 3% of all hospitalizations for TBI are incurred while playing sports. Most sports-related TBI are relatively minor and therefore go unreported.

Causes of TBI

Motor Vehicle Crashes	Gunshot Wounds	Falls	Assault	Pedestrian	Sports
64%	13%	11%	8%	3%	1%

Table 1: Statistical percentage breakdown of causes of TBI

The severity of traumatic brain injury can vary greatly, depending on the part of the brain affected and the extent of the damage. A mild traumatic brain injury may cause temporary confusion and headache, but a serious one can be fatal.

Traumatic Brain Injury (TBI) (appendix C) includes two stages – primary and secondary injury[8]. Primary injury is the damage that occurs with the initial injury at the scene of the accident or crime. Secondary injury occurs after the initial damage and is the ongoing destruction of the brain created by swelling, blood or cerebral spinal fluid (CSF) pooling, or chemical reactions within the brain. Secondary injury typically occurs during the patient's emergency department and inpatient hospital stay. Brain damage occurs if the brain swelling is not closely monitored and reduced to normal ranges along with the strict management of other physical and metabolic side effects of elevated head pressures.

Secondary injury related to brain swelling threatens further unnecessary brain damage and a profound decrease in the patient's overall recovery potential. Among other things, poor recovery translates into a longer length of stay in the hospital. Until the patient's neurological status is finally stabilized, successful early intervention is again the key to preventing further brain damage and the many dangerous side effects of immobility that increase the length of hospital stay and cost. Of course, every case is specific in that the damage and subsequent health limitations are unavoidable, but decreased mobility is related to many complex and expensive health problems. The risks of skin breakdown, infection, pneumonia, gastrointestinal stasis, and bone loss are just some of the many acute and chronic illnesses associated with immobility. The need for long-term rehabilitation and further invasive therapy for related healthcare issues may be avoided with early detection, documentation and management of secondary brain injury[9]. Certainly this decrease in length of stay, decrease in need for intensive and invasive care, and decrease in exposure to potential nosocomial (hospital acquired) infection creates a humanitarian and economic case for early and ongoing intervention for Traumatic Brain Injury patients.

The following is a TBI scenario that is all too familiar and tragic.

Mr. C, 23 years old and his wife were on their way to a celebratory dinner when a deer jumped out in front of their car. Mr. C. swerved to miss the deer, ran off the road into an embankment, and hit a tree head on. His wife was wearing her seat belt and had only minor cuts and scratches, but Mr. C. wasn't. His head hit the windshield. He lost consciousness, sustained several large cuts to his forehead, and was bleeding from his nose and mouth. His wife used her cell phone to dial 911.

Mr. C. has sustained a Traumatic Brain Injury (TBI). As soon as Mr. C arrives at the emergency department, the trauma team, rapidly assess the medical situation of the patient. The tools used to assess brain function includes the Glasgow coma scale, pupil responses to light, intracranial pressure monitoring, discrete and continuous lab values, and reflex assessment (Appendix C). Zealous and frequent monitoring of these parameters for extraordinarily subtle changes signaling damage to brain tissue is critical.

In this scenario, Infosphere Stream analytics can help with the streaming data interpretation. Streaming data interpretation could be continuously monitoring Mr. C's vital signs for rapid assessment of increased intracranial pressure that require timely intervention to save brain function. Other potential streaming data in this scenario includes blood oxygen level, carbon dioxide level, blood pressure, pulse, and core temperature.

The volume of continuous data available in this situation is stunning and combined with individual pieces of data intermittently collected (i.e. pupil responses to a light source[10]) appropriate clinical assessments can be made. Other monitoring devices include the Pupillometer (appendix C), which more accurately defines pupil velocity and size. Pupil size and response to light is a clear indicator of brain swelling and potential ongoing secondary damage.

With constant interpretation of the Intracranial Pressure (ICP) waveform utilizing InfoSphere Streams alerts and immediate intervention when the pressures within the skull are elevated, Mr. C stands a better chance of recovery with optimum brain function and less catastrophic long-term consequences. Alerts for abnormal readings using InfoSphere Streams monitoring could create a safer atmosphere for patients and speed health care delivery.

4. Conclusion

James F. Bell said "To face tomorrow with the thought of using the methods of yesterday is to envision life at a standstill. Each one of us, no matter what our task, must search for new and better methods, for even that which we now do well must be done better tomorrow."

Healthcare is definitely not at a standstill. Health management can clearly be "done better tomorrow", if we are insightful and innovative. It is time to prepare for streaming data interpretation and data organization. Artemis has the potential to manage massive amounts of streaming patient data and make it controllable for timely and potentially life saving intervention.

When time is vital, the risk to quality of life is critical, and the resources limited, data streaming interpretation can be an essential tool. With these interpretive tools in place the clinician has another avenue for patient safety. Huge amounts of data can be assessed and recorded continuously, enabling early intervention. Along with patient monitoring and subsequent intervention, data stream interpretation enhances data documentation and research opportunities by accurately capturing and storing data.

As you have read, we have outlined the capabilities of IBM's stream processing technology, created use case scenarios that connect this new technology to the real world of caring for critically ill people and outlined the significance of this new technology in a rapidly evolving healthcare environment.

Initially there may still be more questions than answers. Questions like, how do I integrate this technology with my existing systems? What further resources in people, time, equipment and skill set are necessary to take this product to market? What are the legal implications of this type of health care stream data programming? How specifically can this technology help us take better care of patients? Will this affect clinical jobs or staffing? Will this programming make my institution more competitive? What will be done with the massive amount of data that will require storage and recovery? What about HIPAA and JCAHO requirements? Continued research and refinement of the application will get to the bottom of these questions and concerns.

