Shared Mental Models for Decision Support Systems and Their Users

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Abstract. Decision support systems (DSSs) aim to assist people in their decision making process. We argue that a shared mental model between the human user and the DSS enables and enhances their collaboration. This paper presents an approach based on shared mental models, for analysing user-DSS cooperation, which results a set of concepts that a shared mental model of the user and the NSS should contain. This analysis also indicates the various reasons that discrepancies between the individual mental models may arise. The results of this analysis provide a basis for improving the sharedness of the mental models of the user and the DSS, and thereby, improving their cooperation. We illustrate our approach with an example: negotiation support systems.

1 Introduction

Decision makers often seek various forms of external information support to aid their decision making process [6], in order to aid their cognitive deficiencies in judgement and decision making. This had led to the development of interactive computer-based systems that aid users in judgement and choice activities: decision support systems (DSS) [5].

A DSS and its user can be regarded as a team, which has the task of making a decision. They form a specific kind of team, in which each has their own, complementary capabilities. It is well-known from the social psychology literature that performance of human teams is positively influenced by the team members having a shared understanding or *shared mental model* (SMM) of the task and the team work involved ([11, 14]). We maintain that having an SMM is not only important in human teams, but also in human-agent teams. Discrepancies between the mental models of the DSS and the user may at best result in innocent misunderstandings, but at its worst may result in a dysfunctional cooperation. We thus argue that the SMM concept is important for DSS development.

In this paper, we present a sketch of an SMM-based analysis of the user-DSS task and interaction. We believe this analysis provides a basis for improving the shared mental model of the user and the DSS, which in turn should improve user-DSS cooperation.

We illustrate our analysis with an example: a negotiation support system (NSS). We analyze the negotiation task and the interaction between user and

NSS, to determine the essential components of their SMM. Furthermore, the analysis serves to determine the possible causes of discrepancies between mental models, for example, the constructive nature of preferences and the bounded rationality of humans. Future work will address how this analysis can be used to determine how the SMM, and thus cooperation, can be improved.

This paper is organized as follows: Sect. 2 presents an introduction to shared mental models and an outline of our SMM-based analysis method. Sect. 3 presents the NSS example, in which we illustrate how our SMM-based analysis can be applied to negotiation. Finally, we discuss future work in Sect. 4.

2 Shared Mental Models in User-DSS Cooperation

2.1 Shared Mental Models

Mental models have received a lot of attention in literature regarding team performance. Several studies have shown a positive relation between team performance and similarity between mental models of team members (e.g., [2, 11, 14]). That is, it is important for team performance that team members have a shared understanding of the team and the task that is to be performed, i.e., that team members have a SMM. The concept of SMM is defined in [3] as:

> knowledge structures held by members of a team that enable them to form accurate explanations and expectations for the task, and, in turn, coordinate their actions and adapt their behavior to demands of the task and other team members.

SMMs thus help *describe, explain and predict the behavior of the team*, which allows team members to coordinate and adapt to changes.

We maintain that SMM theory, as developed in social psychology, can be used as inspiration for the development of techniques for improving teamwork in human-agent teams.

We emphasize that not all knowledge in the mental models needs to be shared. This is especially true for user-DSS teams, in which each team member has complementary skills, and correspondingly, a distinct role. Therefore, the first step in our approach is to determine what knowledge is complementary and what should be shared. Based on this, a *desired SMM* can be defined. The actual SMM consists of the knowledge actually shared (similar) between the two mental models. The desired SMM consists of the knowledge that ideally should be present in the SMM. In this desired SMM, we want the knowledge not only to be similar but accurate.

We consider a *discrepancy* between mental models to exist when one model contains information regarding an element, and the other model contains either conflicting information regarding this element, or no information regarding this element. Once a discrepancy is detected, it can be resolved by adapting (one of) the mental models. Note that discrepancies may also exist for elements that need not be part of the desired SMM. In this paper, we are interested in those

discrepancies that impair the desired SMM, and hence, possibly the cooperation. We will sometimes use the term 'problematic discrepancy' to emphasize that we are referring to a discrepancy regarding an element of the desired SMM.

