Healthcare Process Support: Achievements, Challenges, Current Research

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ABSTRACT

Healthcare organizations are facing the challenge of delivering high-quality services to their patients at affordable costs. To tackle this challenge, the Medical Informatics community targets at formalisms for developing decision-support systems (DSSs) based on clinical guidelines. At the same time, business process management (BPM) enables IT support for healthcare processes, e.g., based on workflow technology. By integrating aspects from these two fields, promising perspectives for achieving better healthcare process support arise. The perspectives and limitations of IT support for healthcare processes provided the focus of three Workshops on Process-oriented Information Systems (ProHealth). These were held in conjunction with the International Conference on Business Process Management in 2007-2009. The ProHealth workshops provided a forum wherein challenges, paradigms, and tools for optimized process support in healthcare were debated. Following the success of these workshops, this special issue on process support in healthcare provides extended papers by research groups who contributed multiple times to the ProHealth workshop series. These works address issues pertaining to healthcare process modeling, process-aware healthcare information system, workflow management in healthcare, IT support for guideline implementation and medical decision support, flexibility in healthcare processes, process interoperability in healthcare and healthcare standards, clinical semantics of healthcare processes, healthcare process patterns, best practices for designing healthcare processes, and healthcare process validation, verification, and evaluation.

Keywords: business process management, clinical guidelines, healthcare process support

INTRODUCTION

Healthcare organizations are facing the challenge of delivering high-quality services to their patients at affordable costs. Specialization of medical disciplines, prolonged medical care for the ageing population, increased costs for handling chronic diseases, and the need for personalized healthcare are prevalent trends in this information-intensive domain. The emerging situation necessitates a change in the way healthcare is delivered to patients and healthcare processes are managed.

Enterprise-wide, process-oriented information systems have been demanded by healthcare institutions for over 20 years and terms like "continuity of care" have even been discussed for more than 50 years. Yet, healthcare organizations are currently using a plethora of specialized, non-standard information systems and continue developing systems for specialized departments that only consider internal processes. In particular, many existing healthcare information systems are still function- and data-centric, such as imaging, drug order-entry, laboratory test result storage, storage of diagnoses and progress notes in electronic medical records (EMRs), alerts and reminders, and billing. Consequently, information systems and decision-support systems (DSSs) managing patient care processes are still scarcely developed. Such patient care management systems are highly complex and pose many challenges. For example, they require availability of encoded data coming from different sources and flexibility in deviating from the implemented process at the discretion of the user (e.g., physician). Further, they may involve a team of clinical staff members that together take care of a patient in a coordinated way. The recent trend towards healthcare networks and integrated care further increases the need to effectively support interdisciplinary cooperation. Recent studies discussing the preventability of adverse events in medicine recommend the use of information technology, since insufficient communication and missing information have turned out to be among the major factors contributing to adverse events. Yet, there is still a discrepancy between the potential and the actual usage of IT in healthcare.

The three ProHealth workshops that were held during 2007-2009 focused on the IT support of healthcare processes. In particular, these workshops brought together researchers from the Medical Informatics and the BPM communities with the vision that ideas from both fields and a mutual understanding of relevant research issues will create new insights and boost interdisciplinary

research. In the remainder of this introduction we discuss what the two communities have achieved so far and what top issues they have been addressing. The latter will be done along with suggestions of how to bring these issues together.

ISSUES ADDRESSED BY THE MEDICAL INFORMATICS COMMUNITY

The Medical Informatics community has targeted supporting patient care processes mainly by developing EMR systems (Hayrinen et al. 2008). These store patient data and document patient encounters, thus keeping a sustainable record of the patient's health state. Further, DSSs have been developed (Peleg and Tu 2006) fostering decision-making and action management. Special-purpose formalisms, known as task-network models (Peleg et al. 2003), were developed to specify evidence-based clinical guidelines as representations that are computer-interpretable and at the same time can be depicted as a visual algorithm being easily understood by medical experts. Unlike general-purpose process models, the computer-interpretable guideline (CIG) formalisms addressed issues that are important for sharing guidelines among different implementing institutions and for linking them to EMRs, focusing more on the medical knowledge driving decision-making rather than on organizational issues such as scheduling and resource management. These issues included (Peleg et al. 2003) use of standard clinical terms, modeling of clinical concepts and medical knowledge needed for decision-making, definitions of clinical abstractions, patient information models and expression languages used to specify temporal clinical decision criteria, and representation of different types of decision models, including if-then-else rules, argumentation rules, and decision-theoretic models such as decision trees and influence diagrams. Some of the guideline models have also addressed issues such as representing the guideline's intentions (Shahar et al. 1998), allowing assessment of adherence to intentions, and fitting into organizational workflows (Quaglini et al. 2001; Tu et al. 2004).