With healthcare, we simply must do better tomorrow. How can we compete without tools that manage massive amounts of clinical information? It is our sincere hope that we can help delineate strategies and opportunities for a more efficient way to manage and interpret massive amounts of patient data in order to lead IBM in the upcoming healthcare revolution.

5. Appendix A

Late Deceleration:

A cardiotocograph is the machine used to monitor women in labor. This monitor attaches to the top of the mother's abdomen to monitor the contracting uterine muscle activity and also, using either an internal or external monitor strapped to the lower abdomen, the constant heart beats (heart rate) of the fetus working hard to be born.

In a labor and delivery department, a late deceleration is defined as a gradual decrease in fetal heart rate (FHR) where the onset of deceleration to the deepest point (also called the nadir) is both greater than 30 seconds and the onset of the deceleration occurs after the peak or most intense point of the contraction. In the picture below it is easy to see how just as the uterine contraction is subsiding (or "relaxing" as in the tracing marked contraction) the fetal heart rate is also decreasing in an upside down bell curve that does not fully return (or recover) to baseline until the contraction is completely finished.

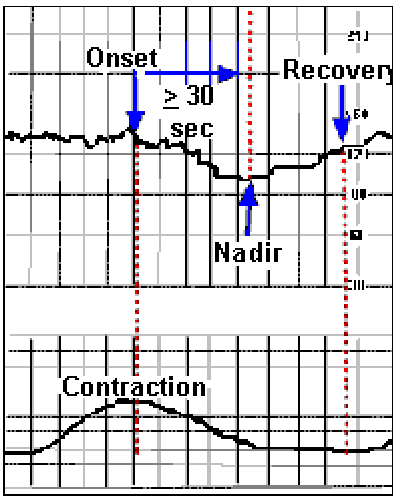


Figure 4

This graph represents one complete contraction lasting 45 seconds to a minute. The top portion shows the fetal heart rate in beats per minute. The FHR heart rate is documented in direct time correlation with the lower graph that documents the mother's uterine contractions. Therefore, we are watching how this fetus is responding to the stresses of labor, contraction by contraction.

This specific pattern of late decelerations is ominous for a fetus and is a very clear sign to intervene by giving the mother oxygen, repositioning her to her left side (for better circulation of oxygen to the fetus), preparing to surgically deliver the fetus, and other immediate preparations for delivery. This fetus is clearly unable to hold their oxygen level within normal range throughout an entire contraction as evidenced by a dangerously decreasing heart rate. Possibly there is umbilical cord compression with the contraction but more likely this situation occurs when the pregnancy is right at 40 weeks (full term) or after. The placenta begins to break down and function less efficiently as labor progresses. The placenta with the attached umbilical cord is the only oxygen lifeline for a fetus.

6. Appendix B

The combination of a p-wave, QRS complex and t-wave is indicative of one complete "heartbeat". A QRS complex represents the ventricles contracting and pushing blood throughout the body and lungs, or in other words, the "blood pumping" capability of the heart. To count how many beats are in one minute, count the R waves (upstroke of the QRS complex) in a 6 second EKG strip and multiply by 10. Therefore, there are two heartbeats displayed in figure 6. The resting baseline between the end of the "QRS" complex and the beginning of the "T" wave is called the ST segment. It is the elevation of this ST segment up from the baseline that is the area of concern in scenario two and is indicative of a heart attack.

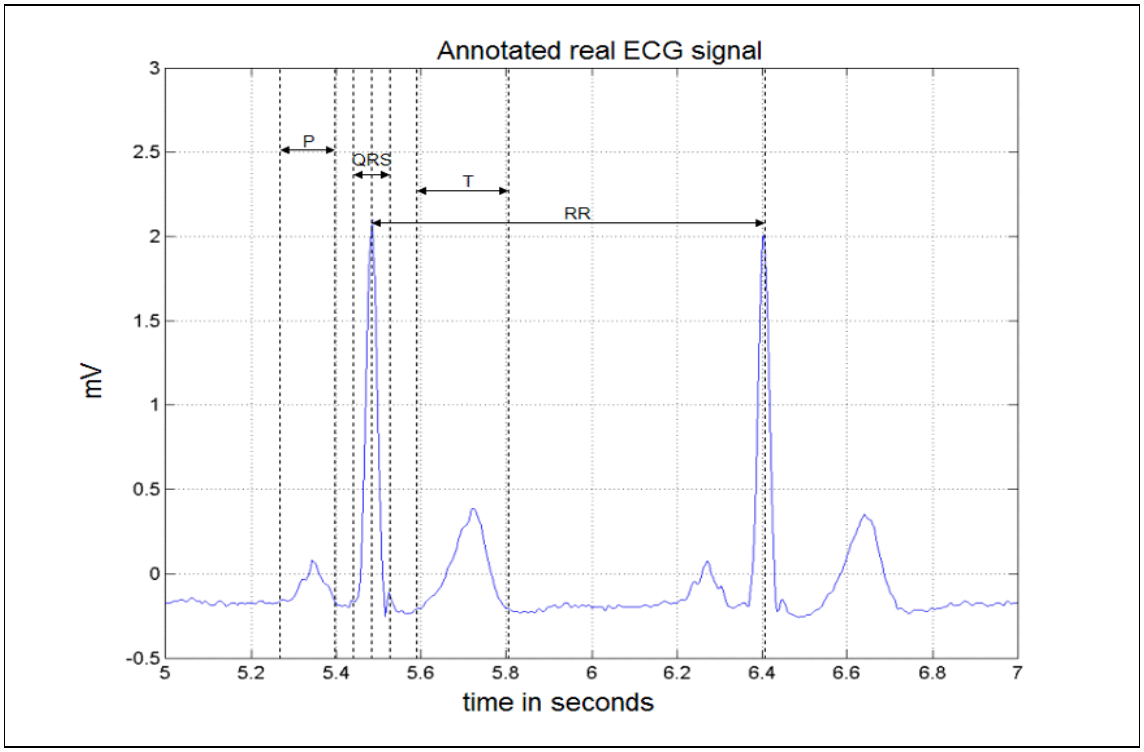


Figure 5

Typically, when a patient is in an ICU (intensive care unit) or in the Operating Room, the EKG (electrocardiogram also called ECG) monitors the patient in one lead only, as in figure 6 (compared to figure 7 which is a 12 lead EKG). Therefore if a change in the appearance of the wave form is noted in this one lead, as in the difference in the ST segment of A and B in figure 6, then a full 12 lead EKG should be done to confirm the ST segment elevation is present in several other leads.