2.2 SMM-Based Analysis of User-DSS cooperation

We argue that when a user does not understand or agree with the DSS advice, there is a discrepancy between their mental models. However, it is not always immediately clear how the discrepancy should be resolved, as there are different kinds of discrepancies. In order to reduce and resolve these possible discrepancies, we first must determine what they can be, when they arise and why. We therefore propose an SMM-based analysis of user-DSS task and teamwork. This analysis aims to gain insight into the user-DSS cooperation and how it may be improved. The analysis consists of two steps:

1. Analysis of the user-DSS task, interaction and their different roles. This allows us to determine what should knowledge is complementary and what should be part of the desired SMM.
2. Analysis of what humans find difficult about the task, and other possible reasons that sharedness may be difficult to achieve. This allows us to determine what areas might need extra focus when trying to achieve and maintain sharedness.

The results of this analysis can form the basis for improving the SMM of user and DSS.

3 Example: Negotiation Support Systems

In this section, we illustrate our approach of analyzing user-DSS cooperation, based on SMM, with an example: negotiation (support systems). Negotiation is an interactive decision-making process between two or more parties. The following four major stages can be discerned in integrative negotiation: private preparation, joint exploration, bidding, and closing. *Private preparation* is about information gathering and reflection before meeting the other party. In *joint exploration* the negotiating parties talk to each other, but do not place bids on the table. During *bidding*, both negotiators exchange bids according to the agreed protocol, typically a turn-taking protocol. For each incoming bid, the negotiator has to decide whether to accept, to make a counteroffer, or to stop. During the *closing* stage the outcome of the bidding stage is formalized and confirmed by both parties.

3.1 Related Work

Negotiation is a complex process that involves emotions as well as computational complexity. As a result, even experienced human negotiators can fail to achieve

efficient outcomes [15]. This has motivated the development of negotiation support systems (NSSs), which assist a human negotiator (user) in negotiation by, for example, aiding communication, enhancing negotiation skills, and reducing cognitive task load.

A number of NSSs have been or are being developed [7]. Inspire[1] is a web-based NSS with a facility for specification of preferences and assessment of offers, an internal messaging system, graphical displays of the negotiation's progress, and other capabilities. It has been used to support humans in negotiation, as well as to collect data about such negotiations for research purposes. Another example of an NSS is Athena[2]. This system has primarily been used in education. In both Inspire and Athena, users have to build content models themselves. That is, users have to provide the domain structure. The provided support does not include predefined repositories of content models, interaction support, or assistance in selecting a bidding strategy. Smartsettle[3] is a commercial NSS, which also provides bidding support.

The Pocket Negotiator project [7] strives for synergy between NSS and the human negotiator that it assists by exploiting their complementary skills. The aim of the Pocket Negotiator is to provide focus and structured support, which will increase the user's capacity for structuring and exploring the negotiation space, and to reduce the cognitive task load while doing so. The aim is not to supplant the human in negotiation, but to create an intelligent artificial partner.

In general, an NSS does not engage directly in the negotiation. Its purpose is to provide assistance during the negotiation process by structuring the process and possibly offering analysis support [7]. This can be contrasted with automated negotiating agents, which do engage directly in a significant part of negotiation, acting on behalf of their human or artificial principal [9].

Several technical challenges must be faced when developing an NSS [7]. However, in this article, we assume that an NSS has been created successfully, and has the technical means to assist with preference elicitation, domain and opponent modelling, and strategic bidding. NSSs can differ in the number of parties they support, and also the type of negotiation they support: bilateral or multilateral. For example, an NSS may be built to support both parties during a bilateral negotiation, or one party during a multilateral negotiation. We are interested in the cooperation between the NSS and one of the parties it supports, i.e., the user. In this illustrative example, we assume the user is involved in bilateral negotiation.

3.2 The Interaction Between Human Negotiator and NSS: What to Share?

In this section we analyze the interaction between user and NSS to gain insight into the task division between user and NSS. This helps determine the contents of the desired SMM that needs to be cultivated between user and NSS.

