Agent-Based Careflow for Patient-Centred Palliative Care

Ji Ruan, Wendy MacCaull, and Heather Jewers

St. Francis Xavier University, Canada
ji@jiruan.net,{wmaccaul,mjewers}@stfx.ca

Abstract. In this paper, we propose the use of an agent-based architecture to enhance workflow system capacity to support interprofessional, patient-centred palliative care delivery. This paper outlines the concept of palliative care and describes how agents can be used to assist care providers to address the needs of the patient and family. Agents are described in terms of the services they provide, and the dependencies among them (which determine the information flow, facilitating the communication and collaboration among the patient and care providers). We present how this architecture integrates with a healthcare workflow system and discuss the issues of work assignment, scheduling and monitoring.

Keywords: Agent-based Modelling, Patient-centred Palliative Care, Workflow, Scheduling, Monitoring, Formal Methods.

1 Introduction

The work described in this paper is part of a large research and development project that is being conducted by our interdisciplinary research team, and involves ongoing collaboration with healthcare stakeholders and a software engineering industry partner. The project is developing an information and workflow management system for two community-based healthcare programs, namely, Patient-centred Palliative Care, and Senior Care. This paper focuses on the first program and elaborates on the approach announced in [16].

Palliative care refers to the physical, psychological, spiritual and practical care given to patients and their families when they are dealing with the issues associated with serious illness. As patients are usually part of a family, when care is provided, the patient and family are treated as a unit. The main focus of palliative care is to ease the suffering of the patient and his or her family and to help them to cope with their difficulties. The patient's needs and priorities for care are at the core of care provision; therefore, it is called patient-centred care. This contrasts with traditional models of care that are typically illness focused, provider driven, or determined by the care setting. Palliative care is ideally delivered by an interdisciplinary care team with the requisite knowledge and expertise required to address the many domains of issues that are commonly experienced by patients/families experiencing a serious illness. The composition of the team varies and is determined by the nature of the patient/family needs and issues, which often fluctuate over the course of the illness. Fig. 1 gives a view of many of the care

M. Szomszor and P. Kostkova (Eds.): E-Health 2010, LNICST 69, pp. 285–294, 2011.

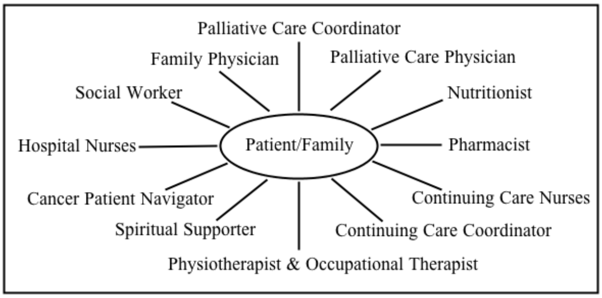

Fig. 1. A Patient-Centred Palliative Care Team

providers who may compose a palliative care team, where the patient/family is at the centre of care.

In a recent study [8] by our team, palliative care professionals identified the following needs desirable for a palliative care information system: *(1) streamline work processes and reduce manual steps; (2) effectively manage communication and information flow among the patients and caregivers; (3) offer flexible scheduling and calendaring capability; (4) monitor patients' health status and care delivery; and (5) provide remote network access and offline mode.* To address these needs and to facilitate better access to knowledge for decision-making during the care, we propose the use of autonomous agents. Isern et al. [7] summarized some key benefits of agents applied to healthcare: (1) offering a natural way of tackling inherently distributed problems with heterogeneous sources; (2) offering advanced platforms for building expert systems to assist individual clinicians in their work; and (3) having the potential to improve the operation of healthcare organizations, where failures of communication and coordination are important sources of error.