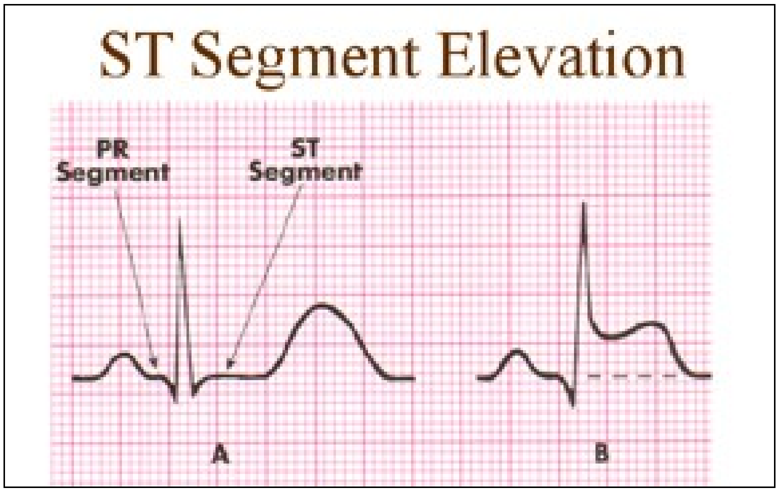


Figure 6

Figure 7

A very subtle elevation or depression of the tracing between the QRS complex and the T wave (known as the ST segment – see the highlighted areas in figure 7) is an indicator of decreased blood flow to the heart and an impending heart attack or "MI" (myocardial infarction). Because we don't typically keep a patient hooked up to a 12 lead EKG around the clock, it is important to monitor for ST elevation in the single lead (figure 6) for ST elevation. Often a patient will mention chest discomfort alerting us to look for ST changes, but if the patient is in a coma, on a ventilator or sedated and cannot communicate chest pain, monitoring the single lead for ST elevation and following up with a 12 lead when there is a suspicion is important. Once elevation is identified on a single lead as in figure 6, then a 12 lead should be accomplished to determine if we are dealing with true ST elevation in several leads which can be indicative of a STEMI (ST elevation MI)

The 12 lead EKG tracing (figure 7) shows both ST elevation and ST depression in several leads highlighted. Currently there are EKG machines that can interpret these changes and correlate the specific ST changes with the precise wall (or side) of the heart that is damaged or is becoming damaged. For example, an anterior wall MI is located across the front of the heart muscle and this ST elevation pattern correlates to a specific heart vessel (coronary artery) that is either clogged up or spasming. From a 12 lead tracing it can be determined that a specific coronary artery is in trouble and needs intervention either with medicines – clot busters and blood thinners, or with balloon angioplasty (open the vessel with a balloon), or possibly open heart surgery coronary artery bypass grafts (or CABG).

7. Appendix C

Traumatic Brain Injury (TBI) includes two stages – *primary and secondary* injury. It is now up to medical professionals to minimize the damage done by secondary injury that includes swelling, chemical changes in the brain, increased pressure, and other changes that increase the permanent impact of the initial damage. Monitoring and intervention is key to saving brain tissue and function.

A quick review of intracranial pressure:

The cranium – or skull - is an enclosed space that houses three components: brain tissue, blood, and cerebrospinal fluid. The pressure within the skull, intracranial pressure or ICP, is determined by these three components. When one of these three components increases in volume, one or both of the other components must compensate or shift by decreasing. When the limits of compensation have been reached, ICP increases to over 20 mmHg, compromising brain perfusion and causing brain tissue death.

Once the patient has been transferred to the ICU, his neurological care will focus on close observation and monitoring to prevent secondary brain injury. To achieve this goal, nursing will closely monitor ICP, cerebral blood flow (CBF), cerebral perfusion pressure (CPP), and vital signs, along with neurological and pupil status.

Figure 8: This diagram shows various brain monitoring devices[11], parameters, and normal values for proper brain function.

Brain monitoring by the numbers

Device	Parameter measured	Normal value	Critical value
ForSite pupillometer	Size and velocity of constriction of the pupil	Pupillary change >10% and constriction velocity >0.6 mm/sec	Pupillary change <10% and constriction velocity <0.6 mm/sec
Intraventricular catheter	Intracranial pressure (ICP)	10 – 15 mm Hg	>20 mm Hg
INVOS cerebral oximeter	Regional oxygen saturation (rSO_2)	58 – 82 points	≤40 points
LICOX brain oxygen monitor	Partial pressure of brain tissue oxygen ($PbtO_2$)	20 – 35 mm Hg	<15 mm Hg
Capnometer	Expired end-tidal carbon dioxide ($EtCO_2$)	35 – 45 mm Hg	<35 mm Hg

Sources: 1. Bader, M. K., Littlejohns, L., & March, K. (2003). Brain tissue oxygen monitoring in severe brain injury, I. *Critical Care Nurse, 24*(4), 17. **2.** Bullock, R., Chestnut, R. M., et al. (2000). *Management and prognosis of severe traumatic brain injury*. New York: Brain Trauma Foundation. **3.** Arbour, R. (2004). Intracranial hypertension: Monitoring and nursing assessment. *Critical Care Nurse, 24*(5), 19. **4.** Edmonds, H. L. Jr., Ganzel, B. L., & Austin, E. H. 3rd. (2004). Cerebral oximetry for cardiac and vascular surgery. *Semin Cardiothorac Vasc Anesth, 8*(2), 147.

