EMIKA – Real-Time Controlled Mobile Information Systems in Health Care Applications

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Abstract: This paper presents an approach to control and management of real-time hospital patient logistics by decentralized coordination in a time-critical application environment. Responsible for coordination are software agents implemented on mobile, spontaneously network end-user devices like PDAs or RFID chips. The coordination is achieved by real-time bilateral negotiation, location awareness and exception handling. The application scenario of the EMIKA project is the patient logistics of the University Hospital Freiburg in the areas of transport service and radiology.

Keywords: Software Agents, Real-time Coordination, Patient Logistics, Ubiquitous Computing, Location-based Services

1 Coordination Challenges in Patient Logistics

Without hospital information systems, the enormous amount of data needed for patient treatment in a hospital would be impossible to manage. They are essential for the automated processing of accumulated data and to manage patient care procedures. Efficient and timely information is of paramount importance for keeping workflows and processes running. In patient logistics, information systems are mostly used for scheduling appointments and resource allocation, and for path optimization. To achieve this, different participants such as wards, central services (transport service) and diagnostic services (radiology) simultaneously access and modify the given databases.

The main problem of the information system is the reaction to immediate changes which cannot be anticipated, e.g. emergencies, delays and sudden cancellations, and the timely forwarding of changed information [Sch90]. The duration of surgery or the occurrence of an emergency may be statistically approached, but cannot be planned in each individual case. Every concrete schedule or transportation path has to be acknowledged as preliminary and subject to change, from the time of its generation until the finish of its execution.

The high dynamics of the environment poses a strong problem for existing information systems, which are based on analytical improvement of business performance figures, such as minimization of lead times, idle times or capital commitment [Blo97] for controlling logistics. The imponderability of the environment limits the applicability of the analytical solutions. This is of high economic importance, as most patients' treatment paths contain costly diagnostic or treatment procedures. Radiology is a principal example. Using magnetic resonance tomography incurs high costs, so that idle times or outages directly affect the revenues of the hospital – especially so, when profits are given as is the case with diagnostic related groups (DRG).

This discrepancy between application requirements and technical capabilities results in lacking information feedback and frequent postponement of resource allocations and leads to

1. discontentment among patients and discrepancies in their treatment schedule,
2. expensive idle times of resources,
3. high work loads for staff,
4. non-planning of transport services and
5. an increased and costly duration of patients' stay on the hospital wards.

As a reaction to this situation, the human participants in the patient logistics of the university hospital in Freiburg coordinate using telephones, beepers and human decision making, but not the available IT-supported scheduling and resource allocation systems. This shows that the goal of providing IT support to real time logistics has more to do with speed of reaction and less allocation optimality, focusing on performance figures such as fault tolerance and reliability. The fast forwarding of information is directly correlated with anticipation of erroneous resource allocation and timely re-planning, which in turn leads to an enhancement of economic performance without direct optimization.

2 Real-time Coordination of Mobile Resources

However, a solution approach for an information system that supports real-time coordination of distributed, mobile hospital resources is not science-fiction. A *combination of today's existing technologies* such as software agents, mobile user devices, multi-agent systems coordination, databases, ubiquitous computing technologies and autonomic computing is sufficient to construct an information system that can provide

1. real time comparison between the actual and required state of the application environment and
2. spontaneous networking of the technical resources using automated reconfiguration without the necessity of manual intervention.

The key component is the deployment of locatable, interactive Personal Digital Assistant (PDA) to connect human participants to the information network; physical resources are connected by means of locatable Radio Frequency Identification (RFID)-Chips. In addition, each device is tied to the information system via an individual autonomous software agent.

2.1 The Technical Concept

With the availability of smallest mobile, wireless and spontaneous networkable IT devices, it is technically possible to access information systems from everywhere and at all times. The information itself is stored on devices in continuously reconfiguring networks, which may eventually lead to a completely decentralized network model without the need for a centralized controller. These hardware-driven visions of networking have yet no conceptual equivalent in the software domain.

In 2001, the Japanese electronics company Hitachi introduced a very small Radio Frequency Identification (RFID)-Chip [Hit01]. The so-called "myu"-hip has a form factor of 2 by 2 millimeters and a 128-bit ROM that can be read from a 20 centimeter distance. This RFID chip identifies a passive resource (e.g. a medical device, a hospital bed, a patient document, or a test tube) and permits access location and movement of a mobile resource. Because of their small size, these chips can be sewn into textile material, glued on or laminated under surfaces. The physical objects can be represented in the information system by a so-called shadow object. The shadow object holds data and methods which can be attached to the device, but not physically stored. Most concepts have this shadow object as passive or reactive, but in principle a software agent is also applicable.

