TCM: A Trust Computation Model for collaborative decision making in Multi-agent System

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Summary

Collaborative Decision Making (CDM) is an important human activity and it has many practical applications in society, economy, management and engineering, etc. Many real world decision problems are involving uncertainty in which information may be incomplete or not available. This situation makes decision making a complex task to the experts. Various methods such as voting, ranking and negotiation exist and they share common objective of synthesizing or aggregating judgments or preferences when uncertainty exists. Existing groupware based on these models do not have tools to effectively analyze and provide support for social facets of group work. Hence there is a need to embed social issues in groupware and to analyze this system and the work of the groups which use them. Trust is one such factor which is a basic feature of social situations and plays a critical role in problem solving and group decision making. Also social trust models like recommender system, trust management for pervasive computing, trust model for decision in peer-to-peer networks are becoming invaluable part of distributed systems. In this paper we present a trust computation model for multi agent collaborative work and a social decision making algorithm capable of aggregating the decisions of individuals based on trust. This model supports a diverse problem space and a trust based social decision algorithm for a distributed environment. Our approach provides enhanced group consensus compared to voting method.

Key words:
Collaborative Decision making, Trust, Multi agent system, Bayesian Network

1. Introduction

Groups play an important role in organizations and as a model for structuring organizations, the concept of group or team is an important development. Today's worldwide market has forced many companies to decentralize their organizational structures [1] [2] [3]. As the result of the realization of the importance of groups in organizational decision making, information systems researchers have been engaged in building Group Decision Support Systems (GDSS) [2] and Computer Supported Cooperative Work (CSCW) [3]. Decision making under uncertainty is one of the important aspect in group decision making. In Collaborative Decision Making (CDM) [2], decision is not made by a single decision maker but a group of decision makers. These decision makers are often referred to as experts. Each expert may have different preferences over the choice set. Methodologies for group decision making aimed at improving its decision support capabilities, leaving the uncertainty parts of the problem for the decision maker's judgment.

In a distributed environment of an organization, experts are geographically dispersed. Under this environment, organizations are forced to use Collaborative decision making models, which provide same time different place framework for the group. Such situations commonly arise in industrial environments when a group is trying to select a vendor, a new employee or supervisor, a new project, or GIS based decisions such as natural resource planning, spatial decision making etc., from a set of possible choices. Depending on the organizational settings, group decision making methods are classified as Decision by authority, Decision by Majority or Voting and Decision by Ranking. In decision by authority, final decision is done by a single person (coordinator or facilitator). Group holds a vote on particular alternative in voting method [4]. The alternative with maximum vote is the final decision. Individuals rank each alternative and ranks are aggregated [5] [6] in ranking method. The alternate with highest total is selected as final decision.

Limitations of above methods are: decision by authority may not reflect group's decision or decision may be biased as final decision is made by single person. Voting allows majority to overwhelm minority views. Decision by ranking may result in a final decision that no one in a group fully support. According to Arrow's Impossibility Theorem [7], no group decision making method is perfect. This offers scope for research on group decision making

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methods towards better quality. Also, groupware systems based on these decision models have emphasized technological issues at the expense of social issues such as social trust, cooperation, relationship and social protocol which are integral part of any organization. To overcome above limitations, there is a need for social decision making algorithms or Collaborative decision support system which integrates social issues. Trust, empathy, belief, emotions are some of the social issues which are gaining importance in E-commerce [8], Grid computing [9], pervasive computing [10], web based resource sharing [11] etc.

Trust is a basic feature of social situations and has a critical role in industrial environment where team work and group decision making is important. Also, trust is a key factor in the efficacy of intra-group and inter-group activity. In many industries, a strategic issue in work organization is how to enhance the team effect and consensus generated by the cooperation among members. As trust plays a vital role in group decision making, to effectively support group participation in decision making, social trust based computation models and decision analysis tools must be integrated. Since trust is one of the social issue and integral part of team work, we have considered trust factor in collaborative multi agent system. Also, our work focused on trust computational model and integrating it with collaborative decision making, so that trust between agents can be effectively used for quality decision making and to improve cooperation among group members during collaboration. This cooperation through trust improves consensus in the group so that decision making results in better quality.
In our previous paper [1] we have presented an agent framework for collaborative decision making. In this paper we mainly focus on building trust model and integrating it with collaborative framework.