The CIG formalisms are quite expressive and have many benefits, yet using them to encode guidelines is a long and difficult process. Several groups have focused on methods to ease, standardize, and even partially automate guideline encoding. Tools for marking-up guidelines have been created (Karras et al. 2000; Peleg 2006; Miksch 2007), design patterns for specifying clinical guidelines and their components have been developed (Miksch 2007; Peleg and Tu 2009), and natural language processing has been used to parse narrative guidelines in order to identify linguistic patterns describing clinical actions (Serban et al. 2007). Researchers have also considered different approaches for dividing and coordinating the encoding task among people with different expertise: knowledge engineers and clinical domain experts (Peleg et al. 2008; Shalom et al. 2008).

Since clinical guidelines provide recommendations for care and not a strict inflexible assembly line, they are modeled as flexible care plans that can be executed according to physicians' discretion, who can deviate from the original care plan. Allowing such deviations (Quaglini et al. 2000) yet controlling and managing their scope, in order to prevent medical errors, is an active line of research as well as assessing clinicians' compliance to clinical guidelines (as specified by a formal guideline model) (Advani et al. 1998; Micieli et al. 2002; Advani et al. 2003).

The focus of the Medical Informatics community is complementary to that of the BPM community, allowing synergism. As suggested in (Terenziani 2009), an integration of the approaches used for healthcare process management by the two communities could potentially be achieved using a hybrid approach in which a computer-interpretable guideline approach is used to focus on "physician-oriented" issues, a workflow approach is used to cope with the related "business-oriented" issues, and the integration of them is obtained at the underlying semantic level, where also general inferential mechanisms operate.

ISSUES ADDRESSED BY THE BPM COMMUNITY

Historically speaking, business process support has been a major driver for enterprise information systems for a long time. The overall goal is to overcome the drawbacks of functional over-specialization and lack of overall process control. Technology response to this business demand was met with a suite of technologies ranging from office automation to workflow systems to BPM technology.

Just as DBMS provide a means of abstracting application logic from physical data aspects, workflow management systems (WfMS) separate coordinative process logic from application code (Leymann and Roller 2000). Although workflow technology has delivered much productivity improvements, it has been mainly designed for the support of pre-specified and repetitive business processes requiring a basic level of coordination between human performers and some application services. More recently BPM has been used as broader term to reflect the fact that a business process may or may not involve human participants, and often crosses organizational boundaries.

Currently, there is a widespread interest in BPM technologies, especially in light of emerging paradigms surrounding service-oriented computing

3

and its application to dynamic service orchestrations and choreographies. In this context, the notion of PAIS (Process Aware Information System) provides a guiding framework to understand and deliberate on the above developments (Dumas et al. 2005). As fundamental characteristic, a PAIS provides the basic means to separate process logic from application code. Furthermore, challenges, features and limitations of existing PAISs can be discussed along the phases of the process lifecycle (Weber et al. 2009; Weber et al. 2009); e.g., process design, implementation & configuration, enactment, monitoring & diagnosis, and evolution.

