Multi-Agent Strategy Synthesis in Smart Meeting Environments

René Leistikow

Abstract. A significant challenge of Ambient Intelligence (AmI) systems and applications, such as smart meeting environments, is how to assist the user unobtrusively by using ubiquitous information technologies and computing capabilities. Furthermore, the user should be able to integrate his personal mobile devices into the existing device ensemble of the environment to create a coherent ad-hoc ensemble. Hence, these systems require inter alia a dynamic strategy synthesis that fulfills inferred user's intention and integrates components seamlessly. Multi-Agent systems support such kind of dynamic system behavior, so that we assume that it is a suitable paradigm to model strategy synthesis in these environments.

In spite of several solutions for different planning problems in smart meeting environments, a concrete domain specification and a combination of these solutions are still unavailable. This doctoral paper describes the current research and explains how the author's PhD topic fits into this research area.

Keywords: strategy synthesis, planning domain, smart meeting environments, multi-agent system.

1 Introduction

> "The real power of the concept comes not from any one of these devices - it emerges from the interaction of all of them." [19]

Problem. There exists numerous proposals for addressing planning and device cooperation in smart meeting environments, but, to the best of our knowledge, a concrete planning domain specification is still unavailable. Today, there is no unified, comprehensive catalogue defining the set of planning problems that have to be considered in smart environments. Therefore, there is only little knowledge on how

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Fig. 1 Goal-based user assistance

different subproblems in smart environment control interact and how they can be captured within a unified modeling approach. However, without a unified model it is not possible to identify, let alone to resolve, interactions and conflicts between different subproblems. In addition, specific algorithmic strategies have proven to be effective in solving specific device cooperation problems in smart environments. However, it is not very well understood, how to combine these different strategies (e.g., causal planning on the one hand, resource optimization on the other), within a unified algorithmic framework.

2 Background

Goal-based User Interaction. In our group, we pursue a goal-based interaction approach (cp. Figure 1) instead of a function-oriented approach to realize Mark Weiser's vision of an unobtrusive user assistance in a ubiquitous computing environment [19]. The reason for this choice is that when people are using a technical infrastructure they have goals they want to achieve. Thus, they do not want to think about concrete device functions [10].

In the goal-based interaction model, the intention analysis initially tries to infer the user's goals from perceived (sensor) data (e.g., via speech recognition, user's position) using, typically, artificial intelligence approaches like dynamic Bayesian networks [9]. Accordingly, the inferred user's goals have to be transformed / decomposed into (achievable) goals of the environment. This process is called *goal refinement*[1]. Then, the strategy synthesis performs means-end reasoning by using goals of the environment as well as domain (e.g., device descriptions) and perceived world knowledge (e.g., temperature or luminosity). The data sets are, typically, encoded in PDDL [8], using STRIPS operators [6] with preconditions and effects for each device function. The solution of this planning process is an action sequence, which can be executed in the last step by instructing devices of the ensemble. In this paper, we focus on the strategy synthesis and action sequence generation in smart meeting environments.

SmartLab. A smart meeting environment, called Smart Appliance Lab (SmartLab), serves as an experimental infrastructure for our research (cp. Figure 2). This room is equipped with sensing devices, such as luminosity sensors, real-time location systems (active badge system and sensitive floor tiles), motion sensors and cameras; and actuators, such as (steerable) projectors, motor blinds and motor screens. In addition, devices are connected and controlled via the European Installation Bus

[1] Please notice that this process is not explicitly shown in Figure 1.

Fig. 2 Unversity of Rostock's Smart Appliance Lab (SmartLab)

(EIB) or KNX respectively[2]. To simplify the access, devices and their capabilities are encapsulated in Java objects. Moreover, these objects can be published either via network or via a specialized tuple space middleware [1].

3 Planning Domain

In this section, we identify a selection of the numerous different planning issues in smart meeting environments to gain a more detailed understanding of this domain.

Temperature and Luminosity Control. First, it might be desirable for the smart meeting environment to provide a pleasant room atmosphere (e.g., adjust lighting conditions, regulate heating system), which needs to be adjusted to the individual requirements of users. [3, 10]

Recording Meetings. For documentation, archiving and indexing of meeting results, it could be helpful to record the meeting using video cameras and microphones. [2, 14]

Distributed Meeting. A distributed meeting involves people in smart meeting room as well as other places, possibly in different countries, with access to different devices. [13]

[2] `http://www.knx.org/`

Display Mapping Problem (DMP). "So called Multi-Display Environments [e.g., SmartLab] support collaborative problem solving and teamwork by providing multiple display surfaces for presenting information. [...] One difficult task here is the Display Mapping problem - that is, deciding which information to present on what display in order to optimally satisfy the users' needs for information." [10]

Unfortunately, the DMP belongs to the class of Quadratic Assignment Problems, which have a NP-hard computational complexity.

4 Planning Algorithms

In this section we present two exemplary strategy synthesis approaches which were developed by our colleagues and are aimed to solve the DMP as one example, among others, of a sophisticated planning problem in a smart meeting environment. Therefore, we classify these techniques into two paradigms of distributed planning, introduced by Durfee in [5].

