A Multiagent System to Support an Interdisciplinary Healthcare Team: a Case Study of Clinical Obesity Management in Children

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Abstract. An interdisciplinary healthcare team (IHT) has been advocated as a way to manage chronic illnesses. There is growing evidence that operation of an IHT can be improved with better coordination of team's activities and improved collaboration among team members. This paper proposes MET4 – a multi-agent decision support system developed to facilitate collaboration and coordination among the IHT members by aligning execution of tasks according to a patient management workflow and assigning appropriate team members to these tasks. The system uses the concept of capability and associated competency to do the task – IHT members matching. We illustrate the MET4 system design and operation using a case study describing management of clinically obese children.

Keywords: interdisciplinary healthcare team, capability and competency, multi-agent architecture, clinical decision support system

1 Introduction

Increasingly complex patients' health conditions have necessitated new approaches to patient management. One approach has been to draw upon research on clinical practice guidelines and develop workflows (broadly defined as a sequence of steps corresponding to clinical tasks and decisions) to structure all activities associated with a patient management process. While these workflows can be processed (analyzed and/or executed) by a computer system [1], this becomes challenging when multiple healthcare practitioners are needed to perform tasks from a workflow. Such situation often occurs because complex and/or chronic diseases rely upon management by an interdisciplinary healthcare team (IHT) consisting of physicians, nurses, and other healthcare practitioners.

Operation of the IHT is driven by a fact that its members share a common goal of providing comprehensive and effective care to a patient. In order to accomplish this goal they collaborate by performing workflow tasks in a coordinated manner. *Collaboration* among team members is defined as the correct alignment of tasks to be executed [2], while *coordination* of their activities is defined as the assignment of the appropriate team members to the tasks at hand [3]. A coordinated and collaborative IHT can result in improved patient satisfaction, improved quality of care, decreased clinical staff turnover, and improved cost-effectiveness of care delivery [4].

Research on typologies of an IHT [5] has shown that there exists an extensive variability in terms of a team's structure (i.e., members may join or leave the team) and role assignment (members may play different roles that does not have to be predetermined or defined strictly by their specialties). Handling of such variability, especially related to role assignment, requires characterization of the healthcare practitioners that is more specific than categorizing solely by their clinical specialty. In [6] it is proposed to characterize practitioners with capabilities, and while the authors focus on nurse practitioners, such characterization can be extended to other healthcare practitioners. We follow this approach when defining a conceptual model of an IHT.

In the paper we describe a clinical decision support system (CDSS) called MET4 that supports coordination and collaboration among IHT members. The system uses a concept of capability (explained in Section 3) to form and maintain an IHT, to assign team members to tasks from a workflow, and to support them in executing these tasks. Design of the MET4 system follows a multi-agent system (MAS) architecture and builds on our earlier research where we combined MAS with an ontology-driven design to create an environment (called MET3) for developing a family of CDSSs for supporting individual physicians during an emergency patient management process [7]. MET4 extends this support for the IHT and for other management processes that are not limited to emergency patients.

The paper is organized as follows. In the next section we briefly discuss related research. In Section 3 we present the foundations of the MET4 system, including the conceptual model of an IHT. The design of MET4 is described in Section 4 followed by a case study of an IHT needed for executing a workflow for management of pediatric clinical obesity. The paper concludes with a discussion.

2 Related Research

The issue of collaboration among multiple decision-makers has been the subject of research in fields such as computer supported cooperative work (CSCW) [8] and it resulted in a blueprint for designing collaborative systems for improving team performance [9]. Considering that patient management processes (modeled by workflows) are complex, this blueprint was also applied in healthcare [9]. However, most of healthcare workflow management systems have primarily been concerned with representing workflows or with scheduling activities from a workflow, with less emphasis on coordinated care delivery by an IHT. This is well illustrated with the HealthFlow system [10] that offers a set of user-friendly tools for creating and maintain workflows. Another relevant example is the HeCaSe2 system [11] that was designed to align activities and services across a number of healthcare organizations.

