Toward Careflow Management Systems

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Abstract—Health care systems are prime examples of ultra large scale systems involving complex, distributive processes with a high degree of variability. There are ubiquitous communication and massive data and knowledge management requirements including documentation and reporting. Health care systems are also critical systems, where errors can be very costly in terms of lives, quality of life, and/or dollars. The efficient use of limited resources is not only desirable but necessary. Designing these processes and managing their performance is difficult and error prone. We present a web-based Careflow Management System, currently under development, that extends existing workflow management systems with formal verification features applying high performance computing methods to support real-time monitoring and adaptation. Healthcare ontologies are integrated into the system to allow advanced reasoning and to ensure accurate and relevant knowledge sharing among the various collaborators and enhance interoperability between specialized systems devoted to each area.

I. INTRODUCTION

Healthcare systems are prime examples of "ultra large scale systems" where information and services are distributed, data is largely unstructured and unmanaged, processes are complex and evolving, errors are expensive and compromise safety, and computations are often complex. As an added twist - implementations require a high degree of flexibility to deal with inherent variability. While there are many technology-related successes in the health/medical field, capacity for process and information management is critically lacking. Innovative software to integrate and organize data, to provide real time intelligent process and information management, to provide quality assurance, and to adapt processes to changing conditions is critical.

Consider a typical scenario in a healthcare setting: A patient, Bertha, has cancer. She is confused, has issues with pain and needs assistance in the home. She will need:

- Assessments: pain, home care etc;
- Procedures: chemotherapy, blood transfusions;
- Frequent tests at the lab;
- Therapy: various people/various locations;
- Medications prescribed by various physicians;
- Periodic reevaluation: every 3-4 weeks or as often as necessary.

There are complex dependencies among the tasks, some are required before or after others while some tasks may be done in parallel. Throughout the care process, there are documentation and communication requirements with services being delivered by geographically and organizationally separated care providers. In addition, the process must be diligently monitored to ensure compliance with best practices with clinical guidelines and with legal and ethical regulations. Continual evaluation of the processes is needed to improve policy and patient centred care. There are many activities for a single patient and with the many patients that a healthcare system must handle and therefore many sources of errors.

A report from 1999 cited in [7] estimated that approximately 98,000 deaths per year in the United States were the result of medical errors and that many of the errors could be traced to faulty processes. Other errors do not lead to death but are costly for the system and adversely affect the patient. Types of medical errors include reasoning errors, errors due to a lack of knowledge, fatigue and distraction. Automated decision support can improve the task of complex reasoning. Lack of knowledge includes incomplete information caused by delays in communication or lack of proper access to information. Fatigue and distraction can be traced, in part, to the complexity of the processes involved coupled with limited and strained resources. Information technology can provide solutions by streamlining processes, easing communication and documentation, and helping to provide the most up to date information to clinicians and care providers as they need it.

The StFX Centre for Logic and Information [20] was established under funding from The Atlantic Canada Opportunities Agency (ACOA), Canada Foundation for Innovation (CFI), and the Nova Scotia Research and Innovation Trust (NSRIT) with the goal of building decision-support through dynamic workflow systems for health care. An interdisciplinary team consisting of of researchers and students in computer science, informatics and health related fields have been working working closely with clinicians, administrators and other healthcare providers toward providing next generation workflow process and information management systems which can maximize the potential of Canada’s emerging electronic health record and improve health services delivery by providing automated decision support. We propose a Careflow Management System (CFMS), currently under development, that will integrate: (1) traditional workflow management to aid the design, assessment, management, and monitoring of the complex processes,
II. CURRENT PROCESS AND INFORMATION MANAGEMENT IN HEALTH CARE

In this section we examine three common approaches currently used to improve the management of healthcare systems: clinical guidelines, workflow management systems and electronic health records. We give some background information where needed.

A. Clinical Guidelines

Clinical guidelines, or protocols, guide decisions by providing criteria regarding diagnosis, management, and treatment in specific areas of healthcare, e.g., post-stroke rehabilitation and diabetes management. Clinical guidelines have been used for thousands of years as a way to pass on the best known medical care practices. The goals are to standardize medical care, raise the quality of care, and to reduce the risks involved. Clinical guidelines define the most important questions related to clinical practice and identify possible decision options and their outcomes. However, clinical guidelines have traditionally been evaluated and validated through informal methods such as peer reviews. Further, the guidelines themselves are often described using language that may be ambiguous. A formal definition can identify the ambiguity, as well as identifying inconsistencies in the guidelines [5].

B. Workflow

The Workflow Management Coalition provides the following definitions[3].

A workflow is the automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules.