Centralized Planning for Distributed Plans. The first paradigm describes a planning system which develops a plan for a group of agents in a centralized manner. The central instance gathers world and domain knowledge, plans and distributes parts of the plan to the agents. Additionally, it is responsible for a synchronized execution of the device actions.

In [12], Marquardt et. al. pursued a centralized classical AI planning approach. They implemented a central component called *Composer*, which consists of three main functional units. For gathering information (e.g., user's intentions, world state, device descriptions) a *domain assembler* is used. In addition, it is able to create a planning problem by using the gathered data sets. The *plan selection and monitoring* unit wraps and controls different general-purpose AI planners (e.g., LPG, UCPOP or SGP). This unit sends the planning problem to the controlled planners, which try to solve a planning problem in a simultaneous manner. The *Composer* selects the solution of the fastest planner, validates the plan using the *plan validation* unit and distributes the parts of the plan to device-controlling agents.

Distributed Planning for Distributed Plans. The second paradigm describes how a group of agents can cooperate with each other to form individual plans, while dynamically coordinating their activities along the way. In this case the agents may be *selfish* which means that each agent wants to maximize its own utility value instead of maximizing the social welfare utility. Thus, it is possible that coordination problems arise (e.g., resource conflicts) and agents may need to negotiate to solve these conflict situations. It should be noted that this is the most sophisticated, but also the most flexible and robust, paradigm.

In [16, 17], Plociennik et. al. suggested a decentralized extension of Pattie Maes' action selection algorithm [11] for the use in smart ad-hoc environments. In the original algorithm an autonomous agent consists of a set of *competence modules*. The relationship between the *competence modules*, or, to be more precise, the relationship between the preconditions and effects of the *competence modules* can be expressed by several types of links (e.g., successor, predecessor and conflicter links). Linked *competence modules* are able to activate and / or to inhibit each other by exchanging energy via different links. Therefore, the action selection is an emergent property of this network of *competence modules* which means that the *competence module* with the highest amount of energy will be executed.

Nonetheless, it should be noted that there are other methods which deal with planning problems in smart environments. In the majority of cases, these approaches are based either on condition-based rule systems (e.g., Microsoft's EasyLiving Project [3]) or plan recognition methods (e.g., Intelligent Classroom Project [7]). A further detailed description would go beyond the scope of this paper.

5 Main Issues

Below, the main open issues which have to be resolved according to reach the overall goal of an multi-agent unified algorithmic framework for the strategy synthesis in smart meeting environments are mentioned[3].

1. **Definition of a Domain Specification.** As mentioned above, a concrete planning domain specification for smart meeting environments is still unavailable. However, such a description is essential, for example, for the goal refinement process (see section 1) and for a better understanding of the application domain "smart meeting environment". In section 3, we identify four different planning issues in smart meeting environments.
2. **Identification of Planning Subproblems.** With a concrete domain specification, we assume that it is possible to identify independent subproblems of the planning domain, based on the assumption that it is easier to solve many small problems than one big problem. The temperature, for example, could be controlled independently from lighting conditions.
3. **Selection of Planning Algorithms.** The division of the planning domain allows to choose suitable algorithms and heuristics for each individual subproblem. That requires an extensive evaluation of suitable algorithms for each subproblem. For instance, we expect that the usage of (lightweight) reactive behaving agents instead of a (heavyweight) deliberative planning process should be sufficient enough to solve several problems (e.g., adjusting lighting conditions). For instance, the DMP could be solved with one of the algorithms mentioned above (see section 4).
4. **Finding Optimal Solutions for the Planning Problems.** Moreover, it is possibly necessary to define metrics for planning problems to decide which plan is the most appropriate one in a given situation or, to be more precise, leads to the highest utility value for the ensemble in terms of optimal plan generation. It should be noticed that users also accept suboptimal solutions in some situations [15].

[3] These issues are preliminary and could be changed in the running research process.

5. **Dealing with Conflicting User Goals.** In [4], Cook et. al. identified the problem of conflicting user goals. To deal with this problem, we want to create a hierarchical model which is able to inhibit action executions by prioritization of subplans and their related actions to resolve the conflicts.

In addition to the main issues mentioned above, other problems arise in the strategy synthesis' deployment process itself. For example, since we want a distributed planning and execution process (based on a multi-agent system), we have to take the communication efforts for negotiation into account. More detailed descriptions of these issues can be found in [18].

6 Conclusion and Future Work

In this doctoral paper we described a project that aims to optimize existing strategy synthesis methods and algorithms in dynamic ad-hoc environments particularly smart meeting environments. Therefore, the primary goal is the creation of a multi-agent unified architecture for strategy synthesis in smart meeting environments, which is able to identify and to solve planning problems using user intentions, domain and world knowledge. In this process, planning problems will be decomposed into subproblems. Then, the latters will be handed over to specialized and optimized planning algorithms, which generate action sequences for the ensemble.

With respect to the early state of the research, only the idea for further investigation on this topic is defined.

Based on predefined possible intentions of users, we now start to decompose these intentions into achievable goals of the environment to gain a precise understanding of the described application domain, to give a formal definition of the planning domain and to derive subproblems.

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