It has been shown that MAS paradigm can be used for modeling CSCW requirements including the use of heterogeneous and distributed decision-makers, the distributed management of data, and remote collaboration [12]. An example of a MAS implementation in healthcare is the K4CARE system that supports care provision to elderly patients [13]. In the K4CARE system, healthcare practitioners are assisted by agents whose actions are governed by intervention plans (corresponding to workflows). K4CARE provides a solid foundation for developing a CDSS for supporting an IHT, however it provides a relatively basic support for coordinating tasks (team members have to be explicitly associated with tasks they are able to execute) and for maintaining a team (members are temporarily recruited to execute specific tasks).

We draw upon the K4CARE system's foundations and combine them with our earlier research to develop the MET4 system to support coordination and collaboration in an IHT. Specifically, MET4 follows a workflow for proper alignment of tasks to be executed. Moreover, it relies on the concept of capability to characterize team members and workflow tasks. This provides a mechanism for dynamic creation and maintenance a team during execution of a workflow and allows for multiple team members to compete for execution of a given task.

3 Foundations of the MET4 system

A conceptual model of an IHT implemented in the MET4 system is built around the concept of *capability*. This concept is generally defined as *an ability to take appropriate and effective action to formulate and solve problems in both familiar and unfamiliar and changing settings* [6]. However, for our purposes we made this definition more specific by stating that a capability is defined as *an ability to perform a certain clinical task*.

We associate capabilities with practitioners – potential members of an IHT – and workflow tasks in order to characterize possessed abilities to perform a task and the abilities required for a task to be completed. To simplify further description we assume a task can be associated with a single required capability, while a practitioner may possess multiple capabilities. We further characterize capabilities with numerical scores. A capability associated with a practitioner is characterized by a *competency value* that indicates the competency of this practitioner to perform tasks requiring this capability (for example, a physician and a nurse have capability to conduct a physical examination, but the competency value for the physician is higher than the competency value for the nurse indicating that physician is more competent for this clinical task). A capability associated with a workflow task is characterized by a *competency threshold* that indicates the minimal competency value needed for execution of the task. Currently competency values and thresholds are established manually with a help of a collaborating domain expert, but there are tools designed for assessing capability in evidence-based practice (e.g., [14]) that can be adapted for this purpose.

Using the capabilities together with the competency values and thresholds to describe IHT members and tasks from a workflow supports coordination by facilitating assignment of tasks to the most appropriate team members. A given team member is assigned to a task only if she has the capability required by the task and if her competency value satisfies the task's competency threshold. In the case of multiple candidates, the one with the highest competency value is selected. Providing a fine-grained description of practitioners and workflow tasks also supports the role variability often required by an IHT [5], where a role is interpreted as assignment to a set of specific tasks. It is also used for forming and maintaining an IHT as discussed below.

There are two approaches to team formation – static and dynamic [13]. In the static approach the team is formed in advance and all members stay in the team until the workflow terminates. Such an approach ensures that all tasks can be executed without delays associated with finding and recruiting appropriate team members (they may not be available at all times). On the other hand, static team formation may result in inefficient use of team members who may be idle while waiting for a request to execute a task. In the dynamic approach members are recruited as needed in order to execute a specific task. Once a task has been completed, the recruited member is dismissed. Such an approach clearly addresses the issue of idleness but at a cost of increased effort related to team maintenance, and in extreme cases, may put execution of a task on hold if no healthcare practitioner with the required capability is available.

In the MET4 system we use a hybrid approach. Similarly to the dynamic approach a member is recruited to an IHT when a task needs to be executed. However, instead of dismissing after a task is completed a member is retained in the team if she can be assigned other tasks that are executed later in the workflow (a retained member can be dismissed by her own request at any time). While theoretically this may be not optimal (a practitioner with better competency value may become available), a hybrid approach minimizes the effort associated with team maintenance and the chance of delays in workflow execution. An additional advantage of the proposed approach is that it supports an IHT characterized by variable personnel composition [5].