A Workflow Management System (WFMS) is a system that defines, creates and manages the execution of workflows through the use of software, running on one or more workflow engines, which is able to interpret the process definition, interact with workflow participants and, where required, invoke the use of information technology tools and applications.

A process definition is the representation of a business process in a form which supports automated manipulation, such as modeling, or enactment by a workflow management system.

The process definition consists of a network of activities and their relationships, criteria to indicate the start and termination of the process, and information about the individual activities, such as participants, associated applications and data, etc.

WFMS are used to identify needs, reduce waste and duplication of work, ensure completion of projects on time and in accordance with plans, improve efficiency, facilitate documentation, and to create solutions based on the analyzed process requirements. WFMS’s can improve efficiency and decrease errors by providing support for modeling, execution and monitoring of workflows. Processes are defined using some (often graphical) modeling language; an example of a process for healthcare is shown in Figure 1. Most WFMS’s allow the simulation of processes to and changes can be made to the model based on the observed results. However, many healthcare processes involve the synchronization of numbers of workflow processes carried out in a distributed setting with dependencies between tasks, agents and resources. The processes must adapt to changes in the patients’ situations as well as changes in the system environment, e.g., resource availability. It is difficult, and time consuming, to determine the full ramifications of such local changes on the overall process and many processes are extremely time sensitive. Formal verification methods can be used to automatically detect whether the process satisfies requirements both before and after changes.

Verification is not widely available in WFMS’s, which leads to workflows being enacted without the certainty of correctness. This often results in errors that need to be handled in an ad hoc manner at runtime and at prohibitive cost [1]. Ad hoc exception handling of errors is unacceptable for workflow for healthcare. Traditional workflow management is typically concerned with efficiency and timing of the workflow. While these are important factors in health care workflow, there is an added factor that the ‘work’ passing through the workflow includes human patients with needs and preferences that a manufacturing or paper-pushing process does not need to consider. Current systems are sufficient for established, well-defined activities such as manufacturing or processing insurance claims. However, most systems lack the flexibility to adapt to a changing environment in which not all information is known in advance.

Verification can also be applied to executions of the workflow by monitoring the processes. Monitoring consists of observing the flow of a workflow execution or simulation. It involves logging and tracking of aspects of the workflow or workflows. Histories are kept for aggregate data such as average time to complete or maximum wait time for resources. WFMS’s typically allow users to indicate what aspects they wish to monitor, or track. Reports generated from this information are then used to guide the reconfiguration or redesign of the workflows. Runtime monitoring can be used to ensure compliance with guidelines or to capture reasons for deviation that may also lead to process redesign.
C. Electronic Health Records

Electronic health records (EHR), when available, can greatly enhance communication by facilitating the sharing of information. Canada Health Infoway lists among the benefits of EHR’s; reduced wait times, management of chronic care, and improved access to care in rural areas [10]. EHR’s alone do not provide these benefits [19]. The EHR must be integrated with effective and efficient means of extracting and sharing knowledge in a secure manner. To facilitate this, the knowledge contained in the EHR must be highly structured.

Clinical guidelines, workflow management systems and electronic health records each address the complexity of healthcare processes. While each approach is successful to a degree, an integrated approach, using advanced technological methods such as high performance computing, structured knowledge bases and, where possible, automated reasoning, can provide improved, safer, more timely support for healthcare management.

III. An Innovative Approach to Careflow Management

A Careflow Management System, i.e., a workflow management system for health care, must start with the formalizing of clinical processes and guidelines to provide clear, unambiguous process definitions which will, in turn, permit detailed, automatic verification. The system must be able to seamlessly integrate the emerging EHR and should build on the proven success of current workflow managements systems while adding additional functionality to address the more stringent correctness requirements of healthcare processes. A conceptualization of the system is shown in Figure 2: it includes a workflow management component, a data management component utilizing EHR and ontologies (see below), and a verification component, along with associated user interfaces (UIs). The process definition will be created within the workflow management component and validated and informed by verification of the specifications. The ontology structures the data contained in the EHR and database(s). The verification component uses this structure to identify implicit dependencies as well as the full effects of changes in the process definition.

A. Knowledge management using Ontologies

An ontology is a method of structuring knowledge in a usable format to allow reasoning about and sharing of this knowledge. Ontologies have been used extensively in artificial intelligence to describe agents, agent attitudes and information sharing amongst agents. Ontologies provide an efficient method of managing medical/health and organizational knowledge and can be used to identify minimum data sets for specialized medical domains. Minimum data sets are used to ensure that all data collected is relevant to the process execution. Ontologies can support different views of processes for the diverse participants. An ontology for organizational structure, such as that of a healthcare organization shown in Figure 3, can be used to facilitate automatic communication and report generation and routing. By having a formalized and structured knowledge base, the system can be easily
customized to be appropriate for different patients, health authorities or provinces.