In this article, we present an agent-based architecture to facilitate patient-centred palliative care. The novelty of our work lies in the integration of workflow management systems, structured knowledge bases (i.e., ontologies) to capture background information, and techniques from formal methods with agents for enhancing health services deliveries, focusing on the needs of a specific community-based and patient-centred program. Section 2 gives an overview of the agent-based architecture and how it enhances patient-centred palliative care. Section 3 discusses three important services in more detail: work assignment, scheduling and monitoring. Section 4 discusses related work and concludes the paper with directions for further work.

2 An Agent-Based Architecture

We illustrate our agent-based architecture in Fig. 2. There are two layers: a Careflow Management System (CfMS) and a network of interacting agents. RESTfull web services APIs provided by the CfMS support communications between the layers.

The CfMS is largely based on [11]. It integrates the following components: *a Workflow Management System (WfMS)*, which is a system that defines, creates and manages

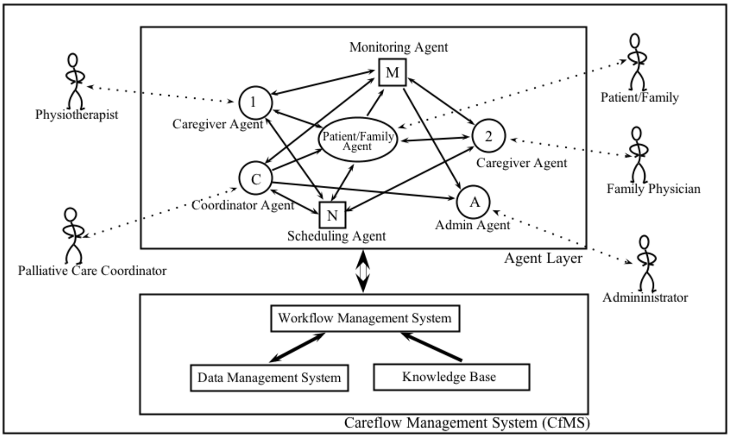

Fig. 2. An Agent-based Architecture for Patient-centred Palliative Care

the execution of workflows; *a Data Management System (DMS)*, which stores the data that are produced during the execution of healthcare workflows and supplies it to the WfMS as necessary for decision support; and *a Knowledge Base (KB)* which manages ontologies that store healthcare knowledge and guides the execution of workflows. Currently our team has developed methods to represent and verify the correctness of workflows [10], and has implemented ontologies (e.g., an access control ontology [4]) for the KB. Our industry partner is developing the DMS.

In the agent layer, we divide agents into two categories: agents that interact with humans directly (e.g., patient agent, coordinator agent), and agents that interact only with other agents (e.g., monitoring agent, scheduling agent). Various stakeholders have "agent assistants" which they can access via a web interface or specialized software client in mobile devices such as cellphones, netbooks etc. Communication between users and agents is indicated by dotted lines; communication among agents is indicated by single lines; arrows indicate directions of information flow. These software agents can support patient-centred palliative care delivery as follows:

– *To facilitate personalized workflow execution.*
– *To facilitate communication and collaboration among stakeholders.*
– *To enhance data and privacy protection.*
– *To facilitate scheduling and monitoring in reactive or proactive manners.*

We now describe the services that agents provide and how they facilitate collaboration in patient-centred palliative care.

– **Patient/Family Agents:** Upon a patient's intake to the palliative care program, an agent is created for this patient. The patient agent provides the following services: (1) maintaining all the relevant information related to this patient including the personal and health status information, and patient/family's specific preferences and priorities; (2) communicating and collaborating with other agents, e.g., to set up appointments with caregiver agents via a scheduling agent, or to send health status information to a monitoring agent; (3) sending reminders to the patient/family with scheduled appointments, medications, etc.