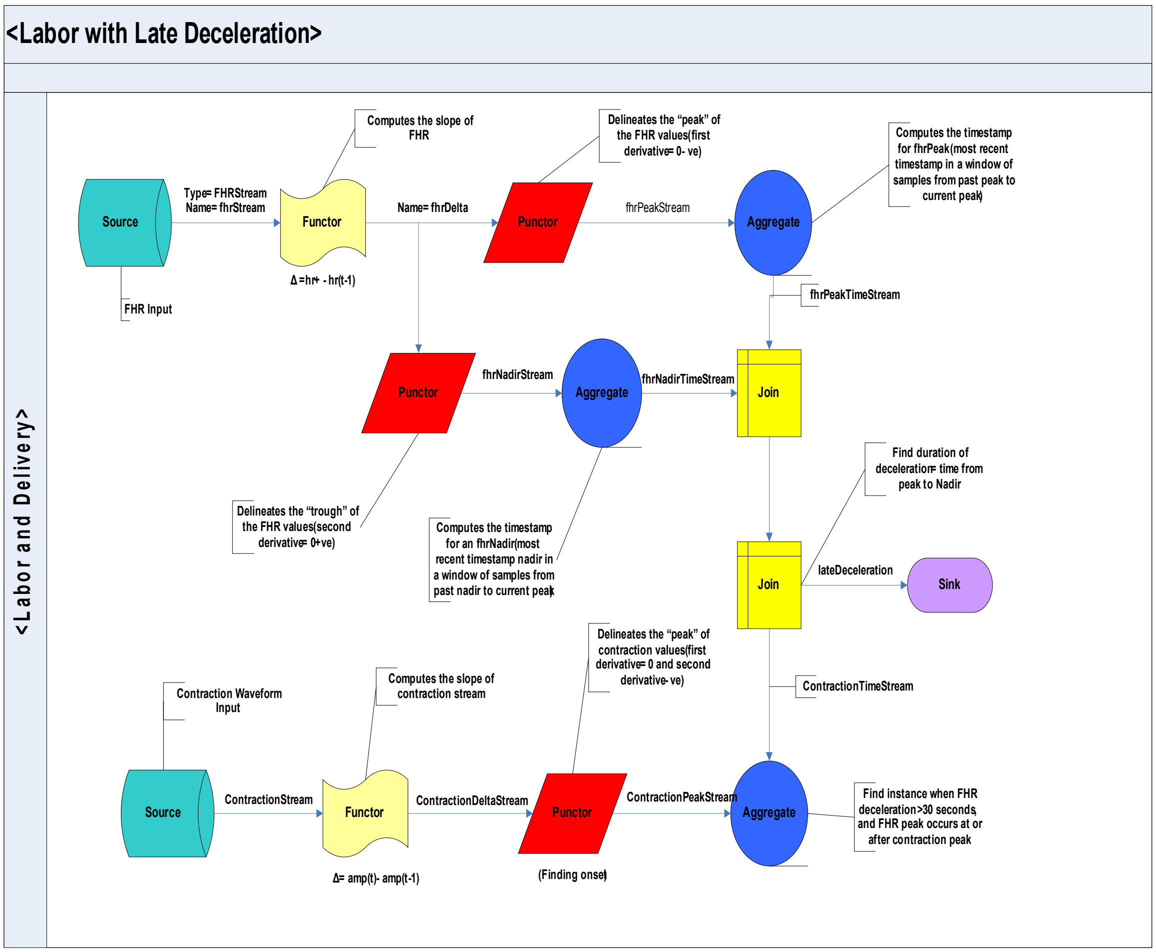
A variety of ICP monitoring devices are available. A ventriculostomy is a tube placed directly in the ventricles of the brain and then attached to a manometer or a transducer to measure the pressure in the brain. Ventriculostomy devices are preferred over other types of devices because they are highly accurate and they allow you to lower ICP by draining cerebral spinal fluid out to directly lower the intracranial pressure in the brain.

Pupil assessment is another important tool for assessing the pressure inside the skull and is a fundamental part of any neurologic exam. Using a penlight and pupil gauge, the size, shape, and reactivity of the pupils are indicators of neurologic function; a failure to react to light or a sluggish response suggests that the patient has elevated ICP, which typically means a reading above 20 mm Hg.

The challenge in using a pupil gauge is that it is somewhat subjective. One nurse may read the pupil size as 2mm with a brisk response and the next as 3mm with a sluggish response. This variance of just one mm and discrepancy in response is huge in relation to what is going on inside the brain. Did the patient have a big turn for the worse or is that just a difference of interpretation between two individuals? One alternative is an automated pupillometer, which yields more reliable and less subjective results than a manual eye examination.

8. Appendix D

8.1 InfoSphere Streams stream processing flowchart on Scenario 1 (For readability, many finer details, such as the techniques for computing the baseline FHR are omitted).