At process design time the process logic has to be explicitly defined based on the constructs provided by a process modeling language. In this context, a variety of workflow patterns (e.g., control and data patterns, resource patterns, time patterns) are suggested, enabling the comparison and evaluation of existing modeling languages (van der Aalst et al. 2003; Lanz et al. 2010). Other work targets involvement of end users in the design process by increasing model quality and understandability (Mendling et al. 2007; Weber et al. 2011). At process run-time a PAIS orchestrates the processes according to the defined process model and coordinates corresponding applications and other resources. Examples of PAIS-enabling technologies include WfMSs like WebSphere Process Server (Kloppmann et al. 2008), ADEPT2 (Dadam and Reichert 2009), AristaFlow (Reichert et al. 2009), and YAWL (van der Aalst and ter Hofstede 2005) as well as case handling frameworks like FLOWer (van der Aalst et al. 2003) and PHILHarmonic Flows (Kunzle and Reichert 2011).

In spite of several success stories on the uptake of PAISs and the growing process orientation of enterprises, BPM and related technologies have not had the widespread adoption that was expected. A major reason for this is the limited process flexibility offered by existing PAISs, which inhibits the ability of an organization to respond to business changes and exceptional situations in an agile way (Dumas et al. 2005; Weber et al. 2009). To deal with exceptions, uncertainty, and evolving processes, it is widely recognized that a PAIS needs to provide run-time flexibility (Reichert et al. 2009). This can either be achieved through dynamic structural process changes or by supporting loosely specified process models, which can be refined during run-time according to pre-defined criteria and rules. To address this need paradigms like adaptive processes (Reichert and Dadam 1998), case handling (van der Aalst et al. 2003; van der Aalst and ter Hofstede 2005), and declarative processes (Pesic et al. 2007) have emerged. Generally, they can be characterized along three fundamental requirements, namely support for flexibility, adaptation, and evolution:

- **Flexibility** represents the ability of the implemented process to execute on the basis of a loosely or partially specified model which is completed at run-time and may be unique to each process instance (i.e., case). Due to the high number of choices, not all of which can be anticipated and hence pre-specified, frameworks like DECLARE (van der Aalst et al. 2003; Pesic et al. 2007), Alaska (Zugal et al. 2011), and PocketsOfFlexibility (Sadiq et al. 2005) allow defining process models in a more relaxed manner; the model can be defined in a way that allows individual instances to determine their own (unique) processes. In particular, declarative approaches allow for loosely-specified process models by following a constraint-based approach. While pre-specified process models define exactly how the overall task has to be accomplished, constraint-based process models focus on what should be done by describing the set of activities that may be performed as well as the constraints prohibiting undesired process behavior. Generally, loosely specified models raise several challenges including the flexible configuration of process models at design time (Hallerbach et al. 2010) or their constraint-based definition during runtime (van der Aalst et al. 2003; Pesic et al. 2007).

- **Adaptation** represents the ability of the implemented processes to cope with exceptional circumstances. On the one hand, existing PAISs like YAWL provide support for the handling of expected exceptions, which can be anticipated and thus be captured in the process model (Russel et al. 2006). Alternatively, adaptive PAISs like ADEPT2 also cover the handling of unanticipated exceptions, which are usually addressed through structural ad-hoc changes of single process instances (e.g., to add, delete or move process steps during process execution) (Reichert and Dadam 1998; Reichert et al. 2009; Weber et al. 2009). Clearly, such dynamic process adaptations necessitate a comprehensive framework ensuring correctness and robustness of the PAIS in the context of ad-hoc changes as well.

- **Evolution** represents the ability of a process implemented in a PAIS to change when the business process evolves (e.g., due to legal changes or process optimizations). The assumption is that the processes have pre-specified models, and a change causes these models to be modified. The biggest challenge is the handling of the potentially large number of long-running process instances, which were initiated based on the old model but are required to comply with the new specification from now on. Approaches like WASA2,

4

ADEPT2 and WIDE allow process engineers to migrate such process instances to the new model version, while ensuring PAIS robustness and process consistency (see (Rinderle et al. 2004)).

In practice there often exists a significant gap between what is prescribed and what actually happens. Generally, a PAIS records the actual execution behavior of a collection of process instances in an execution log. Furthermore, in adaptive and flexible PAISs, deviations from the pre-specified model can be recorded in change logs.