- **Caregiver Agents:** As there are many types of caregivers (see Fig. 1), we need different types of caregiver agents as well. Some of the common services provided by caregiver agents include: (1) obtaining tasks from the care coordinator agents (described below); (2) scheduling appointments with patient agents, and meetings with other caregiver agents via the scheduling agent; (3) receiving information from patient agents and the monitoring agent; (4) sending reminders to caregivers regarding scheduled appointments, meetings, and workflow tasks. A caregiver agent can be configured to fit a specific caregiver. For instance, an oncologist may only need information related to the patient's cancer status, while a spiritual or social worker would only require information relevant to their specific domain; agents help to filter out irrelevant information to prevent information overload.
- **Care Coordinator Agents:** This agent is a special type of caregiver agent, and in addition to the common services described in the caregiver agent, it provides two essential services to assist the human care coordinator:
  1) Assigning work requests (from workflows in the CfMS) to caregivers via agents.
  2) Automatically managing the agents for a care team. For instance, a patient may need a physiotherapist during the course of care. The care coordinator decides to bring a physiotherapist into the patient/family's care team. Correspondingly the care coordinator agent automatically establishes links between the physiotherapist's agent and the agents for other caregivers already on the team, thereby giving the physiotherapist access to information and enabling communication with other team members.
- **Scheduling Agent:** A scheduling agent helps other agents to schedule work items, such as, lab tests, appointments, meetings, etc. Each agent has its own calendar, and it can be accessed by the scheduling agent. The goal of the scheduling agent is to meet numerous requirements (such as temporal dependency and priority among the work items) as well as to improve the overall efficiency of care delivery.
- **Monitoring Agent:** Caregivers' work is guided by certain requirements to ensure safe, quality care and prevention of errors. A monitoring agent processes information from patient agents and caregiver agents and then checks whether the requirements are being followed. If not, the monitoring agent can automatically generate and send alerts to relevant caregiver agents, and then these agents remind the caregivers they are assisting.
- **Administrator Agent:** This agent supervises the overall performance of the system, and communicates only with care coordinator agents. For instance, the administrator agent gathers statistical information from the care coordinator agents to assist budgeting and strategic planning for the organization.

3 Work Assignment, Scheduling and Monitoring

We now describe how caregivers get work items from the CfMS through agents. Fig. 3 shows a high-level palliative care workflow built on the National Principles and Norms of Practice from Canadian Hospice Palliative Care Association (CHPCA) [5]. Workflows are composed of units of work called tasks. A workflow specification can define which tasks should be performed, under which conditions and in which order, which data, documents and resources are required to perform each task, etc. It should be noted that tasks can include the important and less tangible aspects of quality care, such as emotional and spiritual support. Being able to manage tasks is an important factor in effective, efficient use of resources and efficient care delivery. There are two kinds of tasks: atomic tasks and composite tasks. For example, in Fig. 3, *Referral* and *Discharge*, represented as single-lined boxes, are atomic tasks; while *Intake*, represented as a double-lined box, is a composite task, and it can be decomposed to a lower-level workflow.

A workflow can be instantiated as a result of an event. For example, a pain management workflow is instantiated every time a new issue of pain arrises from a patient. A work item is a particular instance of a task that needs to be performed as part of a given workflow instance. When a patient is referred to a palliative care program, a caregiver creates a case for this patient in the CfMS. The first work item is to process the referral, i.e., an instance of the *Referral* task in Fig. 3. After this work item is finished by the caregiver, he or she will make a decision on whether to accept the patient into the palliative care program. In the case of 'No', a new work item of an instance of *Explanation* is available, and subsequently the case is closed. In the case of 'Yes', a new work item of an instance of *Intake* is available. In this step, a care coordinator starts to handle this case, and his or her agent maintains the information related to this case.