8.2 SPADE Program Specifications for Scenario 1

```
[Application]
artemisScenario1 fetal

[Typedefs]
typespace artemisScenario1

[Program]

#*
Note that this is a 'simplified' version of the operators
we discussed. In particular, note that:
```

```
i) this doesn't include the computation of FHR BASELINE
(when this is done, the punctor will not be based
on a slope of 0, but rather 'return to baseline')
ii) Both the FHR and Contraction streams will need
to be passed through a low-pass filter to eliminate
noise.
*#


#*
==============================================================
Define the streams that will be used in this program.
==============================================================
*#
vstream FHRStream(
   heartRate  : Integer,
   timestamp  :  Long,
   patientID  :  String,
   sensorID:     String)


vstream ContractionStream(
   amplitude :  Float,
   timestamp:   Long,
   patientID:   String,
   sensorID:    String)

vstream lateDecellerationStream (
   alert:   String,
   timeStamp:   Long,
   patientID:   String)

#*
==============================================================
Source to read the FHR Stream
==============================================================
*#
stream fhrStream(schemaFor(FHRStream))
 := Source()["sctp://artemisHub.ibm.com:12345", nodelays, initdelay=5,
throttledRate=2, csvformat]
  {}

stream contractionStream(schemaFor(FHRStream))
 := Source()["sctp://artemisHub.ibm.com:23456", nodelays, initdelay=5,
throttledRate=2, csvformat]
  {}

#*
==============================================================
First obtain the points of fhr Peak and Trough
==============================================================
*#

stream fhrDelta(delta: Integer, heartRate: Integer, timestamp: Long,
patientID: String, sensorID: String)
 := Functor(fhrStream)[] {delta:= heartRate- ^1.hearRate}
```

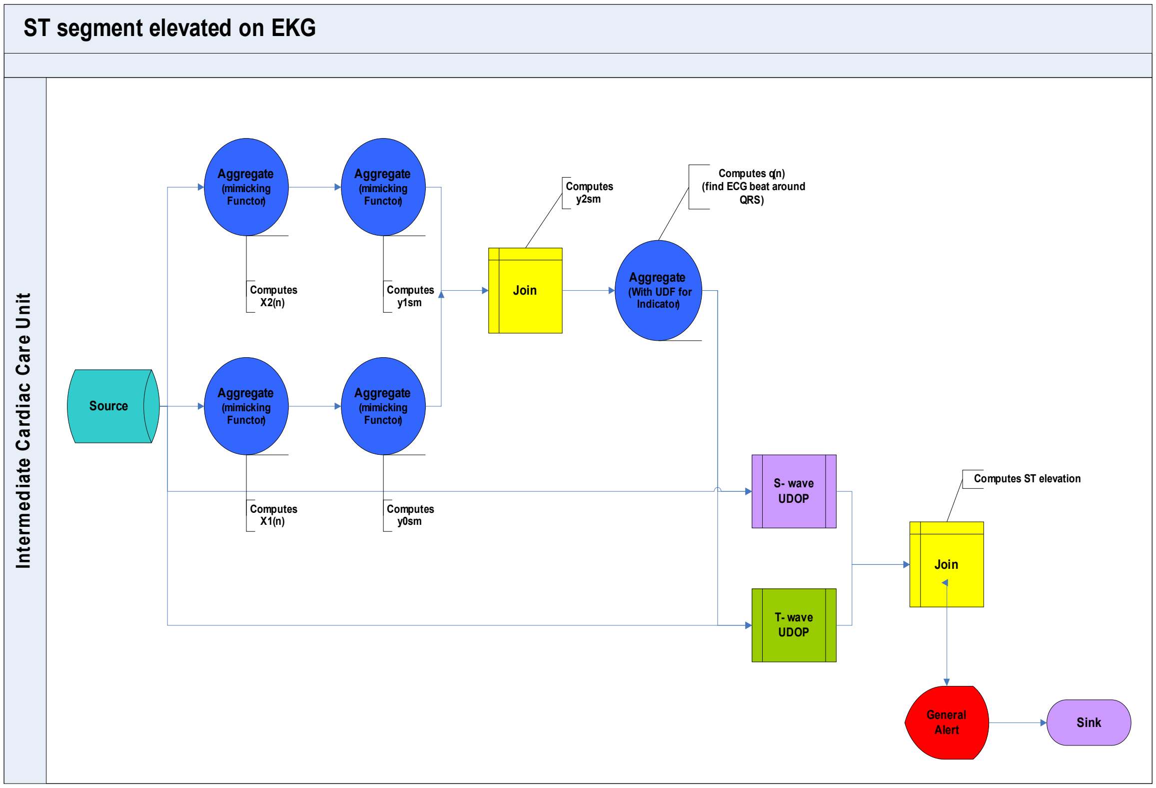
```
stream fhrPeakStream(delta: Integer heartRate: Integer, timestamp:
Long, patientID: String, sensorID: String )
  := Punctor(fhrDelta) [delta<0 & ^1.delta >=0, before]{}

stream fhrNadirStream(delta: Integer heartRate: Integer, timestamp:
Long, patientID: String, sensorID: String )
  := Punctor(fhrDelta) [delta>0 & ^1.delta <=0, after]{}

stream fhrPeakTimeStream( peakTime: Long, numSamples: Integer,
patientID: String, sensorID: String)
  := Aggregate(fhrPeakStream<punct()>,perGroup)[patientID]
     {Last(timestamp),  Cnt(), Any(patientID), Last(sensorID)}

stream fhrNadirTimeStream( nadirTime: Long, numSamples: Integer,
patientID: String, sensorID: String)
  := Aggregate(fhrPeakStream<punct(),perGroup)[patientID]
     {Last(timestamp),  Cnt(), Any(patientID), Last(sensorID)}

#*
=============================================================
Now, match the peak and troughs to get deceleration interval
=============================================================
*#

stream fhrDeccelerationStream( startDecTime: Long, endDecTime: Long,
patientID: String)
 :=  Join(fhrPeakTimeStream<time(5000),perGroup>,
fhrNadirTimeStream<time(5000, perGroup)>)
     [{patientID}={patientID}, $1.timestamp<$2.timestamp &
$1.timestamp> $2.^1.timestamp]
     { startDecTime:=$1.timestamp, endDecTime= $2.timestamp,
$1.patientID}


#*
=============================================================
Similarly, get the contraction Peak and Trough
=============================================================
*#

stream contractionDelta(delta: Float,  amplitude: Float, timestamp:
Long, patientID: String, sensorID: String)
 := Functor(fhrStream)[] {delta:= amplitude- ^1.amplitude}

stream contractionPeakStream()
  := Punctor(fhrDelta) [delta<0 & ^1.delta >=0 & amplitude >=
2.0*BASELINE, before]{}

stream contractionNadirStream()
  := Punctor(fhrDelta) [delta>0 & ^1.delta <=0 & amplitude <= BASELINE,
after]{}

stream fhrContractionTimeStream( peakTime: Long, numSamples: Integer,
patientID: String, sensorID: String)
  := Aggregate(contractionPeakStream<punct()>,perGroup)[patientID]
     {Last(timestamp),  Cnt(), Any(patientID), Last(sensorID)}
```

```
#*
==============================================================
Now, see if there is a late decceleration of >30 seconds
==============================================================
*#
stream lateDecelleration(schemaFor(AlertLateDecelleration))
 := Join(fhrDeccelerationStream<time(5000), perGroup>,
contractionTimeStream<time(5000,perGroup)>)
      [{patientID}={patientID}, $1.startDecTime<= $2.peakTime &
$1.endDecTime> $2.peakTime
                  & $1.endDecTime-$1.startDecTime> 30000L}]
       {alert:= "Late and Long Decelleration", timeStamp= $2.peakTime,
patientID:=$1.patientID}

#*
==============================================================
Sinks for the alert
==============================================================
*#
Null := Sink(lateDecelleration)
["file:///alerts.dat",nodelays,csvformat]{}
```