4 Design of the MET4 system

The design of MET3 (precursor to the MET4) system was driven by two main requirements – provision of support for a single healthcare practitioner during the entire emergency patient management process, and the ability to exchange information with hospital information infrastructure [7]. The MET3 architecture was developed using the O-MaSE (Organization-based Multi-agent System Engineering) method which was combined with an ontology-driven design to translate system requirements into a set of models describing the specific architectural components (see [7] and [15] for details). Since MET4 extends support to multiple healthcare practitioners, it has to satisfy the new requirements of supporting collaboration and coordination among IHT members while executing tasks coming from any (explicitly represented) workflow.

Following a design process similar to the one used for developing MET3 system, we started by defining the requirements for MET4, that were later translated into a goal model using O-MaSE. Then, a corresponding agent class model, together with a domain model, protocol models, and plan models were developed. Due to space limitations we only discuss two of the models here – the agent class model that defines the agent classes and non-agent components (e.g., data repositories) comprising the

MET4 system, and the domain model that introduces the ontology used by the agents to communicate.

The agent class model is shown in Fig. 1. It includes the following agent classes:

- *Practitioner assistant* that acts as a healthcare professional's proxy assisting in executing tasks from the workflow,
- *Team manager* that forms and maintains the team following the hybrid approach and identifies most appropriate member for a given task,
- *Workflow executor* that executes workflow and delegates tasks to team members identified by *team manager*,
- *Data manager* that manages data of the patients currently handled by MET4; this data is stored locally in a *data repository*,
- *Data synchronizer* that receives and passes the messages between MET4 and a hospital information system (HIS) so changes to patient data are propagated and synchronized,
- *Evidence provider* that provides clinical evidence from the *evidence repository* that is searched by applying a disease- and patient-specific evidence model to available patient data (see [16] for details),
- *Evaluation suggester* that suggests diagnostic and non-diagnostic evaluations by applying disease-specific evaluation models to available patient data,
- *Therapy suggester* that suggests pharmacological and non-pharmacological therapies by applying disease-specific therapy models to available patient data,
- *Therapy reconciler* that reconciles multiple therapies devised by individual IHT members by identifying interactions and addressing them with help of interaction and revision models (see [17] for detailed description),
- *Model manager* that manages models codifying knowledge used by *therapy reconciler*, *therapy suggester*, *evaluation suggester* and *evidence provider*; these models are stored in the *model repository*.

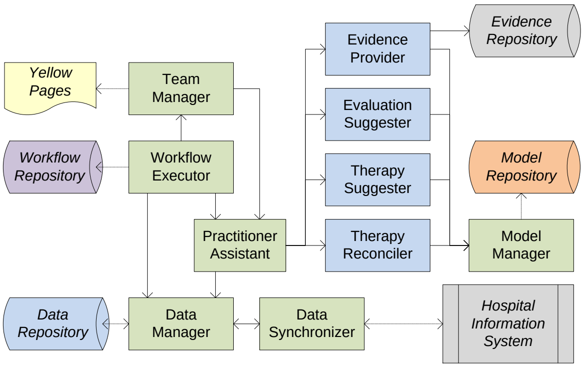

Fig. 1. Agent class model for MET4

The MET4 system includes multiple *practitioner assistant* agents (i.e., instances of the *practitioner assistant* class) that act on behalf of specific healthcare practitioners (1:1 relationship). These agents are annotated with capabilities and competency scores of the practitioners they represent, and they publish this information in *yellow pages* – a shared directory that is checked by the *team manager* agent when searching for new team members.

