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Evaluating social choice techniques into intelligent environments by agent based social simulation

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ABSTRACT

The primary hypothesis stated by this paper is that the use of *social choice theory* in *Ambient Intelligence* systems can improve significantly users' satisfaction when accessing shared resources. A research methodology based on *agent based social simulations* is employed to support this hypothesis and to evaluate these benefits. The result is a sixfold contribution summarized as follows. Firstly, several considerable differences between this application case and the most prominent social choice application, political elections, have been found and described. Secondly, given these differences, a number of metrics to evaluate different voting systems in this scope have been proposed and formalized. Thirdly, given the presented application and the metrics proposed, the performance of a number of well known electoral systems is compared. Fourthly, as a result of the performance study, a novel voting algorithm capable of obtaining the best balance between the metrics reviewed is introduced. Fifthly, to improve the social welfare in the experiments, the voting methods are combined with cluster analysis techniques. Finally, the article is complemented by a free and open-source tool, *VoteSim*, which ensures not only the reproducibility of the experimental results presented, but also allows the interested reader to adapt the case study presented to different environments.

1. Introduction

Ambient Intelligence (AmI) focuses on adapting to people's needs and particular situations. This is possible by incorporating omnipresent computing elements that communicate ubiquitously among themselves [61]. The interaction between human beings and these computing elements allows AmI systems to gather context-information in a dynamic and distributed way. This information is used to offer services that support daily user tasks in a smooth and adaptive way. Therefore, AmI systems need to be aware of users' preferences, intentions, and needs [19] to offer different services whose main goal is to augment their quality of life.

Some examples of applications of the AmI paradigm introduced above are: designing office spaces that smoothly move information between displays, walls, and tables; and, learning to customize lighting and temperature based on learned resident preferences [19]. These services raise an important question: what happen when resources are shared and there are conflicts between users' preferences? In the scope of the research projects THOFU [5] (Technologies for the future of hotels) and CALISTA [1] (Agent Technologies and Engineering Services Diagnostics and Configuration of Home Network using

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a Mobile Phone), the authors have observed that there are plenty of scenarios where AmI systems not only have to offer a good service considering users' preferences, but also to make a decision in an attempt to maximize the users' welfare when they access shared services. For example, an intelligent hotel may offer a number of configurable and shareable services: screening rooms, decoration based on dynamic decorative panels, dance clubs, heated swimming pools, etcetera. In these cases, AmI systems have to decide how to configure these services (in the given examples: the projected film, the decoration, the music and the pool temperature). And this decision involves trying to make hotel customers as happy as possible while avoiding "resource starvation" (which, in this context, means that some customers' preferences are constantly denied in favor of the common good). As a result, AmI services have to reach consensus trying to maximize users' satisfaction.

Although this issue of accessing shared resources has not been explored in the AmI specialized literature, fortunately, *agreement technologies* (ATs) [34] have studied it in depth. ATs deal with technologies for practical application of knowledge in order to reach agreements automatically. ATs have covered a large variety of negotiation aspects such as: multi-issue negotiations, concurrent negotiations, strategy-proof mechanisms, argumentation, auctions, voting, etcetera [33]. In this scope, the use of *social choice* theory, which is concerned with the evaluation of alternative methods of collective decision-making [10], appears as a straightforward solution because its primary goal is to make a group decision.

However, the proposed solution to the problem addressed in this paper an introduced above, the social choice theory, has mainly focused on theoretical works which deal with political elections [47]. Therefore, there are a number of dilemmas to be solved in this scope: what are the benefits of using a voting system in an intelligent environment?; what are the most suitable voting systems?; and, what differences does this case present when compared to political elections? Since "there is no one silver bullet", AmI developers have to choose several of these agreement technologies to be evaluated in the specific AmI system. In this paper, the use of *Agent Based Social Simulation* (ABSS) is proposed to solve the aforementioned dilemmas.

ABSS, proposed to solve a number of dilemmas in the novel application of social choice theory for AmI systems, has become one of the most popular technologies to model and study complex adaptive systems. For example, ABSS has already been employed to study users in AmI systems [28,50]. ABSS combines computer simulation and social science by using a simple version of the agent metaphor to specify single components and interactions among them. This paper follows Gilbert and Troitzsch's [30] methodology to study systems by ABSS. This methodology involves: (1) studying the target system, (2) modeling it, (3) implementing a simulation, and (4) studying the results after executing the simulation. This methodology is interesting in this context for two main reasons. Firstly, it pays the necessary attention to the model building, i.e. the implementation of the model. Other widely used methodologies in social simulation omit this step, such as the one proposed by Fishwick [24,25]. Secondly, it is the most popular methodology for developing social simulations [21]: Gilbert and Troitzsch's book [30] has been cited over 1900 times and it is the obligatory reference in the ABSS field.

The main contribution of this paper is the use of ABSS to support the hypothesis that the social choice theory application in AmI systems can improve considerably users' satisfaction when accessing shared resources. This involves studying the differences between this application case and the most prominent social choice application, political elections. One of the main and more significant differences found is that, since there can be several services of the same type in the environment, the voter can choose the group to vote in. This allows the AmI system to use *machine learning techniques* [31] to suggest the best group in order to maximize the global satisfaction. Besides, different metrics are proposed to evaluate a number of voting systems in the AmI case such as: accumulated satisfaction, number of users with wanted configurations, or the longest wait to get a wanted configuration. These metrics are employed to study the suitability of well known voting methods such as: plurality voting, Borda voting, range voting, approval voting, and cumulative voting. Additionally, a novel voting algorithm called *exchange of weights voting* is presented to maximize the metrics reviewed. The experimental results are given in the scope of an intelligent hotel where users can share TV screens in the hall. Finally, a free and open-source tool called *VoteSim* is given to guarantee the reproducibility of these results and to allow developers to evaluate social choice techniques for different environments.

Note that the central contribution is not defining new social choice techniques but considering them in the scope of AmI systems which, among others, requires defining a novel generic agreement service for shared resources (see Section 3) and modeling it with ABSS techniques (see Section 4). Note also that although the only innovative voting system introduced in this paper is the *exchange of weights voting* (explained in Section 6.1), the remaining voting systems (defined in Section 4.2.1) have been reconsidered under a common agreement design pattern, formalized using this pattern, and implemented in a free and open-source tool.

The paper is organized following the Gilbert and Troitzsch's methodology introduced above. After revising the background in Sections 2, 3 studies a general agreement service for AmI environments, Section 4 proposes a model to simulate this target, Section 5 deals with its implementation by VoteSim, and Section 6 presents the experiments conducted with the simulation and the results obtained. The paper finishes with the conclusions and future works in Section 7.

2. Background

This paper proposes the use of agreement technologies to cover an open problem in AmI and, more specifically, the use of social choice. Additionally, the use of simulations is proposed as a method to decide the specific social choice algorithm to be used and how to optimize the global satisfaction before deploying the final systems. Therefore, this background consists of three main blocks: (1) an introduction to agreement patterns; (2) related works in social choice; and, (3) simulation platforms conceived to evaluate applications in AmI environments. It is important to note that, since both the agreement technologies and AmI systems are usually implemented by *multi-agent systems*, most related works fall into this category.