Agent-Based Patient Scheduling

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INTRODUCTION

Agent-oriented software engineering has, by many researchers, been dubbed the new paradigm in software development, and from its original concepts in the early '80s, agents and agent systems are now active research areas in computer science.

This evolution offers a promising approach to the development of patient scheduling systems. Coordinating and processing a vast amount of complex variables, such a system should be designed to stock and schedule a wide range of resources based on the patients' health condition and availability, drawing on the advantageous data control and optimization abilities of agent technologies.

This article presents the design of a working agent-based patient scheduling system prototype.

BACKGROUND

Agent Systems Definitions

A software agent is an autonomous entity capable of performing actions and interactions typically based on notions of beliefs and goals. In addition to autonomy and pro-activeness (Wooldrige & Ciancarini, 2001), typical characteristics of agents are anthropomorphism, situatedness, and social ability.

Agent systems can consist of just one such agent or a collection of agents performing different tasks based on individual or common goals. Due to the individualistic characteristics described above, an agent system can collectively draw on further advantages, including mobility, dynamic sizing, and complex cooperation through negotiation.

Historical Context

The term agent can be traced back to the *Actor Model* first presented by Hewitt, Bishop and Steiger (1973). This early concept simply defined agents as entities with a memory address and computational behavior to help solve common tasks.

In the late '80s, the Belief-Desire-Intention (*BDI*) model was proposed (Bratman, Israel, & Pollack, 1988). The model represented a novel approach of giving human properties to digital agents. Through available information about the environment (beliefs), the agents are given a set of certain possible actions (desires) which are activated based on agent goals (intentions).

With sophisticated communication, agents can interact to cooperatively achieve global tasks and goals. But this coordination needs more than sufficient shared semantics. It also requires planning and scheduling techniques to govern the order and partition of tasks. Roughly, there are two general frameworks developed over the last decades to deal with these challenges; namely, the partial global planning (PGP) algorithms, and the joint intentions framework.

PGP (Durfee & Lesser, 1991) was an early attempt at planning in a distributed dynamic environment. By sharing and communicating intentions globally, the framework allowed agents to make optimal decisions locally.

Joint intentions present another approach in coordinating and planning node actions. Instead of passively collecting information to decide on optimal actions, the joint intentions frameworks is mainly focused on reaching common goals through agreement (Jennings, Sycara, & Wooldridge, 1998). The model is that of a team's intention, rather than the individual agent's goals. As the main focus of communication in these frameworks is reaching agreements, a natural consequence is *negotiation*.

Almost all negotiation in agent systems is based on some notion of auction (e.g., Luck, McBurney, Shehory, & Willmott, 2004). The bids used in auctions are often based on game theory mechanics and utility functions. Basically, game theory is the study of decisions in environments where several players interact (Vlassis, 2003). Game theory frameworks include the Nash Equilibrium solution concept (Nash, 1950) and Operations Research (Phillips, Ravindran, & Solberg, 1976), amongst others.

Application to Patient Scheduling Systems

Decision support systems and patient scheduling systems in particular, have become an increasingly important factor in many hospitals and medical institutions (Manansang & Helm, 1996). The primary goal of patient scheduling systems is to treat as many patients as possible in the shortest possible time (Bartelt, Lamersdorf, Paulussen, & Heinzl, 2002).

The examination and treatment process for patients involves a high degree of uncertainty regarding time spans and the resulting diagnosis, thus patient scheduling systems have been deemed complex (ibid.). Modern patient scheduling system design focuses on patients, rather than specific tasks or resources (Guo et al., 2004).

Hence, patient scheduling systems exhibits many of the same characteristics as those recognized in the agents and agent systems literature. Characteristics like entity-focused design, and high complexity and abstraction levels are well-founded identifiers in agent-oriented literature

Some earlier proposals exist—most noteworthy, the MedPage project (e.g., Bartelt, Wagner, & West, 2002), which is an ongoing attempt to introduce agent planning and scheduling systems at German hospitals.

AGENT SCHEDULING SYSTEM DESIGN

Following the theories presented, this article proposes a patient scheduling technique founded on software agents. Using well-established optimization theories from various fields of science, including optimal decision processing and game theory, this section will present an agent system labeled *AgentMedic* to effectively schedule patients in a medical institution.

The following four subsections will describe this system in detail. First, we define the three distinct agent types used in the system, focusing on their tasks and goals. Second, the communication and utility data flow between these agents are introduced. The third subsection defines the optimal decision functions used to determine the relevant value of patients and their position in the treatment cycle. And lastly, the optimization and scheduling processes are presented.

Agent Specifications

When choosing the types of agents needed in such a system, it is convenient to remember the typical agent characteristics presented earlier in this article. The design should allow for the agents to make use of their anthropomorphic and pro-active nature, so as to represent a live entity in the best possible way (Foner, 1993). Furthermore, autonomous entities requiring both social and flexible behavior must, in particular, be considered for agent abstraction (Wooldridge & Ciancarini, 2001).

This in mind, *AgentMedic* contains three distinct types of agents, each representing different roles in the context of a treatment process and the actions performed in a medical institution:

- A patient agent is responsible for coordinating the full examination and treatment process of the patient it is representing. The agent must, at all times, keep track of the progress of the patient, his/her health condition, and the management of upcoming examination or treatment tasks.
  - **Goals:** *Get examined/treated as fast as possible*
  - **Possible actions:** *Apply for appointment*
- A personnel agent represents a member of the hospital staff. Its tasks involve keeping track of the personnel competence as well as availability. Further, a personnel agent must use these properties to optimize and coordinate examination and treatment tasks with the patient agents.
  - **Goals:** *Treat/examine patients as fast as possible*
  - **Possible actions:** *Grant/deny appointment, examine/treat patients.*