The domain model for MET4 is shown in Fig. 2. It provides a structured representation of the concepts described in Section 3 (e.g., *capability*, *workflow*, *task*) and the concepts used to represent patient-related data (e.g., *patient*, *disease*, *episode*, *observation*, *result*). The concept of a *workflow* needs to be further explained. We assume (following standardized workflow representations) that a workflow in MET4 is made of decisions and activities (see Fig. 2). Decision corresponds to selection of one of many alternative branches described by logical expressions that use patient data (such choice is made automatically by *workflow executor*). An *activity* is an abstract construct that either represents a task – an atomic action that is executed by a single team member, or represents a sub-workflow. The structure of a workflow and a sub-workflow is the same – the only difference is that a workflow is associated with a specific disease, while a sub-workflow is disease-independent and may be shared across multiple workflows. Moreover, sub-workflow may be nested – a sub-workflow may invoke other sub-workflows.

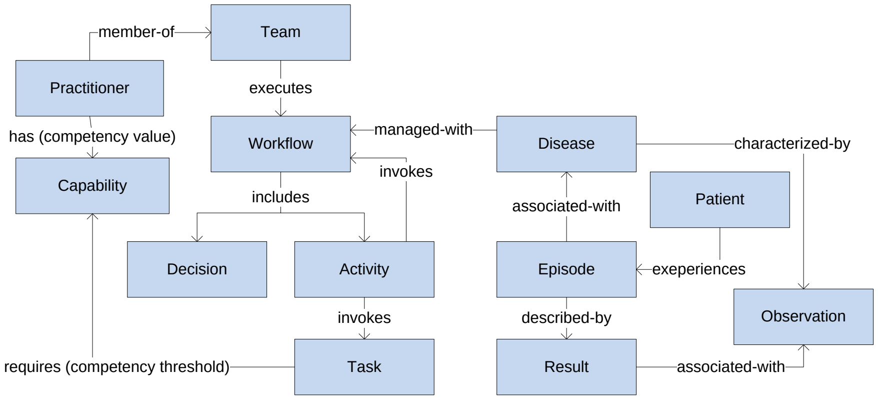

Fig. 2. Domain model for MET4

5 A Case Study: Pediatric Clinical Obesity Management

A condition of pediatric clinical obesity is determined by the body mass index (BMI) value. If for a given child this value places him/her in the 99th percentile of children from the same sex and age, or in case of pre-existing comorbid condition, places him/her in the 95th percentile, then a child is clinically obese. Such children are usually managed in dedicated facilities such as the Centre for Healthy Active Living at the Children’s Hospital of Eastern Ontario (CHEO) in Ottawa. A workflow approved and used at CHEO asks for capabilities demonstrated by a pediatric endocrinologist, registered nurse, psychologist, child and youth worker, social worker, exercise specialist and a dietitian.

5.1 Workflow for Pediatric Clinical Obesity Management

A simplified workflow developed with a help of a domain expert on the basis of the organizational workflow used at CHEO is shown in Fig. 3. It has been implemented in the MET4 system using tools briefly described in Section 6. The workflow is represented according to the MET4 domain model described in Section 4 – shaded blocks represent tasks, while white blocks indicate activities invoking sub-workflows. Due to space limits we show a single sub-workflow that is invoked by two activities: initial assessment and repeated assessment. Moreover, for illustrative purposes all visible tasks in Fig. 3 are annotated with capabilities and competency thresholds (represented on the Likert scale, where 1 indicates the lowest, and 5 – the highest value).