In this context process mining strives to deliver a concise assessment of the organizational reality by mining these logs. Generally, there exist different classes of process mining techniques. Process discovery algorithms analyze execution logs and derive process models from them reflecting the actual process behavior best (van der Aalst et al. 2007). Conformance testing (Rozinat and van der Aalst 2008) analyzes and measures discrepancies between the original model of a process and the actual execution of its instances (as recorded in execution logs). Log-based verification (van der Aalst et al. 2005), in turn, checks the log for conformance with desired or undesired properties; e.g., process instance compliance with corporate guidelines or global regulations. Furthermore, change mining techniques (Gunther et al. 2008) do not only consider the execution logs of process instances, but additionally analyze the structural changes applied during process execution; i.e., they allow visualizing and analyzing dynamic deviations from the original process model. Finally, process variants mining allows discovering an optimal reference process model being "close" to a given collection of process variants (e.g., process instances derived from the same model, but structurally differing due to ad-hoc changes applied to them) (Li et al. 2010).

GAPS AND CHALLENGES

To explain the challenges in supporting processes in healthcare it is important to distinguish the patient-specific medical treatment process from the organizational process that generally coordinates the cooperation between various process participants and organizational units within a healthcare institution (Lenz and Reichert 2007). Medical informatics research starts from the medical tasks and problems of supporting daily work of physicians. This has improved the understanding of how healthcare processes actually work and how complex they are. A number of techniques supporting doctors in clinical decisions have been developed, and some of these, such as alerts and reminders, have already been proven to be effective in preventing adverse events when being used properly (Shea et al. 1996; Del-Fiol et al. 2008). Furthermore, standards for data interchange have been developed in order to improve the integration of heterogeneous systems and thereby improve the basis for an optimized support of organizational processes. It was demonstrated that the usage of order entry and result reporting could improve the quality of healthcare (Overhage et al. 1997), however, modern workflow management technology which promises more transparency and flexibility in process management has not found its way into hospitals yet. The BPM community started with evaluating these technologies and their weaknesses, e.g., how can it be improved and adapted to various real-world requirements and, in particular, how can it be utilized to support healthcare processes. Researchers from the BPM community have developed numerous techniques to model and verify business processes as well as workflow management solutions that are adaptable to a broad spectrum of processes.

Both communities have addressed important aspects of supporting healthcare processes and the contributions of the communities seem to be quite complementary. CIG modeling languages often do not address important managerial activities such as linking these guidelines to order-entry systems, scheduling visits, and so forth. On the other hand, BPM approaches often do not address complex decision criteria that include medical abstractions and temporal expressions bridging the gap between the medical knowledge abstractions used in clinical guidelines and the actual raw data stored in EMRs. Yet, we still have not seen complete integrations of BPM solutions with computer-interpretable clinical guideline solutions, except in the case of decision-support systems developed in the Guide guideline modeling language (Quaglini et al. 2001).

Thus, there is still a gap between domain- and technology-driven approaches. In addition to the aspects addressed so far, many problems have been recognized, but not been solved in an acceptable way yet, and some have even not been understood well enough to suggest workable solutions. Some of these problem areas can be briefly summarized as follows:

- **Integration of heterogeneous systems**. Both WfMSs and DSSs suffer from the fact that operational data in healthcare processes is typically stored in heterogeneous and often autonomous IT systems. Standards for data interchange help to decrease the semantic heterogeneity of data to some degree. Further, approaches for matching clinical abstractions found in clinical guidelines to patient data found in EMRs have been suggested (Peleg et al. 2008; German et al. 2009). Finally, even commercial solutions for presenting data from various EHRs in a harmonized way

(www.dbmotion.com) exist. However, still support for cooperation across systems has not fully been provided and problems such as access control have not been sufficiently addressed.

- **Social issues**. Adequately embedding IT support into routine work practices is one of the greatest challenges. Functionality alone will be not enough if it is not accepted or cannot be adequately used for actually optimizing the healthcare process. Medical informatics research has identified numerous generally applicable rules of thumb for change management. Heeks proposed the design-reality gap model as a tool that helps assessing the risks of IT projects in healthcare (Heeks 2006). Factors influencing success and failure of healthcare IT projects have been identified (e.g., (Sauer 1993; Lorenzi and Riley 2000; Ash et al. 2003)) and, more specifically, general recommendations on how to successfully implement medical guidelines have been given (e.g., (Bates et al. 2003)). However, it is unclear how BPM techniques can contribute to improve process alignment in healthcare, i.e., the alignment of IT functionality and healthcare processes, or in other words the adequate embedding of IT services into routine work practice in order to maximize its benefit.

