

Application Scenarios of Agent-Based Information Logistics in Clinical and Engineering Domains

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Abstract. Coordinated information flow and situated information provision surface as challenging requirements for many processes that operate in distributed environments. The distribution of processes may be founded in organizational or spatial distribution and in the separation of concerns, knowledge, information and data repositories. In this paper, we are focusing on two application domains that show typical requirements for information logistics: (a) Clinical resource and patient management, and (b) engineering processes in simultaneous engineering teams in the automotive domain. We argue that a multi-agent approach, providing methodologies for autonomous, situated, social and pro-active information services, is a well-suited platform for the coordination of information flow and pro-active information delivery in these domains.

1 Introduction

Economic pressure and the rapidly growing amount of knowledge have led to a situation where more and more tasks need to be distributed among specialized, cooperating agents. *Cooperation* can be defined as *communication* between two or more participants with the purpose of work carried out on artifacts [1]. Thus, the communication among distributed agents is a key factor in efficient processes. The effectiveness of communication depends on *coordination* and thus on an efficient logistics of information. As a result, the demand for automation and computerization of this information logistics task is increasing.

In this position paper, we describe two application domains that show a potential for optimization by means of computerized information logistics: (a) Clinical resource and patient management, and (b) engineering processes in simultaneous engineering teams in the automotive domain. The processes in these domains share various attributes, because they both operate in networks of organizationally or spatially distributed units and rely on a separation of concerns,

knowledge, information and data repositories. We show that multi-agent technology, suggesting the development of situated, autonomous and flexible software components, can serve as a suitable platform for supporting the task of information logistics.

This paper is organized as follows. In the following section, we describe the attributes of the processes in the two application scenarios and point at their common coordination requirements. In section 3, we show the potential benefits of utilizing agent technology by presenting information logistics tasks that can be solved by agents. Finally, in section 4, we briefly give some conclusions and discuss some of the open issues that will be dealt with in our future work.

2 Coordination requirements in organizational networks

2.1 Clinical resource and patient management

Modern hospitals are highly distributed environments. Patient health care is performed by a network of various clinical units, including administration, surgery, anesthesiology, laboratories, radiology, intensive-care units, wards, storage and others. These units are not only spatially distributed, but also in terms of concerns and organization. For example, whereas the laboratories mostly act as a mere service provider responsible for the restricted task of analyzing blood samples, anesthetists need to make decisions that can have a critical impact on the patient's health. Furthermore, these decisions depend on a broad range of information about the patient's history, the surgical procedure, test results, the available resources and other aspects. Due to this complexity, anesthesia is a good example for studying the coordination requirements in distributed environments.

An overview of the clinical personnel and the information flow between them is shown in figure 1. The task of operating theatre management, i.e. assigning patients, anesthetists, nurses and material to the available operating rooms, is performed by an attending anesthetist. In the following, we describe a typical scenario from theatre management. The scenario is a result of our work aiming at the development of a multi-agent system for information management in anesthesia [5].

In this scenario, each of the surgical departments has a fixed amount of operating room time per day. Each room is assigned a list of patients by the attending surgeon. This list is given to the attending anesthetist (AA), who sends out available anesthetists for pre-operative visitations to the wards. These visitations result in initial patient information sheets. Based on this information and the available resources (personnel, theatre occupation), the AA either accepts the proposed operation time or notifies the attending surgeon about potential difficulties. After the two managed to negotiate an operation time, the AA assigns the case to one of the suitable anesthetists. The latter is responsible for having the operating theatre prepared with material and drugs.

When the planned operating theatre is about to become available, the patient is requested from the ward and delivered by a nurse. Then, the patient is brought

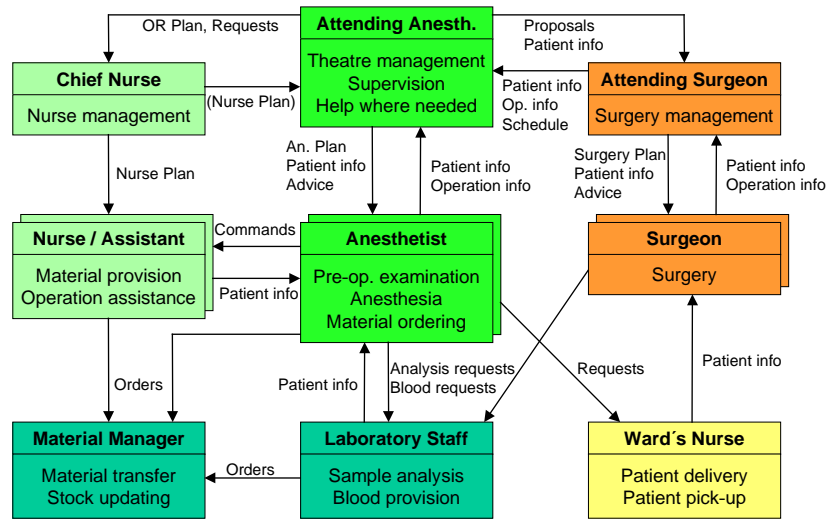


Fig. 1. Some of the human agents involved in the context of anesthesia, their tasks and the information flow between them.