[1] `http://invite.concordia.ca/inspire/`
[2] `http://www.athenasoft.org`
[3] `http://www.smartsettle.com`

In this type of human-machine collaboration, the human weaknesses are covered by the strengths of the machine, and the weaknesses of the machine are covered by the strengths of the human. This implies that tasks should be divided between user and NSS in a way that respects their complementary capabilities:

- The user has a wealth of knowledge about the world and about interacting with other humans, but need not be a specialist in negotiation. The NSS specializes in negotiation. It makes generic negotiation knowledge available to the human.
- The NSS remains rational at all times. The user has emotions that might hinder the negotiation. However, it has been argued that emotions are sometimes needed for decision making [4]. With negotiation, it seems that both the rational NSS and the more emotional human can each provide a useful perspective on the situation, and together achieve a good outcome.
- The user can recognize emotions from voice, face, and body language, but might be at a loss how to deal with them. The NSS has generic negotiation knowledge about dealing with emotions.
- The user has limited working memory and limited computational power, i.e., bounded rationality. The NSS typically has better memory and can search much more quickly through much larger outcome spaces. Nevertheless, the NSS also can have bounded rationality, i.e., in some cases it may lack sufficient information and/or reasoning capabilities. However, for our purposes, we assume that the NSS's computational power suffices for the domains in which it is used.

Because the user and the NSS have complementary skills and tasks, they need not share all their knowledge. However, some shared information is necessary to cooperate and understand each other, hence the need for an SMM. The information and knowledge exchange between these two team members is as follows: during the preparation and exploration stage the user needs to inform the NSS about the current negotiation, e.g., the Opponent, the set of issues I, and outcome space V, and the utility functions of himself (Self) and Opponent. We assume that the user is also responsible for informing the NSS about the exchanged bids. The NSS needs this user input in order to provide assistance during the bidding stage, when strategic, tactical and bidding decisions have to be made.

For this information exchange to be successful, the user must fully understand the process of negotiation and what is expected of him/her by the NSS, and what can be expected in return. This implies that during the negotiation stages, the NSS needs to provide the user (upon request) with generic negotiation information, but also current negotiation information regarding the Opponent, I, V, and utility functions, in as far as such information is available to the NSS.

The user and the NSS thus need shared information about the current negotiation and about their capabilities and knowledge. More formally, the desired SMM of a human negotiator and an NSS contains submodels on:

- domain knowledge D

  - I: set of issues
  - $\forall i \in I$: V_i the value range of issue i
- knowledge about Self
  - u_S: the utility function of Self
  - the emotional status of Self as far as Self is aware of that state
  - the coping style of Self
  - the negotiation model of Self
  - the capabilities and types of knowledge of Self and of NSS
- knowledge about the Opponent
  - u_O: the utility function of the Opponent in as far as known to Self or NSS
  - the emotional status of the Opponent as far as perceived by Self
  - the coping style of the Opponent as far as known to Self or NSS
  - the negotiation model of the Opponent, in as far as this is known to Self or NSS
- bidding knowledge
  - bidding history: the sequence of bids that have been exchanged so far
  - the current bidding strategy for Self
  - the bidding protocol, including information about available time

3.3 The Weaknesses of the Human Negotiator

In this second part of our analysis, we discuss the problems humans have with negotiation, assuming there is no NSS support. There are two ways to categorize the problems humans have with negotiation: related to *outcome*, or related to the negotiation *process*. The outcome related pitfalls in negotiation are: leaving money on the table, settling for too little, rejecting a better offer than any other available option, and settling for terms worse than alternative options [1, 15].

The outcome related pitfalls are caused by the problems people have during the negotiation process, which are related to the following:

- *Lack of training* Humans have difficulty in structuring negotiation problems and thinking creatively about such problems. Moreover, just negotiating in practice does not alleviate these problems due to faulty feedback and self-reinforcing incompetence. Faulty feedback refers to the problem of not getting accurate, immediate, and specific feedback, which can only be solved through regular training. Self-reinforcing incompetence means not being aware of one's limitations, thus not seeing the need to improve one's skills.
- *Lack of preparation* Preparation is insufficient when it leaves the negotiator unaware of an important part of the issues, underlying interests, the preferences and/or circumstances of the parties involved, see e.g., [1, 15].
- *Structural barriers to agreement* This refers to such problems as die-hard bargainers, a bad atmosphere [12], power imbalance [13], cultural and gender differences [8], disruptive or incommunicative people, and a lack of information. The last point can be caused by insufficient preparation, but also by communication problems. See [1] for more information.