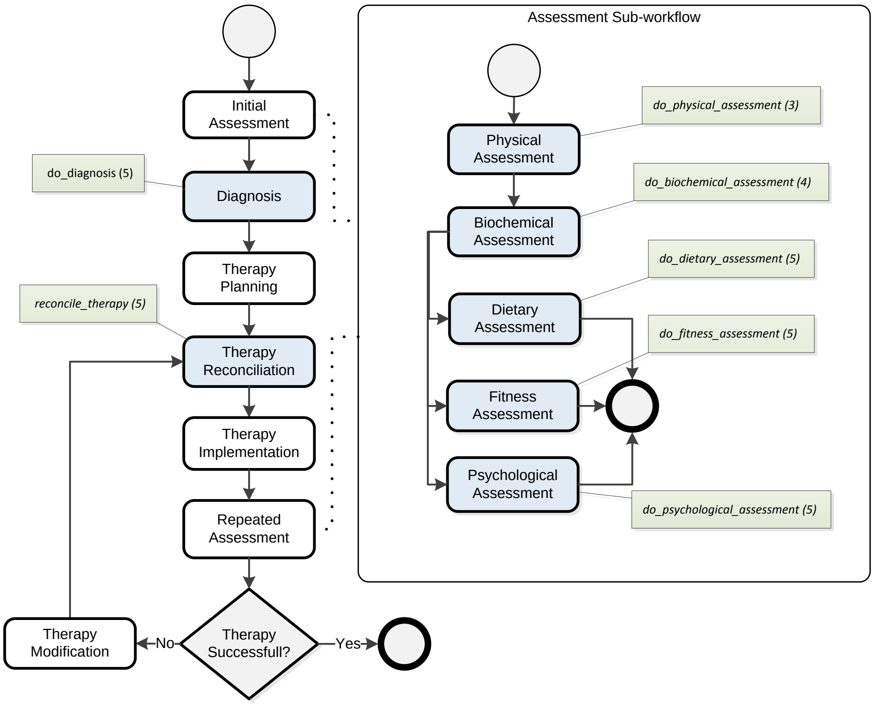

Fig. 3. Workflow for pediatric clinical obesity management

Execution of the workflow starts with the initial assessment. Once all tasks from a sub-workflow are conducted and patient record is updated a diagnosis is established and a therapy plan is prepared. While establishing the diagnosis is a task, therapy planning requires executing a sub-workflow aimed at developing a number of specialty therapies, not shown here due to space limitations. These specialty therapies need to be reconciled by mitigating any possible interactions among them before a unified therapy plan is implemented. After implementation, a patient's condition is reassessed for possible modification of the therapy plan developed earlier.

5.2 MET4 Operations

Below we describe in details selected operations of MET4. Due to space limits we focus on the operations associated with executing an activity invoking a sub-workflow. The relevant agent interactions are presented in Fig. 4. In the figure we annotate specific instances of agent classes with labels – specifically we use the *<label> : <agent class>* notation. For example, *pa-md1* is the label of an instance of the *practitioner assistant* agent class that represents physician *MD1*, while *we* is the label of the *workflow executor* agent. In Fig. 4 we also present capabilities and competency values associated with specific *practitioner assistant* agents. Finally, specific interactions marked as arrows are annotated with numbers indicating their positions in the overall sequence.

The *we* agent starts with the *initial assessment* activity (see Fig. 3). At this point the IHT managed by the *tm* agent is empty, as no task has been executed so far. The *we* agent retrieves an associated sub-workflow from the workflow repository (1) and starts its execution.