The next section will discuss related work. Collaborative decision making framework is presented in section 3 and problem definition in section 4. Section 5 describes Bayesian network model for trust computation. Experimental work is presented in section 6 and section 7 concludes the paper.

2. Related research

Decision making in MAS [2] [5] [21] [22] is an important task that often involves choice from a discrete set of alternatives, for the purpose of attaining a goal. Distributed collaborative decision making is gaining importance among researchers due to its wide application range such as health care, E-commerce, grid computing, pervasive computing, psychological research on team performance and team training [8] [9] [10] [11] [18] [23]. The research on collaborative decision making includes structuring group interaction, information representation and communication methodologies. Social Judgment Analysis [12], Nominal group technique and Delphi [13] are some of the formal consensus development methods.
Trust is one of the most valuable group components and is essential to the process of group influence and collaboration. Several researchers have tried to compute trust in various environments. Much of the research work on the concept of trust is for E-commerce and On-line recommendation systems. Recently pervasive computing and trust are dealt by many researchers. Approaches incorporating trust models into recommender systems are gaining momentum [8] [9] [10] [11], synthesizing recommendations based upon opinions from trusted peers. A computational trust model for analyzing correlation between trust and user similarity proposed by [14] [15], uses user profile of interest. They claim that members of a given domain and context, creates trust and friendship with people of similar profiles. There is a little effort made to restructure CSCW and distributed collaborative applications based on social interactions [16]. Trust framework presented in [16] concentrates on human computer interaction and relationship between group members. Authors have integrated risk aware decision module and trust framework for Pervasive computing devices in [17]. Thus our work focuses on trust factor in order to improve group consensus and decision making.

3. Collaborative decision Framework

Consensuses in collaborative decision making means, that all members genuinely agree that the decision is acceptable. Each expert is represented by an agent framework developed and proposed in our earlier work [1] and [21] as shown in figure 1. It contains eight components. The interface manager extracts task specific requirements and evaluates each alternate based on criteria input; team profile contains agent information such as domain. The knowledge base stores the facts about past experience of an agent; communicator provides communication facility and CDM (Collaborative Decision Making process) records all interactions using message passing system. The decision making process makes the decision. The learning component updates the information in knowledge base. The behavioral process computes trust for cooperation among team members. In this paper we have mainly focused on behavioral process and computation of trust.

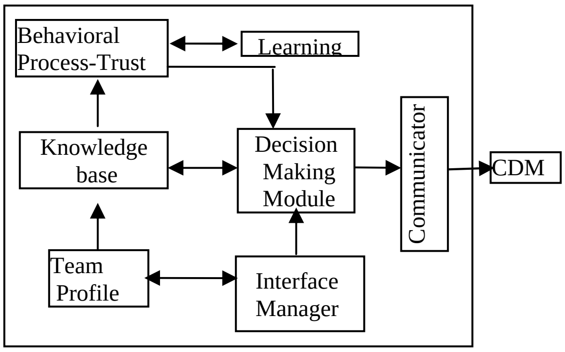

Fig. 1. Collaborative Decision Making agent Framework

4. Problem definition and assumptions made

The objective of problem is to select a single decision by the team based on trust computation. Agents are allowed to discuss among other agents and can clarify by exchange of information. The agents have domain knowledge and alternate solution for the given task is computed by them. The team has to arrive at consensus about one good alternate. We begin by outlining the salient characteristics of a particular group decision situation.