---

9. Appendix E

9.1 Operator Graph Diagram for Scenario 2



9.2 SPADE Program Specification for Scenario 2

```
[Application]
artemisapps fatal

[Typedefs]
typespace artemisapps

[Program]

#*
==============================================================
Define the streams that will be used in this program.

ECGStream:  the input ECG Sample Stream
STAlertStream   = ST Elevation Alert
==============================================================
*#
vstream ECGStream(
```

```
   ecgValue  : Float,
   timestamp    :  Long,
   patientID    :  String,
   sensorID     :  String)


vstream STAlertStream (
   alert:   String,
   timeStamp:   Long,
   patientID:   String)

#*
================================================================
Source to read the ECG Stream
================================================================
*#
stream ecgStream(schemaFor(ICPStream))
 := Source()["stcp://artemisHub.ibm.com:12345", nodelays, initdelay=5,
throttledRate=2, csvformat]
  {}


#*
==========================================================================
===============
First computes the various linear filter terms
Note: We use a per-group Aggregate operation to mimic a per-patient
Functor operation
==========================================================================
===============
*#

stream x1Stream(x1val: Float, ecgValue: Float, timestamp: Long,
patientID: String, sensorID: String)
      := Aggregate(ecgStream<count(5),count(1),perGroup)[patientID]
        {Last(ecgValue)-First(ecgValue), Last(ecgValue),
Last(timestamp), Any(patientID), Any(sensorID)}

stream x2Stream(x2val: Float, ecgValue: Float, timestamp: Long,
patientID: String, sensorID: String)
      := Aggregate(ecgStream<count(2),count(1),perGroup)[patientID]
        {Last(ecgValue)- 2* ^2.First(ecgValue)+ First(ecgValue),
Last(ecgValue), Last(timestamp), Any(patientID), Any(sensorID)}

stream y0SMStream(y1Val: Float, ecgValue: Float, timestamp: Long,
patientID: String, sensorID: String)
      := Aggregate(x1Stream<count(3),count(1),perGroup)[patientID]
        {0.25*Last(x1val)+ 2* ^1.x1val+ First(x1val),  Last(ecgValue),
Last(timestamp), Any(patientID), Any(sensorID)}

stream y1SMStream(y2Val: Float, ecgValue: Float, timestamp: Long,
patientID: String, sensorID: String)
      := Aggregate(x2Stream<count(3),count(1),perGroup)[patientID]
        {0.25*Last(x2val)+ 2* ^1.x2val+ First(x2val),  Last(ecgValue),
Last(timestamp), Any(patientID), Any(sensorID)}
```

```
stream y2Stream( y2Val: Float, ecgVal: Float, timestamp: Long,
patientID: String)
 :=  Join(y0SMStream<time(2000),perGroup>, y1SMStream<time(2000,
perGroup)>)
     [{patientID}={patientID}, $1.timestamp=$2.timestamp]
     { y2Val:=1.3* y0Val+ 1.1* y1Val, timestamp:=$1.timestamp,
pupilvelocity:= $2.pupilvelocity, pupilsize:= $1.pupilsize,
$1.patientID}


stream yqStream( y2Val: Int, ecgVal: Float, timestamp: Long, patientID:
String)
 :=  Aggregate(y0SMStream<window(8),window(1),perGroup)[patientID]
     { y2Val:= BitANDUDF(y2Val[1:8]), ecgVal= Last(ecgVal), timestamp:=
Last(timestamp), patientID:= Any(patientID)}


#*
===============================================================
Then find the S Wave
===============================================================
*#

stream sWave(beginTime: Long, endTime: Long, patientID: String)
:= Udop(yqStream, ecgStream)["sWaveIdentification"]{}


#*
===============================================================
Find the T-Wave
===============================================================
*#

stream tWave(beginTime: Long, endTime: Long, patientID: String)
:= Udop(yqStream, ecgStream)["tWaveIdentification"]{}

#*
===============================================================
Find the ST-Segment
===============================================================
*#
stream stSegment(beginTime: Long, endTime: Long, value: Double,
patientID: String)
:= Join(twave<time(2000), perGroup>, sWave<time(2000),perGroup>,
ecgStream<time(2000)>, perGroup)
      [{patientID}={patientID}, $1.beginTime>$2.endTime,
$2.endTime>$1.^1.endTime]
      {beginTime := $2.endTime, endTime := $1.beginTime, value =
STAvgUDF(ecgStream, $2.endTime, $1.beginTime)}

#*
=======================================================================
==============================================
Now see if ST segment greater than a predefined threshold. We set this
threshold at
compilation time.
```