When a patient enters the start point (the triangle), the care coordinator starts to assign the instances of these tasks to appropriate caregivers. The care coordinator may consider numerous things including:

– the type of caregiver for the identified patient/family issue of need;
– the caregivers' current workload;
– the temporal dependency specified in the workflow, e.g., *care planning* must be performed before *care delivery*;
– the priority levels, e.g., 'urgent' means "responding in 1 working day", 'normal' means "responding in 3 working days";

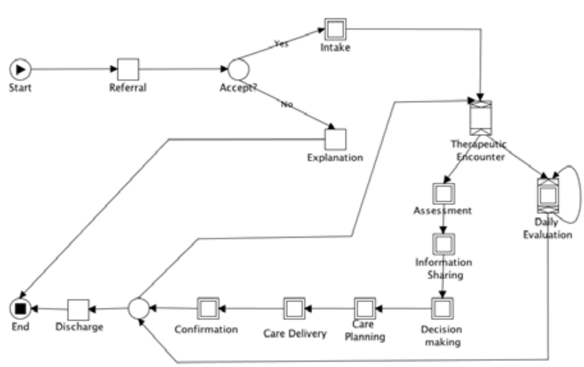

Fig. 3. A High-level Palliative Care Workflow Model

– the location of this work to be performed. In palliative care, patients often move across a variety of settings during their illness, e.g., hospital, hospice unit, home, etc.

Note that the assignment is not complete in the beginning as information during the course of care will affect assignment later in the workflow. The care coordinator agent communicates with caregiver agents to obtain the relevant information and make recommendations to the care coordinator and vice versa. There are general rules that can be applied to the selection process: the caregivers' workloads should be balanced; concurrent work items can be used to improve the efficiency by contacting the most appropriate caregiver for the work to be done; the travel of caregivers, particularly in a rural area, should be minimized. The following example explains how a care coordinator agent facilitates the assignment of work items. Fig. 4 (left) shows a workflow that consists of 5 atomic tasks, among which, P1 and P5 are located in the same place, and P2, P3, and P4 can be executed concurrently.

To minimize the travel distance and improve work efficiency, a *coordinator agent* may give the following recommendation: task instances of P1, P2 and P5 are assigned to caregiver 1, and task instances of P2 to P4 are assigned to caregiver 2 to 4 respectively (see Fig. 4). Note that caregivers 1 and 2 are jointly involved in the work item of P2, such as when a home care nurse and a palliative care coordinator perform a joint assessment of a patient at home.

The care coordinator can review the recommendations and make adjustments if necessary, then his or her approval triggers the coordinator agent to distribute these work items to other agents, and the agents subsequently start to schedule work items with the *scheduling agent*.

The complexity of scheduling lies in the dynamic, variable and frequently unpredictable nature of the healthcare processes, and in the numerous temporal and resource constraints, especially in community-based healthcare program such as palliative care. With the availability of rich information (e.g., calendars, preferences), and the automatic and reactive nature of agents, this complexity can be well addressed.

After a work item related to a patient/family issue has been assigned, a scheduling agent gets relevant information such as caregivers associated with this work item, temporal dependency with other work items, priority level, location, etc. In addition, patients and caregivers' own preferences can be considered by the scheduling agent.

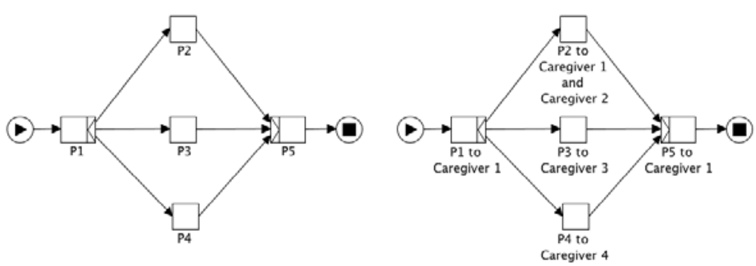

Fig. 4. Work assignment for a workflow with sequential and concurrent tasks

For example, the patient can not come for appointments on certain days, when family members are unavailable to drive him to the appointment. The goal of the scheduling agent is to meet the requirements as well as to improve the overall efficiency of care delivery.