Tools, such as Protégé, based on the Web Ontology Language (OWL), can be used to build, analyze, and query ontologies [22]. An ontology language provides a way to extract implicit knowledge from explicit facts in the knowledge base. Ontologies can also increase flexibility through the use of this implicit knowledge to identify the full ramifications of changes to the processes. For example, one aspect of an ontology is the hierarchical structure of the concepts. This allows for the definition of rules for individual cases, classes of cases or all cases to be formulated. Thus, there may be rules for all medications, other rules for pain medications and still more for ibuprofen. For example, specifying that no drug be taken prior to some test implicitly specifies that ibuprofen cannot be taken prior to that test.

Ontologies for the medical domain, such as ICNP® (International Classification for Nursing Practices) and SNOMED CT® (Systematized Nomenclature of Medicine – Clinical Terms), as well as numerous drug ontologies have been developed for the electronic exchange of clinical health information. However, these are used primarily as glossaries for terms. Our Careflow Management System will allow the ontology to guide and inform the workflow process and decision support using real-time access to dynamic knowledge.

B. Process Verification

Workflow management systems generally provide some validation of structural correctness of modeled processes, e.g., that there is a connected path from the start of the workflow to the end of the workflow. However, WfMS’s do not allow the verification of more meaningful properties, for example, properties involving complex time dependencies. Formal methods of verification are capable of proving whether these properties hold for the process model. Our work is focused on a popular method of verification is model checking. Model Checking is an automatic, model-based, property-verification method. [4]. A model checker verifies that a specified property is satisfied by the model, or description, of a system and, in general, generates a counter-example if the property is violated. A key feature is that this verification is done fully automatically. Model checking can provide quality assurance that goes beyond that which merely testing or simulation can achieve. While a failed test can conclusively prove the presence of an error, a successful test does not prove the absence of errors. Model checking can prove that a process complies with guidelines every time and not just for the test cases. Model checking can determine, for instance, whether some specified condition always holds or sometimes holds, or never holds in a process. In order to specify more complex timing constraints and other constraints, we employ nonclassical logics, e.g., timed temporal logics, modal logics, logics of beliefs, desires and intentions (BDI), and paraconsistent logics.

Many model checkers use implicit time temporal logics which allow the specification of qualitative properties, such as the relative ordering of events. Examples of this type of property would be "A patient must be evaluated by an oncologist before beginning chemotherapy," or "A patient must have an assigned Case Manager at all times." Timed temporal logics can be used which allow for referring to time explicitly. The advantage of using timed temporal logics is that quantitative properties involving time can be specified, e.g., "A patient must have been evaluated by an oncologist within three weeks of beginning chemotherapy."

Modal logics, such as BDI logics, allow specifying properties relating to individuals and their views of the processes. This allows local conditions, such as patient issues or particular challenges faced by rural areas, to be incorporated as a guiding factor in the design and execution of patient specific processes. Paraconsistent logics provide techniques for reasoning in the face of uncertainty; a common occurrence in a healthcare setting.

Verification has been successfully used in the design of hardware and software systems for many years. In 1992, the verification of a protocol for ensuring data consistency in the IEEE Futurebus+ standard was able to find several previously undetected errors and potential errors in the design of the protocol [6]. Verification has also been used extensively in verifying security protocols, access control protocols and communication protocols. Verification methods have been applied to healthcare as well; in [7], for example, errors were detected in a blood transfusion protocol using model checking.

Model checking does have limitations as it requires the exhaustive search through all possible configurations of a system. This can require a very large amount of memory for even moderately complex systems. In addition this search
may take an unreasonable amount time, a critical issue in the very time-sensitive healthcare domain. Many methods have been developed to improve efficiency such as partial state reduction, abstraction techniques, and modular composition. These approaches all seek to reduce the number of states that must be explored. An alternative approach that is emerging is that of high performance computing methods; dividing the model checking problem among multiple processors running in a parallel or distributed environment [17],[21]. Different combinations of these approaches may provide further improvements.

The proposed CfMS would allow patients entered into the system to be followed by diverse but cooperating caregivers through multiple processes. The system would ensure that the processes involved complied with all requirements or alert the appropriate parties if an error or possibly undesirable outcome were detected. The system would facilitate speedy and accurate communication, automatic where possible, between the caregivers, administrators, patients, and other concerned parties. Caregivers would have fast, dependable access to the knowledge contained in the system in real-time and could be alerted to changes relevant to their concerns. Administrators and policy makers would have access to aggregate data needed to perform their duties. The processes would be transparent; allowing patients to monitor and be as active in the process as they desired and was advisable.