- **Evolving processes**. The problem of process alignment is aggravated by continuously evolving processes due to advances in clinical medicine (e.g., new medications, new laboratory tests, and new evidence from clinical trials) as well as process optimization. The challenge is to support continuous learning and ongoing change by IT systems. While it is the responsibility of medical societies to evolve the non-organizational specific healthcare process model, it is the responsibility of the local organization to introduce these changes into their integrated IT systems. However, recommendations in clinical guidelines typically do not explain how to implement them in a given organizational setting.

- **Process tracking**. Another important unsolved problem is how to deal with real-world process that deviate from process documentation. Process mining techniques have helped to learn how real process instances behave by analyzing event logs. However, unlike production processes where progress can be precisely monitored, healthcare processes may contain undocumented process change events. This makes process monitoring and tracking particularly challenging and it requires process participants to be aware of the potential discrepancy between the documented process and the real process. Note, that – though

related – this problem area covers more than guideline compliance, e.g., (Advani et al. 1998); guideline compliance is the degree of how well a process instance matches with a given guideline. The problem described here is different: the documentation of a process instance in the IT system might deviate from what really happened – it might be incomplete or even incorrect (Lenz, Blaswer et al. 2007).

These open issues are unlikely to be solved in the near future, but they serve as a motivation to continue with interdisciplinary research, and this is at the core of the ProHealth workshops.

CURRENT RESEARCH FROM PROHEALTH

Current research initiated by the collaboration between the two communities that resulted in the ProHealth workshops has addressed a variety of topics. Selected topics from the three PROhealth workshops are summarized below.

Workflow-pattern based analysis of CIG formalisms. The aim of this line of research is to study existing CIG formalisms in order to standardize and improve their control flow semantics based on the vast experience accumulated by research on workflow languages. Because much of the resistance by the medical informatics community to use workflow technology has stemmed from the myth that workflow languages are not flexible enough to model clinical processes, Mulyar et al. (Mulyar et al. 2007) analyzed four guideline formalisms in terms of their support of workflow control-flow patterns. They have shown that, in fact, the guideline formalisms support only a limited set of control-flow patterns. Of 43 patterns, PROforma supported 23 patterns; Asbru supported 20, GLIF 17, and EON only 11. There was no support of the multi instance activity pattern and the semantics of Synchronizing Merge was imprecise. In another research, Mulyar et al. (Mulyar et al. 2007) have shown that declarative approaches are more flexible than existing guideline formalisms. They demonstrated how the templates of the CIGDec declarative specification language enable the control-flow constraints of typical healthcare scenarios.

Inspired by the papers described above, Grando et al. (Grando et al. 2008) examined the question of which flexible control-flow patterns are supported by the PROforma guideline modeling language. The authors defined a mapping from the PROforma language to Colored Petri Nets and utilized it to construct formal proofs that PROforma is capable of expressing a standardized workflow pattern.

Flexible IT support for healthcare processes. One of the fundamental challenges discussed in all ProHealth workshops concerns process flexibility.

6

Physicians often have to decide which diagnostics or therapies are necessary or may be dangerous due to contraindications and treatment-typical problems. Generally, decisions about the next steps have to be made during the treatment process by interpreting patient-specific data according to medical knowledge and considering the current state of the patient. As opposed to organizational processes (e.g., order handling) such knowledge-intensive processes usually cannot be fully pre-specified and automated. For example, there are clinical guidelines recommending evidence-based compilations of care processes. However, such care processes cannot account for all possible treatment cases and therefore, the PAIS that executes the guideline-based care processes must allow for deviations. Generally, physicians are not supposed to obey any step-by-step process, but need to provide the best possible treatment for their patients taking the given situation into account.