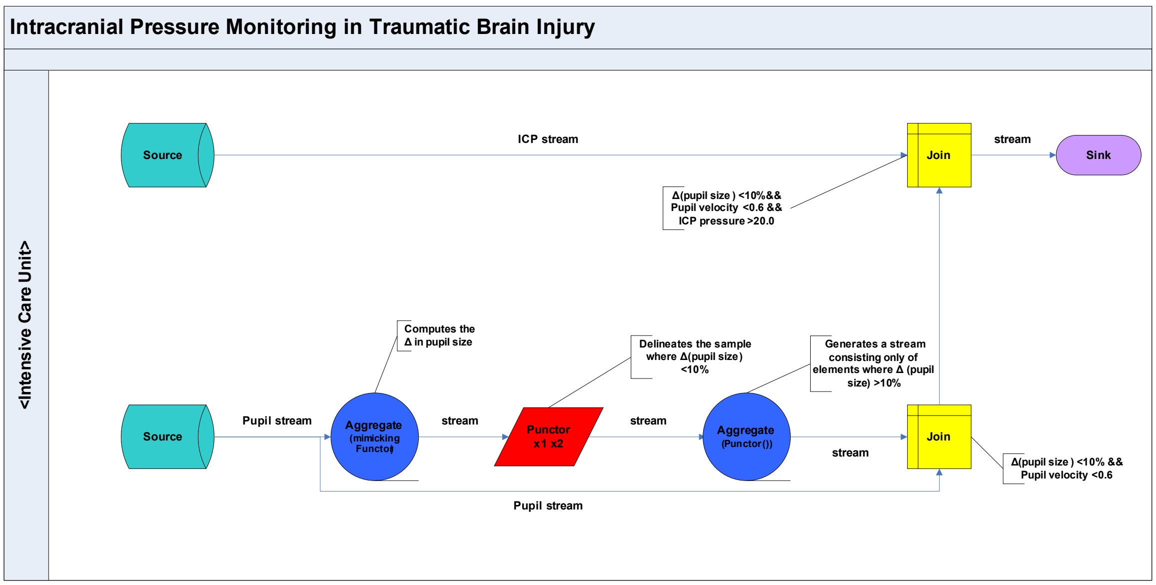
```
==========================================================================
===================================================
*#
stream stAlertStream(schemaFor(STAlertStream))
 := Functor(stSegment)
      [value > %1]
       {alert:= "Elevated ST Alert", timeStamp= $1.beginTime,
patientID:=$1.patientID}

#*
================================================================
Sinks for the alert
================================================================
*#
Null := Sink(tbi)   ["file:///alerts.dat",nodelays,csvformat]{}
```

10. Appendix E

10.1 Operator Graph Diagram for Scenario 3- Traumatic Brain Injury (TBI)

Clinical Data: Pupillary change<10%
Constriction velocity<0.6 mm/sec
Intracranial Pressure (ICP) >20 mm/Hg= ALERT

Data Streams: ICPStream= Intracranial pressure
PupilStream= Size and velocity of constriction of the pupil
TBI'stream= Traumatic Brain Injury (TBI)