Application scenarios for connecting spontaneous networked mobile IT devices and software agents are rare. The projects Impulse [YMK00] and DealFinder [CLL00] process the location information of a PDA so that upon entering a physical retailer store, the PDA-based comparison shopper agent searches for similar offers to those in the store, both in the Internet and in closer physical destinations, and displays the results to the user.

A similar realization of a PDA-based software agent with location-aware services in a hospital environment is the topic of this article. Software agents on a PDA have the possibility to interact with the user, e.g. to prompt an ambulant patient to walk to the treatment room. Other software agents, which are connected to a passive RFID chip, have to interact with other software agents to achieve an action. A bed (RFID chip) could prompt a transport service employee (PDA) to be pushed to another room.

2.2 Connecting the Physical and Logical Space

Patient logistics can be interpreted as a system, whose single elements act as autonomous units that independently coordinate their resources and locally manage knowledge required. Single elements could be resources such as human actors, devices, documents. By adding further resources to an initially small system, it becomes arbitrarily complex until it encompasses a complete hospital information system. For this project, a small patient logistics project is sufficient for a pars pro toto system implementation. Figure 2.2 shows the partitioning of the whole system into different layers: the logical planning space, the logical actual space, and the physical actual space.

The logical planning space allows ex ante to generate plans and to execute actions accordingly, without interference and conflicts between the goals of the system elements.

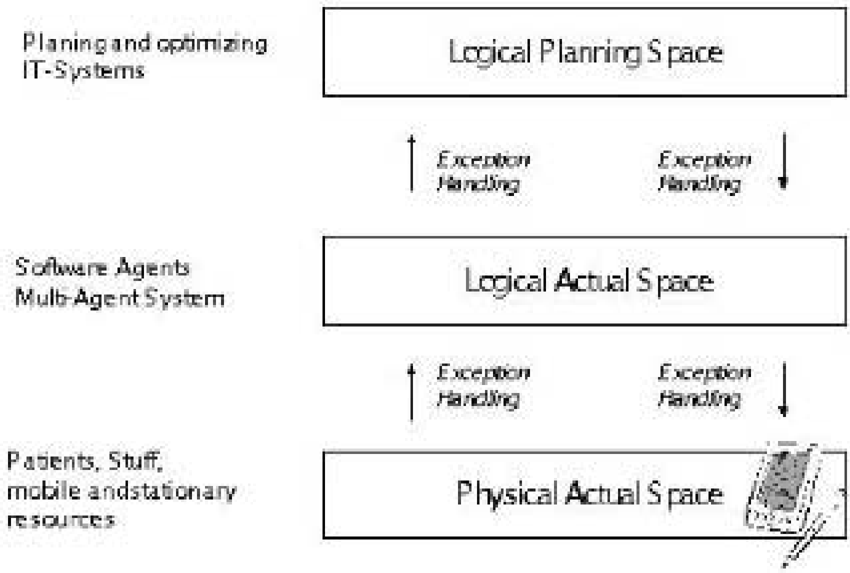

Figure 1: Relations between reality and their representation

This is a typical condition after having optimized the whole information system by using a centralized optimization planner.

The logical actual space is the domain of the software agents, which sense the actual state of the execution environment to construct their world model. This model may be incomplete and error-prone, but may be sufficient to guide the agent in its action. Conflicts between world models of different agents become transparent only when propagated to the logical planning space, or by experiencing actual resource allocation conflicts in the physical environment.

The physical planning space finally is the realm of the human participants, who follow their real goals and strategies and continuously generate new goals and strategies. They act on their own imperfect knowledge of the system state as a whole, and are conceptually regarded as self-interested utility maximizers.

In contrast to classical information systems, multi-agent systems provide the opportunity to begin with conflicting goals of the participants and generate a satisfying compromise later, by way of bilateral or multilateral automated negotiation mechanisms. Some multi-agent simulations investigate this research topic, at the interface between logical actual space and logical planning space [MG01]. The problem with these approaches is the missing link to the actual physical space. Simulations assume a timely provision of data, which in reality is hard to achieve, and employ (non-scalable) optimization functions. In reality, optimized results may already be outdated, as the physical world develops during the optimization process and external shocks (like emergencies) provide and demand new information. To our knowledge, a direct relation between logical planning space and physical actual space has not been achieved in recent research projects.

But changes in the physical actual space, which somehow define medical application environments, need to be coped with in real time in order to change logical plans. In most approaches this demands a direct and willful interaction between human user and information system both for input of the changes and acknowledgement of the resulting output. Inconsistencies between physical and logical actual space can thus not be resolved in real time - this leads to problems of acceptance and execution of action suggestions generated in the logical planning space.

Using spontaneous networking and ubiquitous computing technology [Mat01], the EMIKA project tries to fill this gap. The project builds on existing systems and tries to achieve the next research step, the automatic processing of location awareness information by tracking the devices' position in the physical space. Through interaction with the human user, and by tracking the device's position in the physical sphere, software agents can detect inconsistencies such as unavailable transport or occupied examination rooms. In this case, the resource agent will negotiate a change of plan autonomously and decentrally with other software agents and thus establish a new individual plan of action.