1) The problem/task has multiple alternate/ choices.
2) The team is geographically distributed.
3) The choice set is finite and known to all agents.
4) The objective of team is to arrive at consensus and select one best alternate.
5) Each expert / agent is allowed to discuss among other participants and clarify information regarding each alternate.
6) Information available may be complete / incomplete.

5. Behavioral process: Computation of trust

The definition of trust according to Gambetta [19] is " trust (or symmetrically, distrust) is a particular level of the subjective probability with which an agent assesses that another agent or group of agents will perform a particular action". Also, Josang [18] in his work defined trust as the belief that an agent has about other agent, from past experiences, knowledge about the agent's nature and/or recommendations from trusted entities/agents. Trust relationship between two agents is required to fulfill few properties. Trust is reflexive, non symmetrical and conditionally transitive and every agent trusts itself [18]. Also in real life, recommendation is one of the most commonly employed mechanisms to assist decision-making in daily situations. It helps one infer trust decisions in an unfamiliar context by providing evaluations from others [8] [9] [18] [19].

The Behavioral process in our collaborative framework computes overall trust of an agent for decision making. The overall trust of an agent is computed based on direct interactions of an agent called direct trust and recommendation from other agents, which form an indirect trust. This overall trust is used by an agent to decide whether to cooperate with other agent or not for making decision regarding alternate section.

5.1 TCM: Trust Computational Model

In our model, a decision making agent or expert tries to collect as much information as possible about the other agent in the team. This could come from a third party, past history (reputation), or by observation. A set of required or predefined factors to be known prior to making a trust decision include information about other team members (team profile), past experiences (Knowledge base), and interactions during the current task. A key factor in the trusting decision is how much knowledge one has about the trustee. This knowledge or information could be acquired through:

1. Direct or personal knowledge of the trustee.
2. Indirect knowledge available in team profile as general reputation in our model.
3. Past experiences stored in knowledge base.

Considering the above parameters, Trust in our model is computed by direct trust and indirect trust. Direct trust (DT) is formalized through social interactions such as Familiarity (F), Similarity belief (S) and past experience (E) as shown in figure 2. Indirect trust is determined by Recommendation (R) given by agents about other agents and General Reputation (GR) given in the team profile. During collaboration agents update their trust values dynamically based on the interactions carried out and discussion made regarding decisions.

The notations used for computation of different trust and its formalization are presented here.

a) Set of agents A= $\{A_1, A_2 \ldots\ldots A_n\}$, the set of all agents or experts in the group.
b) Set of decisions/alternate from which agents have to make choice, $X=\{X_1,X_2,\ldots\ldots X_N\}$
c) Set of domains D = $\{d_1, d_2\ldots\ldots d_m\}$, represents the domain of agents.
d) Set of beliefs = $\{b_1, b_2\ldots\ldots b_k\}$, for each domain.

Direct Trust (DT): It contains agent A_i's direct trust level in other agents. This is formalized through Familiarity F and Similarity belief S and Past experience E as shown in figure 2. We have considered 4 levels (L_1, L_2, L_3, L_4) and compute direct trust which is discrete and mapped on to any one level. We consider trust value range for the different levels: L_1 means *'very untrustworthy'*, L_2 means *'untrustworthy'*, L_3 means *'trustworthy'* , and L_4 means *'very trustworthy'* and mapping function is as shown in Table 1.

Table 1: Trust level and linguistic value

Level	***Linguistic values***	***Trust value***
L_1	*Very untrustworthy*	*0 to 0.24*
L_2	*Untrustworthy*	*0.25 to 0.49*
L_3	*Trustworthy*	*0.5 to 0.74*
L_4	*Very trustworthy*	*0.75 to 1*

Familiarity (F): It reflects the agent's observation through social interactions and queries. Familiarity is formalized through observation of the total number of interactions and total number of successful and satisfying interactions in a given time frame. The interactions are observed domain wise and we have considered domains d1, d2 and d3 which are application dependent. It can be extended to different set of values. The conditional probabilities of these domains determine familiarity of an agent with other agents in the team.