IV. CHALLENGES AND RELATED WORK

This paper has described a proposed Careflow Management System being developed as part of an applied research project currently being carried out in close collaboration with local health authorities, university faculty members and students, and industry. The goals of the research are:

1) Formalizing, implementing, verifying clinical guidelines;
2) Developing domain ontologies and identifying minimum data sets;
3) Modeling health care processes for monitoring and tracking.

To accomplish this we are building on previous research with strong interaction with clinicians and other care providers and applying recent advances in computer science.

Much of the research on computer interpretable guideline modeling involves finding a middle ground between a formalism expressive enough to describe all of the aspects of interest but simple enough for non-specialists to use [12]. Asbru, for instance, defines clinical guidelines and protocols as time-oriented skeletal plans to provide a way to reuse existing domain-specific procedural knowledge while allowing for execution-time flexibility to achieve particular goals. [5]. The GuideLine Acquisition, Representation and Execution (GLARE) uses a small set of clearly defined primitives to represent guidelines as different types of actions linked by control relations to define the order of execution [13]. Model checking has been applied to Asbru using SMV and a subset of the properties the model checker can verify. Initial work on model checking GLARE by translating the guideline to Promela, the modeling language for the popular SPIN model checker is presented in [14]. The verification for these systems is limited to particular types of simple properties applied to relatively small guidelines with no runtime monitoring or ontology interaction.

The NewGuide Clinical Guideline Management System was developed at the Laboratory for Biomedical Informatics at the University of Pavia, Italy, for acute stroke care and is currently used in two hospitals. [11] It uses three independent modules: (1) a Guideline Management System that provides clinical decision support, (2) an Electronic Patient Record, and (3) a Workflow Management System that provides organizational support. The main focus is on process management, communication management, and organizational learning. The system uses a semi-automatic, knowledge-based approach to error handling but formal verification is not done [11]. The Electronic Patient Record is in a standard database and can be queried using Structured Query Language (SQL) but does not allow the reasoning available with the query languages for ontologies.

Little-JIL is a graphical language for defining processes that coordinate the activities of autonomous agents and their use of resources during the performance of a task. A model checker for Little-JIL was able to detect errors in a blood transfusion protocol [7] and a chemotherapy process [8]. In [8], it is suggested that the modeling and analyzing of medical processes could benefit from an ontological structure to the domain knowledge but this was not implemented in their study. Initial efforts by our Centre to develop a model checker that interfaces with a medical ontology was presented in [16] and extended in [17].

Developing domain ontologies, especially for a domain as rich as those of healthcare, is a monumental task in itself. It requires close collaboration between developers and clinicians, and other caregivers. Medical ontologies, like SNOMED CT® and ICNP®, as well as innovative techniques to merge ontologies without losing knowledge provide a foundation to build upon and will greatly speed up the work [15]. One current initiative of our Centre is to develop a strategy for, and begin the process of, building a minimum data set for hospice palliative care and to link the data set to service delivery and program/policy development [20]. This initiative is being carried out by researchers at StFX, the University of Ottawa, Dalhousie University and others working in close collaboration with healthcare professional including administrators, clinicians and other practitioners.

Other challenges include issues of user adoption and message delivery. Input from frontline caregivers is a continual process in the research conducted at our Centre to ensure that the solutions are in line with their needs while ensuring compliance with existing and emerging standards, such as HL7, and to ensure interoperability with other health information systems, such as the EHR [23]. As noted in [18], medical professionals do not sit at a computer waiting for alerts. We are exploring innovative methods of getting the messages to
the intended targets are needed, such as web-based and mobile devices.

V. CONCLUSION

Decisions in health care must be made in a timely manner, with possible incomplete information, in a dynamic environment and carry the added burden of having severe or even fatal consequences for failure. Workflow management systems offer a means of reducing human error by organizing and managing the work that must be done ensuring that the work is done according to a plan. Formal verification can further reduce errors by ensuring that the plans involved conform to required standards for patient safety. Incorporating a means to go beyond patient safety and in addition reason about patients’ preferences offer a means of improving the quality of care and the overall experience of the patients.

How would our patient, Bertha, benefit from a Careflow Management system such as that described herein? The processes would be transparent; allowing Bertha to monitor and be as active in the process as she desires. The processed would be verified to ensure: compliance with guidelines and regulations; that conflicting medications are never prescribed; that dependencies are followed; and that information is distributed in a timely manner and only to authorized personnel. Bertha’s schedule would adapt to changes due to patient specific features such as, missed appointments or evolving preferences. Documentation would be streamlined and information would be readily available while real-time model checking would ensure access is limited to those who need it. Communication among caregivers would be enhanced, both in speed of distribution and with reduced errors as well as with greater clarity and the time saved would allow more time with the patient. Administrative personnel would have access to appropriate data for evaluation, planning/scheduling, and policy development.

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REFERENCES