The scheduling agent has to put the work items, such as contacts with the patient/-family, team conferences, etc., into specific time slots in the caregivers' calendars. The temporal dependency of the work items should be kept. For example, in Fig. 4, work item P1 should be completed before work item P2 starts, and work item P5 can start only if P2, P3, and P4 are all completed. To illustrate this, we use an example from actual care delivery. On a home visit, the home care nurse discovers that a patient who wished to remain at home for care has developed nausea and vomiting. He is unable to take his regular pain medication orally. The home care nurse becomes aware of this during a visit. She must then notify the patient's family physician to report her assessment and obtain a prescription for subcutaneous administration of the patient's pain medication and an anti-nauseant. Before she can place the subcutaneous catheter for administration of the medications, the patient's prescription must be filled by the pharmacist and taken to the patient's home by a family member. Once the medication is available in the home, the nurse can implement the subcutaneous catheter and instruct the family members on how to give the medication through the catheter. This must all take place in a sequence within a few hours so that the patient does not experience a pain crisis.

Priority is an important consideration, especially for different patient cases. For example, suppose there is another instance of the workflow in Fig. 4 (for a different patient), and its work item of P1 is more urgent than the work item of P1 in Fig. 4; then this instance of P1 should be scheduled before the one in Fig. 4. The scheduling agent should also consider placing the work items that are physically close into adjacent time slots as much as possible. If, in a work item, a caregiver needs to meet the patient or other caregivers, then the scheduling agent needs also to contact the patient agent or appropriate caregiver agents to find a common free time slot in their calendars.

Rescheduling is another important issue. If for some reason, a work item is delayed, then rescheduling should occur which may affect the schedules of other work items. The scheduling agent wants to make sure that minimal changes are made. For example, suppose P2, P3 and P4 are scheduled to start 1 hour after P1 is completed, and P5 is scheduled to start 5 hours after P1 is completed (of course also after P2, P3 and P4 are completed); if the work item of P1 is delayed by 2 hours, then the work items of P2 to P4 have to be rescheduled, and the scheduling agent will try to reschedule without affecting the start of P5. When an alternative schedule can not be found for the same caregiver, the care coordinator agent is notified and the work item is reassigned to another caregiver.

Monitoring is an essential part of our system and autonomous monitoring agents will provide this service. Two kinds of information are recorded in the CfMS:

1. *Information pertaining to a patient's health status.* For example, the Edmonton Symptom Assessment System (ESAS) is used as a tool to assist in the assessment of nine symptoms common in patients experiencing serious illness: pain, tiredness, nausea, depression, anxiety, drowsiness, appetite, wellbeing and shortness of breath. Patients often need to have regular assessments, including ESAS,

by caregivers. The assessment data should be monitored continuously and be sent to relevant caregivers, such as the patient's family physician and any nurses, or other care providers who are regularly involved in the care. When abnormal health status occurs, such as a sharp increase in pain, the monitoring agent generates and sends alerts to the agents of appropriate care providers, so that the severe pain or other noxious symptom can be promptly addressed. The conditions of alerts can be pre-determined by the patient/family and/or the care providers.

2. *Information pertaining to care delivery.* Caregivers' work is guided by certain requirements to ensure safe, quality care and prevention of errors. In Canada, palliative care is guided by national principles and norms of practice [5] and the Accreditation Standards [3]. E.g., one norm states: "The patient's decision-making capacity is assessed regularly". As this assesment information can be recorded by caregiver agents, the monitoring agent can check whether the actual healthcare practice conforms to the norms of practice and alert healthcare provider(s) when necessary.

The logic-based framework proposed in [15] can be used to monitor the above-mentioned information. The ideas are, in brief, (1) to build linear-time *models* of health status and care delivery information, then (2) to express *specifications* to be monitored in the logical language we proposed, called **FO-LTL-K**, which is a combination of a first-order linear temporal language and a description logic language, and then (3) to use the monitoring agent to *validate whether specifications hold in such models*; the results of checking are then used to generate reminders and alerts. The use of this formal language reduces the ambiguity in the natural language description of the norms and standards, and interfaces well with healthcare knowledge organized in ontologies.