to the induction room, where he is anesthetized. After he is prepared for surgery, the patient is moved to the operating theatre and finally to the recovery room. A successful surgical operation ends with the patient being returned to the ward. The task of the AA is to supervise the ongoing surgical procedures and to offer help where needed. For theatre management, he also has to assess the remaining operation times. Before and even during the operations, the personnel can access services from other units, such as the laboratory and the radiological department. The laboratory processes a queue of blood samples for analysis or is asked to deliver blood conserves. In emergency cases, the lab is expected to modify its task schedule accordingly. Emergency patients also require the AA to quickly shift the use of the available resources, e.g. by postponing planned operations.

2.2 Distributed engineering

The competitive market conditions in the automotive sector have put more weight on the development departments to constantly rethink their strategies and apply new methods for improving both their products and business processes. The question arises of how to optimize engineering processes in the early phases of product development. In order to improve engineering performance, Simultaneous Engineering (SE) was adopted by many enterprises in the automotive industry as an organizational concept for product development. SE is defined as “a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements

of the product life cycle from conception, through disposal, including quality, cost, schedule, and user requirements” [8]. SE teams have been established to implement simultaneous engineering. These teams comprise members of the various functional departments and representatives from suppliers. Due to these and other developments, cooperative work in teams is the most dominant work organization in product development [7].

As an operational consequence of these kinds of distribution, SE teams are often confronted with incomplete information due to the state of the process, the type of coordination or other environmental reasons. Efficient information logistics is instrumental to support SE teams in their operations. Lack of task-specific information surface as a major obstacle to the success of such SE teams. This lack might be caused by several reasons:

- The available documents containing task-specific information are outdated.
- Information is incomplete due to open decisions.
- Various distributed information sources are not synchronized, i.e information is already available at one department, but has not been transmitted to others.

2.3 Common coordination requirements

The tasks of clinical theatre management and simultaneous engineering share a number of common attributes:

- *Distributed*: Tasks, concerns, organization and know-how are distributed among various human agents and departments. For example, each of the clinical units has to deal with only certain aspects of the patient, so that data and information are also distributed. Patient data as well as design and requirements documents from engineering processes are distributed across various types of media, such as fax messages, data sheets, oral communication, or (incompatible) computerized information systems.
- *Parallel*: The clinical tasks as well as the engineering tasks run concurrently. Furthermore, these tasks operate on a shared subject, i.e. the patient or the engineering artifacts, respectively.
- *Non-deterministic*: Since patients are complex and little-understood biological systems, the prediction of the outcome of surgical procedures is difficult. Unexpected emergency cases happen, as do incidents in anaesthesia. Similarly, the outcome of engineering and design processes is hard to predict.
- *Self-organizing*: Responding to the uncertainty, the clinical and engineering staffs have to be able to react in a flexible manner. Although there is a strict hierarchy in terms of commands, for example between attending and other anaesthetists and between group leaders and assistants, the personnel acts to a certain extent self dependent. Many decisions in theatre management are negotiable, since resources are limited.
- *Communication-intensive*: The properties mentioned above demand for sophisticated and efficient communication paths among the personnel. Commands, requests, intentions, schedules, patient information, emergency calls,

new design documents and constraints have to be delivered to the right person at the right time.

Most of these aspects deal with information flow and processing between (human) agents in a distributed environment. In the following section, we will show that the multi-agent paradigm provides a very suitable platform to support this information flow.

3 Agent-based information logistics

In most of the various definitions of agenthood that can be found in the literature, the following attributes are assigned to software agents (cf. [3]):

- *Situatedness*: The agent receives sensory input from its environment and can perform actions which change the environment.
- *Autonomy*: The agent is able to act without direct intervention of humans.
- *Flexibility*: The agent is able to respond in a timely fashion (responsive), to take the initiative (pro-active) and to interact with other human or artificial agents (social).