Mans et al. identified flexibility requirements to be met in order to adequately support the various kinds of healthcare processes (Mans et al. 2008). The authors have shown that several process support paradigms are needed to adequately cope with this challenge (see (Mulyar et al. 2007) for similar considerations emphasizing the need for supporting both procedural and declarative paradigms in connection with the modeling of clinical guidelines).

PAISs relying on pre-specified process models, which are the predominant paradigm for modeling and executing processes, have been applied to healthcare processes for more than a decade. For them a variety of techniques for accommodating the need for flexibility, adaptation and evolution is provided. In the context of ProHealth, van Hee et al. introduced adaptive workflow nets for the flexible modeling of care processes (van Hee et al. 2008). Reijers et al added a methodology for capturing healthcare processes based on a number of workflow and flexibility patterns (Reijers et al. 2009). While these works focus on a particular phase of the process lifecycle, a few approaches stemming from the BPM community enable full process lifecycle support. As example, consider the ProCycle framework (Weber et al. 2009), which enables integrated support of all phases of the process lifecycle ranging from modeling to enactment to ad-hoc adaptations to process learning to process evolution. Finally, assistance for end users in exceptional situations is provided; e.g., by allowing them to reuse previously applied ad-hoc changes when a similar problem context is given.

During the last years, declarative approaches have been applied to clinical guidelines (Lyng et al. 2008; van der Aalst et al. 2009). They suggest a fundamentally different way of describing processes being promising for the support of dynamic patient treatment processes. For example, Declare

and Alaska enable loosely-specified process models by allowing users to defer modeling decisions to run-time. Potential advantages include the absence of over-specification and the provision of more maneuvering room for end users. However, more and more it is recognized that knowledge-intensive healthcare processes cannot always be straightjacketed into activities. Prescribing an activity-centric process model for them would lead to a "contradiction between the way processes can be modeled and the preferred work practice" (Sadiq et al. 2005). Instead object-awareness is required; i.e., full integration of processes with application data consisting of object types and object relations. In accordance to a (patient) data model comprising object types and object relations, therefore, the modelling and execution of patient-related processes can be based on two levels of granularity: object behaviour and object interactions (see (Kunzle and Reichert 2011) for a respective framework from the BPM community). Recently, Neumann and Lenz have picked up this metaphor. With alpha-flow they suggest a document-based approach to the flexible support of inter-departmental healthcare processes (Neumann and Lenz 2009; Neumann and Lenz 2009).

Verification and testing of healthcare process models. The BPM community has been working for many years on methods for verifying and testing business processes. Developing methods for the healthcare domain, Imam and MacCaull (Imam and MacCaull 2008) created a multi-threaded model checker to reason about timed processes in careflows sensitive to patient preferences and care team goals, using temporal logic extended with modalities of beliefs, desires and intentions. In another paper by that group (Miller and MacCaull 2009), they have developed a multi-valued logic based system that allows merging two inconsistent terminologies.

Osterweil, Clarke &Avrunin (Osterweil et al. 2009) developed the Little-JIL process definition language and an integrated collection of tools supporting the precise definition, analysis, and execution of processes that coordinate the actions of humans, automated devices, and software systems for the delivery of healthcare. It is intended to support the continuous improvement of the healthcare delivery processes. Another approach is proposed in (Mans et al. 2009), where the same model is used for specifying, developing, testing and validating the operational performance of a new system. This approach has been applied to a schedule-based workflow system developed for the AMC hospital in Amsterdam.

Coping with semantic heterogeneity in autonomous systems. An important problem complicating process support in healthcare is the

semantic heterogeneity of autonomous systems Neumann and Lenz (Lenz, Beyer et al. 2007) propose a document-based approach to support cooperation in healthcare networks. The basic idea is to use self-describing electronic documents as the unit for information interchange. By including process related metadata into independent electronic documents, inter-institutional processes can be supported without the need to closely interconnect pre-existing IT-systems. An important aspect of this approach is the strict separation of coordinating activities from document contents. By separating these aspects semantic interoperability can be addressed independent of basic coordination tasks, thereby enabling cooperation without the need for prior integration of existing IT systems.