The logical space is thus always dynamic and characterized by an ongoing flow of renegotiation of plans. Given that plans and resources do not change, it may settle to a static optimum after a short time of utility maximizing (pareto-optimal) swaps of resource allocations. In reality, this optimum will be approximated but never reached, as constantly new resources (e.g. patients) are added and old resources are removed. In total, the system automatically reconfigures and self-organizes as a whole.

3 A Research Agenda for Mobile Patient Logistics

The application scenario is the patient logistics of the University Hospital Freiburg, where a logistic unit (transport service) and a medical unit (radiology) collaborate with the goal of optimization of the respective workflow. This scenario is particularly favorable, because all application parameters and resources are accessible, can be specified, and the number of combinations is limited.

Basic requirements for the technical implementation of the multi-agent system can be exemplified in this scenario by three common exceptions to the normal operation of the information system:

1. Emergencies: Patients show up in the radiology without prior scheduling, but have to be treated immediately using the available resources.

2. Delays: Patients with a scheduled appointment show up late and cannot be assigned to treatment in proper time. This can be countered by timely change of the order of patients, with regard to physical presence of the patient, urgency and other priority attributes. If patients have to be transported from other wards, information from the transport service is also taken into account.

3. Constraints: Patients may be scheduled for a device which must not be used. An error of the transferring doctor may, for example, assign a cardiac pacemaker patient to an MR scan. A detection of this condition leads to a re-scheduling both at the original device and the replacement.

The construction and evaluation of the technical and conceptual results of the information system us currently scheduled for four years, beginning 2002, in two distinctive and subsequent phases:

1. The first phase evaluates the functionality of the multi-agent system. The application scenario is modeled in a working software-based multi-agent system called Avalanche [Eym00]. The technical realization of the multi-agent system will base on the software agent middleware Lars 3.1 CE and be programmed in Java 1.3. The coordinative performance of the multi-agent system is evaluated using data and performance measures from hospital routine. In addition, the functionality of the hardware-software combination is tested by a prototypical implementation using PDAs and RFID chips, first to simulate workflows and later to test the technical system in a real application setting. We define interfaces to hardware devices, which will be implemented later with the external partners Living Systems AG and Hitachi, Inc. Similarly, patient information systems like PDV-FR and Prometheus (proprietary information systems of the university hospital) will be connected by so-called wrapper agents to access their information.

2. The second phase focuses on the suitability of the system in real everyday routine. Real situations of the hospital routine are replayed, to investigate the acceptance of human users and to draw consequences about suitability of the technology in general. To evaluate the coordination results of the multi-agent system, test data from the normal hospital routine will be taken and logistical performance figures like lead times, idle times and resource allocation conflicts are measured. A cost-benefit-analysis finalizes the evaluation.

4 Summary

The control and management of real-time hospital patient logistics such as patient / resource scheduling and transport path optimization is inherently faced with immediate changes which cannot be anticipated, e.g. emergencies, delays and sudden cancellations and the timely forwarding of changed information. This application problem prevents an ex ante resource coordination of the hospital units using classical centralized information systems. The application scenario of the project is the patient logistics of the University Hospital Freiburg, at the interface between transport service unit and radiology unit.

The project EMIKA exploits a unique combination of mobile devices and latest ubiquitous computing technology for closing the gap between the physical sphere and the logical sphere of the information system. The conceptual background distinguishes between the logical planning space, the logical actual space, and the physical actual space. To handle environment state exceptions efficiently, an automated matching between the physical actual space and the logical actual space is needed; existing technical solutions are not sufficiently capable to minimize this discrepancy. Software agents and multi-agent systems are software technologies which have the potential to achieve the aspired coordination without the need for some unchanging environment during the mechanism execution.

Software agents are able to detect discrepancies between planned and actual environment state, and react by negotiating with other agents in the logical space. A continuous recording of changing states in the physical actual space, the automated propagation of information to the logical actual space, and the interaction between software agents and human users can thus be achieved. Patient agents constantly monitor the consistency of their treatment schedule with information from the PDA, surrounding RFID chips and other information systems. In case of any inconsistency, the patient agent will autonomously re-plan by negotiating with other agents and thus generate a new treatment schedule.

The focus of the project is the real time coordination of an open information system using exception handling. Existing functionality of planning and optimization legacy systems in the hospital is regarded as complementary and will be included. With regard to agent technology, the project enters new ground by combining software agents, mobile devices, and ubiquitous computing in a highly dynamic application environment. In extension to existing agent-based approaches, this requires extending reactive and proactive capabilities in environment monitoring and action selection mechanisms.

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