10.2 SPADE Program Specification for Scenario 3

```
[Application]
artemisapps fatal

[Typedefs]
typespace artemisapps

[Program]

#*
i) Both the ICP and Pupil streams will need
to be passed through a low-pass filter to eliminate
noise.
*#
```

```
#*
=================================================================
Define the streams that will be used in this program.

ICPStream   = Intracranial Pressure
PupilStream = Size and velocity of constriction of the pupil
TBI'stream   = Traumatic Brain Injury (TBI)
=================================================================
*#
vstream ICPStream(
   icppressure  : Integer,
   timestamp    :  Long,
   patientID    :  String,
   sensorID     :  String)

vstream PupilStream(
   pupilsize     :   Float,
   pupilvelocity :   Float,
   timestamp     :   Long,
   patientID     :   String,
   sensorID      :    String)

vstream TBI'stream (
   alert:   String,
   timeStamp:   Long,
   patientID:   String)

#*
=================================================================
Source to read the ICP Stream
=================================================================
*#
stream icpStream(schemaFor(ICPStream))
 := Source()["stcp://artemisHub.ibm.com:12345", nodelays, initdelay=5,
throttledRate=2, csvformat]
  {}

#*
=================================================================
Source to read the Pupil Stream
=================================================================
*#

stream pupilStream(schemaFor(PupilStream))
 := Source()["stcp://artemisHub.ibm.com:23456", nodelays, initdelay=5,
throttledRate=2, csvformat]
  {}

#*
===========================================================================
===============
First compute the size of constriction of the pupil.
Note: The pupillary light reflex is the reduction of pupil size in
response to light
Note: We use a per-group Aggregate operation to mimic a per-patient
Functor operation
```

```
========================================================================
===============
*#

stream pupilDeltaStream(size_delta: Float, pupilsize: Float, timestamp:
Long, patientID: String, sensorID: String)
      := Aggregate(pupilStream<count(2),count(1),perGroup)[patientID]
        {Last(pupilsize)-First(pupilsize), Last(pupilsize),
Last(timestamp), Any(patientID), Any(sensorID)}

#*
==================================================================
Puts a punctuation at the end of the pupilDeltaStream when the
delta is less than 10% i.e., (x1 - x2) < (x1 * 0.10)
where x1 = pupilsize and x2 = ^1.pupilsize in response to light
==================================================================
*#

stream pupillaryChangeStream(size_delta: Float pupilsize: Float,
timestamp: Long, patientID: String, sensorID: String )
  := Punctor(pupilDeltaStream) [size_delta<0 & size_delta<=
^1.pupilsize*0.10, after]{}

#*
================================================================
Output a new stream called pupilCriticalStream consisting only of those
samples where the pupillary contraction is less than 10%
================================================================
*#
stream pupilDeltaLowStream(pupilsize:Float, timestamp: Long, patientID:
String, sensorID: String)
  := Aggregate(pupilDeltaStream<punct()>,perGroup)[patientID]
     {Last(pupilsize), Last(timestamp), Any(patientID), Last(sensorID)}


#*
================================================================
Output a pupilCritical element on the new stream when, for the same
time instant,
the pupillary contraction is below 10% and the pupil velocity <0.6
================================================================
*#

stream pupilCriticalStream( timestamp: Long, pupilvelocity: Float,
pupilsize: Float, patientID: String)
 :=  Join(pupilDeltaLowStream<time(2000),perGroup>,
pupilStream<time(2000, perGroup)>)
     [{patientID}={patientID}, $1.timestamp=$2.timestamp &
$.pupilvelocity< 0.6]
     { timestamp:=$1.timestamp, pupilvelocity:= $2.pupilvelocity,
pupilsize:= $1.pupilsize, $1.patientID}


#*
========================================================================
================================================
```

```
Now see if there's a Traumatic Brain Injury(TBI) e.g., Pupillary change
< 10%, constriction velocity < 0.6 mm/sec and
Intracranial Pressure (ICP) > 20 mm Hg. As the two streams (pupil and
ICP) come from different sensors, we allow
for a time offset (due to lack of exact synchronization) between the
two streams of up to 100 msecs (0.1 sec)
=======================================================================
=================================================
*#
stream tbi(schemaFor(AlertTBI))
 := Join(pupilCriticalStream<time(2000),perGroup>,
icpStream<time(2000), perGroup)>2)
      [{patientID}={patientID}, ABS($1.timestamp- $2.timestamp)<= 0.1&
iccpressure> 20.0 ]
       {alert:= "Traumatic Brain Injury (TBI)", timeStamp=
$1.timestamp, patientID:=$1.patientID}

#*
=============================================================
Sinks for the alert
=============================================================
*#
Null := Sink(tbi)   ["file:///alerts.dat",nodelays,csvformat]{}
```

8. Acknowledgement

The authors wish to thank the following contributors: Min Wang, Cathy Menkiena, our executive sponsor, Robert Merkel, and Robert Relph for there support and collaboration efforts in this project.

9. Bibliography

"Intrapartum Fetal Monitoring", Mark Curran, MD, last updated 11/27/2007, available at http://www.obfocus.com/cme/fhr.htm (Accessed October 2008)
[2] Ibid
[3] "American Heart Association", Multiple contributors, 2008 updated statistics, available at http://www.americanheart.org/presenter.jhtml?identifier=4439 (Accessed October 2008)
[4] "Heart Disease and Stroke statistics - 2008 update", multiple contributors, 2008 updated statistics available at http://www.americanheart.org/downloadable/heart/1200082005246HS_Stats%202008.final.pdf (Accessed October 2008)
[5] Ibid
[6] Ibid
[7] "Traumatic Brain Injury (TBI), Overview, Anatomy, Incidence and Prevalence, Stanley J. Swierzewski III, M.D., Sept. 01, 2001 available at http://www.neurologychannel.com/tbi/index.shtml (Accessed October 2008)
[8] "Trauma nursing: Traumatic brain injury", Sandra J. Brettler, RN, MSN, CCRN, CNRN, April 1, 2004 available at http://rn.modernmedicine.com/rnweb/article/articleDetail.jsp?id=110100 (Accessed October 2008)
[9] Ibid
[10] Ibid
[11] "Technology today: Brain monitors", Jennifer Schollenberger, RN, CCRN, Megan Rehwoldt, RN, CCRN, Barry Barnhill, RN, CNRN, Jan 2, 2006, available at http://rn.modernmedicine.com/rnweb/author/authorInfo.jsp?id=26896 go to "see articles" link and brain monitors. (Accessed October 2008)
[12] Ibid

[1] “Intrapartum Fetal Monitoring”, Mark Curran, MD, last updated 11/27/2007, available at http://www.obfocus.com/cme/fhr.htm (Accessed October 2008)
[2] Ibid
[3] “American Heart Association”, Multiple contributors, 2008 updated statistics, available at http://www.americanheart.org/presenter.jhtml?identifier=4439 (Accessed October 2008)
[4] “Heart Disease and Stroke statistics - 2008 update”, multiple contributors, 2008 updated statistics available at http://www.americanheart.org/downloadable/heart/1200082005246HS_Stats%202008.final.pdf (Accessed October 2008)
[5] Ibid
[6] Ibid
[7] “Traumatic Brain Injury (TBI), Overview, Anatomy, Incidence and Prevalence, Stanley J. Swierzewski III, M.D., Sept. 01, 2001 available at http://www.neurologychannel.com/tbi/index.shtml (Accessed October 2008)
[8] “Trauma nursing: Traumatic brain injury”, Sandra J. Brettler, RN, MSN, CCRN, CNRN, April 1, 2004 available at http://rn.modernmedicine.com/rnweb/article/articleDetail.jsp?id=110100 (Accessed October 2008)
[9] Ibid
[10] “Technology today: Brain monitors”, Jennifer Schollenberger, RN, CCRN, Megan Rehwoldt, RN, CCRN, Barry Barnhill, RN, CNRN, Jan 2, 2006, available at http://rn.modernmedicine.com/rnweb/author/authorInfo.jsp?id=26896 go to “see articles” link and brain monitors. (Accessed October 2008)
[11] Ibid