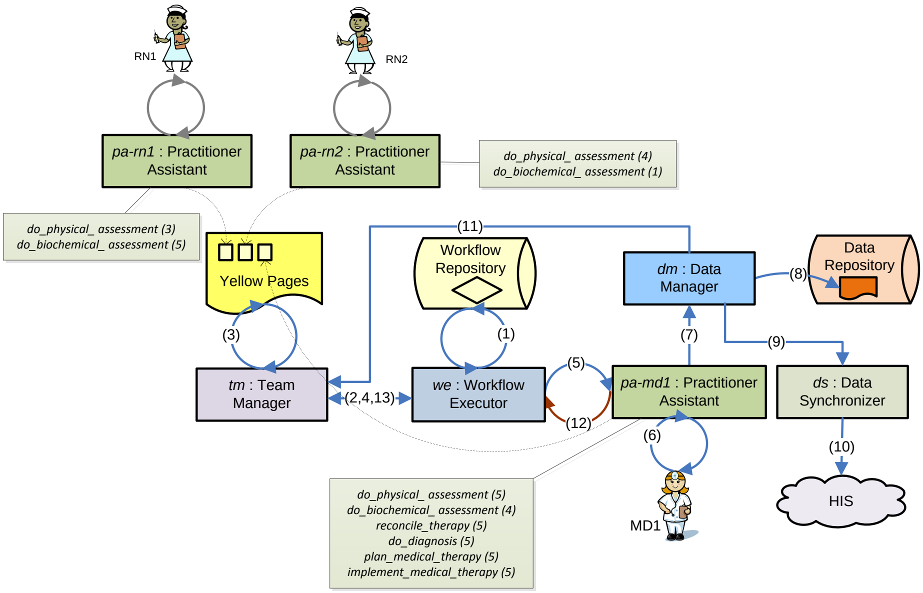

Fig. 4. An example of sub-workflow execution

The first task of *physical assessment* requires the *do_physical_assessment* capability with a competency threshold of 3 (see Fig. 3). The *we* agent sends a request to *tm* (2) to find a *practitioner assistant* agent that satisfies this requirement. The *tm* agent first checks if such an agent is already a team member. Since at this stage the team is empty, *tm* searches for available agents using the yellow pages (3). It finds three candidates (*pa-md1*, *pa-rn1* and *pa-rn2*) and selects *pa-md1* because its competency value is the highest among all candidates. The *pa-md1* agent is added to the team and information about the selected agent is returned to *we* (4). Then, the *we* agent sends a request to *pa-md1* (5) to assist *MD1* in conducting physical assessment using a form-based user interface (6).

The *pa-md1* agent sends collected data to the *dm* agent (7) that updates the patient record (8) and informs the *ds* agen*t* (9), so it can pass proper notification to the HIS (10). The *dm* agent also sends a request to *tm* (11) to notify *practitioner assistant* agents representing IHT members about new data being added. In this case, since currently there is only one team member who provided the data, such broadcast is redundant. Finally the *pa-md1* agent sends message to the *we* agent (12) about completing the task.

Before proceeding with the next activity, the *we* agent analyzes the workflow to identify capabilities required by subsequent tasks, and sends this information to the *tm* agent (13) that in turn updates the team by releasing agents that are no longer required. In this situation, the *pa-md1* agent has capabilities that are needed later as per clinical obesity management workflow (e.g., in the diagnosis task), and this agent is retained as a team member.

6 Discussion

In the paper we have presented foundations, design and operations of MET4 – a multi-agent CDSS that supports an IHT in executing a patient management workflow. More specifically, the MET4 system supports formation and maintenance of an IHT, coordination of activities of IHT members by assigning the most competent agent (from currently available ones) to the task at hand, and collaboration among the IHT members by managing execution of a workflow and facilitating information exchange and awareness among team members.

We have been able to accomplish the above by using a workflow as the frame for managing an IHT, where tasks from a workflow are described with capabilities and competency thresholds, and team members are assigned to these tasks according to their capabilities and competency values. This way we are able to enforce proper task's alignment thus supporting collaboration in IHT, and to maintain a right team with a right set of capabilities in order to support coordination. Our conceptual IHT model allows us to implement a hybrid approach to team formation and maintenance that reduces the need to search for relevant team member before executing a task.

Building on our previous experience, MET4 has been designed using the O-MaSE method combined with ontology-driven design. A prototype version of the system for supporting obesity IHT has been implemented using the Workflows and Agents Development Environment (WADE) [18] for MAS implementation and Protégé [19] for domain model implementation. Following the principles of task- and user-centered interaction design [20] we will create a user interface for mobile devices (smartphones and tablets running Android operating system) that will be employed by *practitioner assistant* agents to interact with practitioners when executing specific workflow tasks.

We are currently working on further enhancement of the conceptual model to take into account task priorities, execution of a set of tasks by the same agent, and joint execution of a single task by multiple agents. The latter will allow us to expand the notion of collaboration beyond the task alignment to the case of multiple agents working together and at the same time to complete a specific task.

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