Similarity belief (S): This reflects the similarity of two agent's domain knowledge. $S_{ij}(d)$ refers to the similarity from agent A_i's beliefs to agent A_j's beliefs with in domain d. If two agents A_i and A_j have similar beliefs $(b_1,b_2,\ldots b_k)$ for a given domain d then similarity belief S is grouped as in Table 2 based on probability of similarity. The conditional probabilities of these values determine similarity of an agent with other agents in a team.

Table 2: Similarity belief and its range

$S_{ij}(d)$	***Value***
High	0.7 to 1
Medium	0.41 to 0.69
Low	0 to 0.4

Past experience(E): This reflects the history of social interactions such as previous direct experience in group work, email, queries on general issues, queries on domain specific issues etc. It is represented as factual knowledge in knowledge base. This fact values are mapped into category of values as "Very good", "Good" and "Poor" based on previous direct interactions.

Bayesian theory [20] is adopted for our trust computational model. According to Bayes' rule in equation 1, P[h] is the prior probability of hypotheses h; P[e] is the prior probability of evidence e and P[h/e] is the probability of h given e; p[e/h] is the probability of e given h.

$$P[h/e] = \frac{P[e/h].P[h]}{P[e]} \tag{1}$$

We represented factors considered in our work by Bayesian network and is as shown in figure 2. This network gives the trust between agents (or experts). Every agent builds the network to compute trust about every other agent. A naïve Bayesian network, to represent the trust between agents is shown in Figure 2.

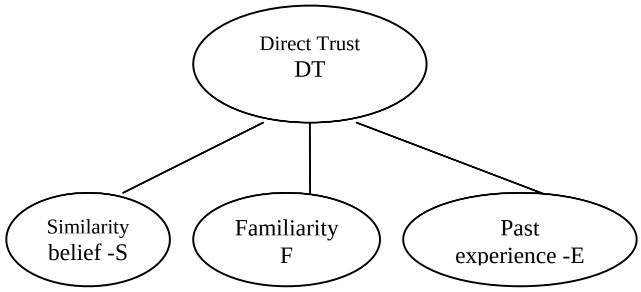

Figure 2. Variables in Bayesian network

Node S represent Similarity belief, node E denotes past experience and node F represent Familiarity. Node DT represents the direct trust level of an agent A_i about other agent A_j. Here, S represents the similarity belief of agent A_j evaluated by A_i. E represents the set of past experience or history of interactions (available from knowledge base in form of facts based on domain interaction and general interactions [1]). F is the interaction of agent Ai with agent A_j in a given domain. Every agent builds a naïve Bayesian network for other agents in a team. Each Bayesian network has a root node DT, P[DT/ S,F,E] represents the value of agent A_i's trust in the agent A_j based S, F and E and is computed by equation 2.

$$P[DT / S,F,E] = P[DT]\ P[S , DT]\ P[F , DT]\ P[E , DT] \tag{2}$$

Also given prior probabilities P[S], P[F] and P[E],

$$P[S, DT] = P[DT/S]\ P[S] \tag{3}$$

represents the probability of similarity belief given direct trust. Conditional probabilities for S are computed based on S_j in Table 2 and equation 4

$$P[S, DT] = C_b / k \tag{4}$$

where C_b is the belief count and k is the total belief in a given domain.

$$P[F, DT] = P[DT/F]\ P[F] \tag{5}$$

represent the probability of familiarity given direct trust and computed by satisfying interactions in domain d1,d2 and d3.

$$P[F, DT] = N_s / N_t \tag{6}$$

where N_s is the number of satisfying interactions when domain queries are involved and N_t is total number of interactions. Conditional probabilities for d1, d2 and d3 for F are computed based on domain interactions.

P[E,DT]=P[DT/E]P[E] (7)

represent the probability of past experience given direct trust based on different conditional probabilities.