The norms [5] and the standards [3] are used in our system in two ways. First, we use them to design workflows for the CfMS (see Fig. 3). Second, we use them to specify properties to be monitored. The precise specifications of norms and standards are usually dependent on the settings of care. Following discussions with caregivers in the Guysborough, Antigonish, Strait Health Authority (GASHA) of Nova Scotia, in [15] we specified some of the norms and represented them in **FO-LTL-K**. Here we extend this treatment to the standards from [3] and user defined properties.

– **Standard 1:** The team reconciles the client's medications upon admission to the organization, and with the involvement of the client. (Indicator: the process includes a timely review of this prior-to-admission medication list with the list of new medications ordered at admission.)

This standard outlines a requirement for medication reconciliation, and the indicator gives details on how to monitor compliance with this standard. Medication compatibility knowledge is kept in the KB, and is consulted in every medication reconciliation process. This standard can be specified and represented as follows:

$$\exists x_1 \exists x_2.(PM(x_1) \wedge NM(x_2) \wedge \neg((x_1, x_2) : \mathsf{MedCompatible})) \\ \rightarrow \mathbf{X}(ActionTaken(g, p))$$

where, the predicate $PM(x)$ denotes "medication x is in the list of the prior-to-admission medications", the predicate $NM(x)$ denotes "medication x is in the list of new medications", MedCompatible is a medication compatibility role in the KB, the constant g denotes "Revise Medication", and p denotes a patient.

Apart from specifying these norms and standards, we can also allow caregivers to specify some properties by themselves. For example, a **User Defined Property** "Use medication Med1 until pain level is less than 3" can be represented as follows:

$$Medication(Med1)\,\mathbf{U}\,\exists x.(Pain(x) \wedge x < 3)$$

4 Related and Further Work

Recent work shows much interest and progress in applying agent technologies to facilitate communication and collaboration among healthcare stakeholders, and to support decision-making and patient monitoring.

The PalliaSys project [13] outlined an agent-based system for improving the management of palliative care. We are addressing similar issues but use different methods such as workflow management systems, knowledge bases, and logic-based formal methods. In [12], the authors provided an agent-based alarm management system for a palliative care unit. They showed how intelligent agents can continuously monitor the evolution of the health status of palliative patients using two kinds of alarms: basic alarms (e.g., *(Hunger < 3) and Extreme weakness : Dangerous weakness*), and evolution alarms (e.g., *Number of evaluations: 2. Δ Weakness > 2 : Fast weakness increase*). We can specify these alarms in our monitoring agent. Moreover, our data model and language are more expressive for supporting complex temporal and knowledge reasoning.

Other work also considered the use of autonomous agents in different areas of healthcare. For example, the SAPHIRE project [9] provided a Clinical Decision Support system for remote monitoring of patients at their homes, and at the hospital to decrease the load of medical practitioners and healthcare costs. The K4CARE platform [2] offered a Knowledge-Based system to support services for individuals living in their houses, namely Home Care services. [17] presented an approach for dynamically generating a customized clinical pathway according to a patient's evolving status. Moreover, recent work [1,6] presented some agent-based scheduling mechanisms, which give hints on how we should realize our scheduling agent.

We conclude that an agent-based architecture can be a useful tool for supporting collaborative, patient-centred palliative care delivery. An early pilot is currently under development in collaboration with our industry partners and GASHA. The purpose is to develop electronic documentation and communication tools, to provide a proof of concept for the monitoring agent, and to interface with an access control ontology. Ongoing close working relationships with palliative care clinicians and managers at GASHA and information from this early pilot will inform a second pilot where we implement a fully functional CfMS (cf. [14] for a prototype) with the agent-based features described here.

Acknowledgment. We would like to acknowledge the support from the Natural Sciences and Engineering Research Council of Canada, the Atlantic Canada Opportunities Agency, and the clinicians and mangers at GASHA. We are grateful for discussions and contributions from students: K. Miller, J. Crawford, F. Rabbi, and N. Leyla.