- *Mental errors* Parties commit mental errors such as the escalation error, biased perception, irrational expectations, overconfidence, and unchecked emotions. The escalation error is the continuation of a previously selected course of action beyond the point where it makes sense. Biased perception is the problem of perceiving the world with a bias in your own favour [1, 15].
- *Satisficing* Due to uncertainty of the future, the costs of acquiring information, and the limitations of their computational capacities, people have only bounded rationality, forcing them to make decisions by satisficing, not by maximization [15].

NSSs aim to relieve some of these problems. At the same time, these problems are also precisely what may make it difficult to achieve the desired SMM, and thus, for the user to understand the reasoning and advice of the NSS.

3.4 Mental Model Discrepancies

We have now identified what should ideally be in the SMM of the user and the DSS. We have also identified what may make achieving such a desired SMM difficult. Together, this provides insight into where problematic discrepancies may arise.

Section 3.2 showed that the NSS relies upon the user for most of its knowledge about the current negotiation. If the user does not provide enough input, the mental model of the NSS may be incomplete.

Section 3.3 discussed the problems humans have with negotiation. These can cause the mental model of the user to lack (accurate) information. For example, lack of training, lack of preparation and/or bounded rationality can cause the user to have incomplete knowledge of the current situation. At the same time, the NSS has generic negotiation knowledge that the user may lack, as well as superior computational abilities. The NSS's mental model can thus contain more accurate information than the user's. In such situations, the user's mental model should be adapted to that of the NSS.

One particular aspect that may lead to discrepancies is the *constructiveness* of domain and preference information. Even with proper preparation, information on the domain and preferences of Self and Opponent is often difficult to determine fully at the start of the negotiation. Humans have been found to discover this information along the way. Due to this constructiveness, the user may discover new knowledge during the negotiation that the NSS does not yet have, thus resulting in a discrepancy.

Table 1 provides an overview of some possible causes of discrepancies between mental models. For each submodel defined above, and for each team member, the table lists what may cause their mental model to lack (accurate) information. This knowledge about problematic discrepancies helps identify for what elements of the desired SMM it may be particularly difficult to achieve similarity.

Table 1. Causes for lack of (correct) information in mental models

submodel	**User mental model**	**NSS mental model**
domain $D = \langle I, V \rangle$	lack of preparation, bounded rationality, constructive domain	lack of user input, constructive domain
knowledge about Self, e.g., u_S	lack of training, lack of preparation, bounded rationality, constructive preferences	lack of user input, constructive user preferences
knowledge about Opponent, e.g,. u_O	lack of training, lack of preparation, constructive Opponent preferences, bounded rationality	lack of user input, constructive Opponent preferences
bidding knowledge	lack of training, lack of preparation, bounded rationality	lack of user input

4 Summary and Future Work

We presented an approach for improving user-DSS cooperation. This approach involves a SMM-based analysis of user-DSS task and teamwork, which provides insight into what knowledge should be shared between user and DSS, and what might make achieving such a SMM difficult. This analysis can then form the basis for improving cooperation. We illustrated our approach with an example: NSSs.

Future work first of all calls for a more precise specification of our analysis method. This requires formalizing the concepts of mental model and shared mental model for user-DSS teams. Moreover, the analysis steps should be made more concrete. This then allows us to apply our method in a more thorough manner to different DSS domains, thereby generating a description of the contents of the desired SMM in those domains.

Once a formal analysis method has been developed, we will investigate ways to achieve and maintain the desired SMM. One technology that we believe is suitable for this is *explanation.* Explanation can serve various purposes, such as improving effectiveness (helping users make good decisions), increasing the user's trust in the system and improving *transparency* of the system [16]. The latter is particularly relevant, as this facilitates detecting and resolving discrepancies between mental models of NSS and user. Transparency means explaining how the system works, thus giving the user a better understanding of the NSS's reasoning process. This allows the user to detect any discrepancies between the mental models, and subsequently to resolve these by updating the mental models where necessary. The results of our analysis can form a basis for these explanations, determining the requirements. In [10], we have made some initial steps herein, where explanation is used to resolve mental model discrepancies regarding preferences.

There are also other ways in which our analysis might be used to improve user-DSS cooperation. The results of our analysis could assist DSS design. For example, the analysis results could provide guidelines for the knowledge that needs to be stored in the DSS database(s). They could also provide guidelines for the user interface design, by indicating what type of interaction is necessary between user and DSS.

This work should be implemented and user tests should be performed to determine if our approach indeed succeeds in improving user-DSS cooperation.

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