These properties correspond to the needs of information management identified in section 2. The software agents we propose are situated in the *distributed* clinical and engineering networks. Each of the various *parallel* processes taking place in this environment can be supported by one or more autonomous agents. These agents are to a certain extent *self-organizing* and therefore require fluent communication pathways to interact with each other and with the human agents they act on behalf of. They need to respond to the *non-deterministic* processes in a flexible and timely fashion.

The following subsections present tasks that can be supported by means of agents.

3.1 Agents in clinical resource and patient management

The strength of computers is to quickly process large amounts of data. For legal and other reasons, clinical decision-making must remain with human agents. Thus, the main task of software agents supporting human decision making by relieving from the burdens of data overload and those tasks that require little intellectual background. We envision small hand-held devices carried by each of the anesthetists, nurses, surgeons and other mobile personnel. Depending on the context, the configurable interface agents running on these devices supply the respective user with information such as patient data and the current theatre management plan. Comparable to the pager devices already present in modern hospitals, the devices might pro-actively notify its wearers about important incoming information via acoustic signals. In particular, we have identified the following tasks for the agents in our clinical setting:

- For the attending anesthetist: Managing the operation schedule (rooms, time, surgical personnel), coping with high-priority cases, such as emergency patients. Proposing suitable anesthesia personnel for the scheduled operations, assisting the attending anesthetist in resource management. Supervising the current surgical procedures by condensing information from the current operations, so that the attending anesthetist is able to quickly assess the future development (e.g. the remaining operation time).
- For the anesthetists: Pro-actively notifying each anesthetist on plan changes and the relevant patient data. Collecting and analyzing the patient data measured by the clinical devices, providing an overview of the patient’s history, state and location.
- For the nurses: Requesting that anesthetic equipment and drugs are made available for each surgery and ensuring that the operating room is in the desired state (cleaned, heated, etc.).
- For the storage: Processing hardware requests and re-ordering hardware if the stock is running low.
- For the ward: Processing calls for delivering the patient from the ward to the operating room or back.
- For the laboratory: Receiving and processing incoming requests for blood analysis etc. Depending on the current task queue, agents can give an assessment of when the results will be available and negotiate with other agents that represent the requirements of the units that placed the orders.

3.2 Agents in distributed engineering

In the context of distributed, simultaneous engineering, agents appear to be instrumental to support the subsequent tasks:

- Pro-actively notifying about updated documents to distribute information.
- Delivering documents among organizationally distributed partners crossing system boundaries while obeying organizational privacy.
- Transforming representations and abstracting information from several sources, e.g. for weekly audits of the development state.
- Negotiating deliverables and dates for coordination meetings. The coordination overhead for handling change request typically takes up to 50 percent of the workload. Agents for coordinating working tasks, i.e. due dates, arranging meetings, and notifying partners about changes, will be crucial for reducing workloads.
- Process auditing, e.g. monitoring timelines and delivering documents properly. More sophisticated agents can be built upon knowledge of the process in order to assess the current state (cf. [9]).
- Supporting coordination procedures. For example, most of the engineering tasks are performed in cooperation with suppliers yielding to the need to obey typical patterns, such as an engineering cycle with five reviews. An agent will typically schedule the review meetings biweekly and check the sequence of reviews with regards to gateways of the entire development process.

4 Conclusion and future work

The main contribution of this paper is the identification and description of two potential application scenarios for multi-agent systems. The software agents described in this document, have the potential to optimize clinical processes both in terms of costs and the quality of patient care. By pro-actively providing the clinical personnel with the right information at the right time, it can support medical reasoning and planning with a reliable information background. Agents can autonomously perform routine tasks or even analyze incoming data to detect potentially critical situations in advance. At the same time, the context-sensitive provision of information can reduce staff workload and time and shorten communication paths. Other potential advantages of agents in clinical health care have already been pointed out in [6] and [2]. In the context of simultaneous engineering, multi-agent systems can be employed to overcome the lack of task-specific information by automating the distribution of document updates. Furthermore, they can assist in monitoring and coordinating timelines.

In future work, our main task will be to tackle technological barriers involved in the development of multi-agent systems. The lack of a clean-room software engineering methodology for single agents as well as their emerging behavior in a multi-agent setting is an especially important issue here [3]. Since the main task of the agents described above is the distribution and sharing of information, such a methodology should provide efficient and flexible means of dealing with and translating information structures, i.e. ontologies. Furthermore, since the complexity of the clinical and engineering processes demands for frequent tests of the executing system, support for rapid prototyping and respective development tools is needed. We are currently upgrading the software engineering method for “single-agent” knowledge-based systems described in [4] for the development of multi-agent systems. The main idea here is to represent ontologies in the object-oriented modeling language UML and to map these models to structure-preserving Java classes, in support of round-trip engineering.

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