References

1. BenHassine, A., Ho, T.B.: An agent-based approach to solve dynamic meeting scheduling problems with preferences. Eng. Appl. Artif. Intell. 20(6), 857–873 (2007)
2. Campana, F., Moreno, A., Riano, D., Varga, L.: K4care: Knowledge-based homecare e-services for an ageing europe. In: Agent Technology and e-Health, pp. 25–54 (2008)
3. Canadian Council on Health Services Accreditation (ed.). CCHSA's Accreditation Program 2008: Standards of Hospice Palliative and End-of-Life Services. CCHSA (2007)
4. Cocos, C., MacCaull, W.: An ontological implementation of a role-based access control policy for health care information. In: Proceedings of the Workshop of Ontologies in Biomedicine and Life Sciences (2010)
5. Ferris, F., et al.: A Model to Guide Hospice Palliative Care: Based on National Principles and Norms of Practice. Canadian Hospice Palliative Care Association (2002)
6. Hutzschenreuter, A.K., Bosman, P.A.N., Blonk-Altena, I., van Aarle, J., Poutré, H.L.: Agent-based patient admission scheduling in hospitals. In: Berger, M., Burg, B., Nishiyama, S. (eds.) AAMAS (Industry Track), pp. 45–52. IFAAMAS (2008)
7. Isern, D., Sánchez, D., Moreno, A.: Agents applied in health care: A review. I. J. Medical Informatics 79(3), 145–166 (2010)
8. Jewers, H., Foshay, N., MacCaull, W., Norgrove, J., Miller, K.: Involving palliative care team members in designing information technology for assessment, communication, and information management for patient-centred palliative care. In: 17th International Congress on Palliative Care (2008)
9. Laleci, G.B., Dogac, A., Olduz, M., Tasyurt, I., Yuksel, M., Okcan, A.: Saphire: A multi-agent system for remote healthcare monitoring through computerized clinical guidelines. In: Agent Technology and e-Health, pp. 25–44. Birkhauser, Basel (2008)
10. Mashiyat, A.S., Rabbi, F., Wang, H., MacCaull, W.: An automated translator for model checking time constrained workflow systems. In: Kowalewski, S., Roveri, M. (eds.) FMICS 2010. LNCS, vol. 6371, pp. 99–114. Springer, Heidelberg (2010)
11. Miller, K., MacCaull, W.: Toward careflow management systems. Journal of Emerging Technologies in Web Intelligence Special Issue, E-health: Towards System Interoperability through Process Integration and Performance Management 1(2), 137–145 (2009)
12. Moreno, A., Riano, D., Valls, A.: Agent-based alarm management in a palliative care unit. In: 3rd Workshop on Agents Applied in Healthcare, IJCAI, Edinburgh (2004)
13. Moreno, A., Valls, A., Riano, D.: Improving palliative care with agent technology. In: 2nd Workshop on Agents Applied in HealthCare (WSECAI 2004), ECAI, August 22-27 (2004)
14. Rabbi, F., Wang, H., MacCaull, W.: Compensable workFlow nets. In: Dong, J.S., Zhu, H. (eds.) ICFEM 2010. LNCS, vol. 6447, pp. 122–137. Springer, Heidelberg (2010)
15. Ruan, J., MacCaull, W.: Data-aware monitoring for healthcare workflows using formal methods. In: Proceedings of the Second International Workshop on Knowledge Representation for Health Care (KR4HC 2010), Lisbon, Portugal, pp. 51–60 (2010)
16. Ruan, J., MacCaull, W., Jewers, H.: Enhancing patient-centered palliative care with collaborative agents. In: Proceedings of the 2010 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (CARE Workshop), pp. 356–360 (2010)
17. Weizi, L., Kecheng, L., Shuzhang, L., Hongqiao, Y.: An agent based approach for customized clinical pathway. International Forum on Information Technology and Applications 2, 468–472 (2009)