Also, the absolute probability P[DT] is computed by

P[DT]= P[S, DT]+ P[F,DT] + P[E,DT] (8)

After each interaction during collaboration, agents update their corresponding Bayesian network values. An agent decides whether an interaction is satisfying or not based on $\mathbf{s_d}$ (degree of similarity). If $\mathbf{s_d}$ is less than threshold θ_1 then interaction is unsatisfying, otherwise it is a satisfying interaction. If an interaction is satisfying, N_s and N_t are both increased by 1. If it is not satisfying, only N_t is increased by 1 in equation 6.

Once the conditional values for parameters S, F and E are obtained, an agent computes the probabilities that the corresponding agent's Direct trust DT value in different aspects by using Bayes' rules, P[DT/ S, F, E]- the probability that the agent/expert is trustworthy in providing domain expert queries in domain d1, d2 and d3 with similar beliefs and with given past experience trust value. This value is stored in variable DT_{ij} for direct trust between agent A_i and agent A_j.

5.1.1 Recommendations

Once an agent computes Direct trust DT about other agents in the group, then an agent Ai collect recommendation R from other agents about A_j. Other agents in team uses General Reputation GR from team profile to compute Recommendation R about agent A_j and Direct Trust DT send it to agent A_i. Agent A_i collects Recommendation from all other team members and stores it as R_{ij}. Using Bayes' rule, given recommendation from k distinct agents in team, the posterior probability is computed as:

$$P[GR/R] = \frac{P[GR]\prod_k P[R_k^i / GR]}{P[GR]\prod_k P[R_k^i / GR] + P[\overline{GR}]\prod_k P[R_k^i / \overline{GR}]} \quad (9)$$

Where i ∈ {0 1} and $P[R_k^i / GR]$ is the probability that agent k confirm General Reputation GR, given GR is true. The direct trust value computed by an agent is mapped to 0 or 1, to represents recommendation weight. Using DT trust levels as weights of recommendation and this probability is equal to trust level. $P[R_k^0 / GR]$ is the probability that agent k does not confirm GR, given GR is true and $P[R_k^0 / GR]$ =1- $P[R_k^1 / GR]$. This is equivalent to an agent A_i do not recommend agent A_j even though the GR is true. After computing the posterior probability for recommendation, each agent A_i stores R_{ij} as recommendation value for agent A_j.

5.1.2 Overall Trust and Cooperation

The direct trust and recommendation of other agents are combined to compute overall trust T_{ij} of agent A_i about agent A_j as in equation 10 and w_1 and w_2 are the importance assigned by agent Ai to weigh the direct trust and recommendations as in equation (10)

$$T_{ij} = \alpha\ (w_1 DT_{ij} + w_2 R_{ij}) \quad (10)$$

where α is the normalization factor. If this value of T_{ij} is above threshold θ_2 ($T_{ij} > \theta_2$), then agent A_i cooperates with agent A_j so that decision of agent A_i and A_j are same about the alternate selection. An iterative process is repeated until all group members arrive at single decision based on overall trust. This enhances the group consensus and result in selection of best alternate.

Our experimental work presented in next section shows the advantage of trust based method compared to voting technique for alternate selection.

6. Implementation and experimental work

For our experimental work we have considered the application of new project selection in an organization. Project Selection is the process of evaluating individual projects, to choose the right project based on an analysis so that the objectives of the company will be achieved. It involves a thorough analysis including the most important financial aspect to determine the best project among all the alternatives.

As Chat forums are a powerful on-line medium for bringing together people located in different geographical locations to meet and discuss common interests and collaborate, we have implemented a chat forum in Java. Each agent is simulated with collaborative framework discussed in section 4. Also we have supported a discussion board which is implemented using threads, enable participants to post comments under particular discussion topics and exchange of messages.