Process mining and goal-based process learning. Inspired by the BPM community, research related to the goals of clinical processes was once again brought to the focus. Early work by Shahar et al. (Shahar et al. 1996; Shahar et al. 1998) targeted intention-based specification of clinical guidelines, where the intentions of guideline plans and their refined lower-level actions were specified as temporal patterns, and critiquing of guideline application based on compliance to the guideline's intentions.

Current research drew ideas and methods from the vast amount of work on process mining done by the BPM community. Mans et al. (Mans et al. 2008) used process mining to discover non-compliance with a stroke guideline and reasons for it. This helped in reconstructing chains of responsibilities concurring to produce errors in a complex patient's pathway, learning how to improve clinical guidelines (Quaglini 2008).

Ghattas, Soffer, and Peleg (Ghattas et al. 2007; Peleg et al. 2007; Ghattas et al. 2009) used process mining at the semantic level to improve healthcare processes. In this approach, healthcare process instance data is used to learn the best path needed in order to achieve desired outcomes for patients with different contextual characteristics. Using a case study of a urinary tract infection care process, they used machine-learning techniques to find the important patient groups, based on similarity of process paths and outcome. They then used a decision-tree learning algorithm to discover contextual data items that could predict the partition into these patient groups. From the decision tree, a semantic definition of the context groups was discovered.

Goal-based approach for exception-handling. The focus that the ProHealth workshop has given to goals in clinical processes inspired Grando and colleagues (Grando et al. 2010; Grando et al. 2010) to develop a goal-based framework that can be used to monitor, detect, and handle exceptions occurring during normal CIG execution. This, in turn, can potentially prevent them from evolving into medical errors. This framework (Grando et al. 2010) allows specifying the goals of a clinical guideline and linking them with recommended tasks that could satisfy these goals. Exceptions are linked with goals that manage them, which can be realized by tasks or plans. To achieve a link between the tasks, plans, goals, monitored effects, and exceptions, the definition of goals and exceptions is state-based. The goal-based approach for exception handling was demonstrated in the domain of hypertension management. In (Grando et al. 2010), the authors extended this framework to deal with exceptions arising from miscommunication that can happen when an actor in an organization assigns an action to another actor. To support this, the goal-based exception handling framework has been extended to formally specify the transfer of responsibility and accountability when tasks are delegated in healthcare teams.

DISCUSSION

The ProHealth workshop series has opened an ongoing interdisciplinary and fruitful discussion on process support in healthcare. Yet, considering the different backgrounds of the participants, it takes effort to build a common ground that can serve as a basis for improving mutual understanding. The ongoing process of building common ground is supported by having each submitted paper reviewed by three reviewers – typically with different backgrounds. It is further supported by inviting experienced speakers presenting the condensed experience gathered over years in their particular research communities. And finally, an important aspect is to leave enough room for discussion.

First results from the ProHealth community-building efforts have been summarized in this editorial paper. Even if details have not been elaborated yet, the general feasibility of applying BPM technology to healthcare has been shown: Mapping guidelines to formal models enables simulation, validation, execution, and verification as well as analyzing the flexibility of control-flow. Goal-oriented monitoring, for example, can help to prevent critical situations that may turn into medical errors. The kinds of flexibility needed to adequately support healthcare processes are better understood. Process mining can give valuable feedback and support organizational learning. Yet, the fact that real-world processes are typically not completely recorded in event logs raises the need to cope with incomplete and imprecise information. Integration of heterogeneous systems is needed to enable cross-organizational cooperation, and semantic integration is the hardest part to achieve. It could be demonstrated that separating semantic

integration from basic coordination tasks is helpful to overcome communication barriers and to enable continuous improvement of cooperation.

Such results encourage us to continue the dialog and try to learn from each other. The contributions have shown that the participants are actually not only members of two communities. Particularly the discussion with Lee Osterweil and Barbara Paech, who organize a similar Workshop in conjunction with the International Conference on Software Engineering showed that other disciplines can also contribute to achieve valuable improvements for a multi-faceted problem area. In order to broaden the interdisciplinary dialog Osterweil has agreed to give the invited talk at ProHealth 2011.

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