Our experiments involve 5 agents. Each agent exchange trust value, recommendations after every 10 interactions with other agents. To simplify our work we have assumed equal priority for w_1 and w_2 and are set to $w_1 = w_2 = 0.5$. The prior probabilities for DT and R are uniformly set for each agent as 0.2. Total number of interactions are 800 and general reputation GR for $A_1 = 0.4$, $A_2 = 0.8$, $A_3 = 0.85$, $A_4 = 0.9$ and $A_5 = 0.6$.

6.1 Results

The team of agents is presented with a task to generate set of alternate solution from which agents have to arrive at consensus on one best alternate. Some projects have high uncertainty for example R&D cost and operating cost and agents have different preferences over these values. Agents generate different alternatives as in Table 3. Out of these five alternatives, one project is to be selected by the team.

Table 3: Different alternates generated by experts / agents

Criteria	***X1***	***X2***	***X3***	***X4***	***X5***
Equipment cost	2500	1500	2500	1750	2000
Engineering Cost	3000	2500	3000	2500	2500
Construction cost	1500	750	1100	1200	1100
Material Cost	1200	1250	1300	1300	1300
Owner's Cost	1500	1200	1200	1200	1500

We have compared voting method and our trust based decision for project selection application. In voting, agents select alternate X1, X2, X3, X4 and X5 based on majority. In our trust model, agents select alternate based on overall trust computation. Results shows voting method do not have any improvement over number of interactions whereas trust based method shows improved group consensus over number of interactions between agents as in figure 3.

The trust values computed by an agent for decision making are given in figure 4. Agent A5‘s computation of trust values reveal that consensus is achieved only after trusting behavior of an agent is above threshold (0.5). As number of interactions increase, based on recommendation values, the overall trust varies as shown in figure 4.

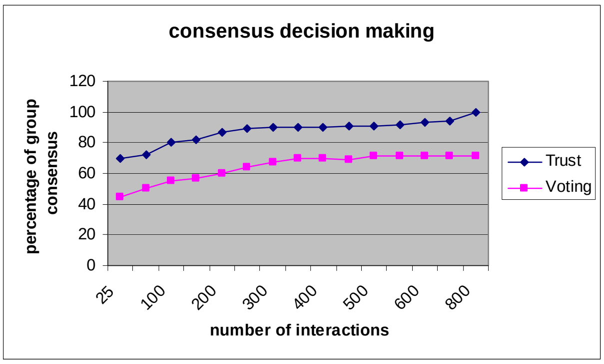

Figure 3: Comparison of voting and trust based decision making

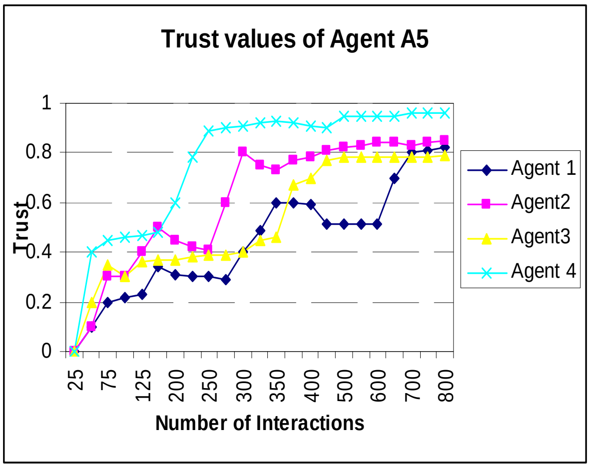

Figure 4: Trust values of an agent about team members

7. Conclusions

In this paper, we have emphasized social aspects of CSCW such as trust between group members for best alternate selection from a given set of alternate solutions. We have provided a model of trusting behavior in collaborating agent framework for representing, reasoning about group activity. This trust model allows multi agents to interact, collaborate and perform decision making. Project selection application is used in our experimental work to show trust based collaboration among a team of agents to arrive at consensus about best alternate. Also results are compared with voting method and we have shown trust based decision making provides better selection agreed by all members.

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