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Certainty, trust and evidence: Towards an integrative model of confidence in multi-agent systems

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ABSTRACT

Introducing confidence in multi-agent systems gives agents a form of control in making decisions and helps to improve the decision making process in such systems. Consequently, modeling confidence of agents is important in heterogeneous agent communities. The inability to detect an agent's confidence can be a reason for inaccurate decision. Several weaknesses have been found in current trust and confidence models in multi-agent systems. Current models propose that the trust of an agent depends on its reputation, past experience, and observations on its behavior. This paper presents another approach to agent-based confidence modeling. Initially, it integrates two confidence requirements, namely, trust and certainty. To further strengthen the model, we include evidence as an additional requirement to the model by which trust and certainty of an agent can be verified. This paper establishes bisection between trust, certainty, and evidence spaces. The modeling mechanism eliminates untrusted opinions, since such certainty level might not be valuable in all states. The proposed technique also separates the global confidence scheme from the local confidence scheme, so as to provide greater reliability for confidence detection.

1. Introduction

Cooperation among agents is very important in achieving the goals of a multi-agent system (MAS), but sustaining cooperation in uncertain environments is risky. For example, agent A might believe agent B, who is actually giving inaccurate information (Barber, Fullam, & Kim, 2003). Agent-based systems have specific peculiarities that require users to support their mechanisms. For instance, the basis of such systems on decision-making indicates that decisions are based on agents' beliefs or specific plans. Beliefs obtained from agents must have reasonable confidence level to be useful. Furthermore, collecting information from multiple sources may depend on services not under the particularity of the agents. Such situation calls for a reliable confidence model of services and information provided by other third-party systems. We propose evidence as an additional requirement to the model by which trust and certainty of an agent can be verified. However, to include evidence as another component for a confidence model, we need to know that information was collected in a reliable way, i.e., with certainty, trustworthiness, etc.

In MAS, measuring confidence is important because confidence gives a form of control in an environment. Collecting the opinions of agents, especially those agents whose trust and certainty are unknown, is risky in making a final decision. The confidence of agents cannot always be judged at face value as the factors by which they are detected are important. For example, the trust of an agent, the reputation with which an agent was evaluated based on past history, collected evidence, and the certainty affect the confidence of agents. In systems of homogenous multi-agents and independent internal structures, the ability to detect the confidence of an agent needs a rational algorithm. Ensuring the ability to check confidence factors is an important step in ensuring that opinions of agents are credible.

In this paper, we propose a new definition of confidence and we show how the factors of confidence can be detected. While other factors may be appropriate for detecting confidence value, we use evidence to detect the confidence level of agents. We aim at improving the efficiency of trust and certainty mechanisms by endowing an Evaluation Agent (*EA*) with some extra information to detect the confidence of agents. In our model, the requirements can be explained as follows: Firstly, the model must support the

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confidence metric of an agent, which utilizes trust and certainty. Such model allows one to distinguish between agents in that one agent can be recognized as more confident than others. Higher confidence level means a greater influence on the process of decision-making, while a lower confidence level means otherwise. Secondly, the evaluation agent must not assume that the opinions of other agents are enough for reaching a decision. Thus, the model must be able to collect evidences from the environment to support the opinions of agents. However, current models do not allow an agent to assess the certainty level of agents' opinions and to use the result for accurate evaluation of the opinions provided by those agents. To achieve this requirement, we have developed a model named Agent Opinion Confidence (*AgentOpCo*), which is a confidence model that detects the confidence of agents in multi-agent systems.

This paper is organized as follows: Section 2 reviews the related work in the context of this study. Section 3 describes the proposed confidence model. Section 4 builds up the mathematical model of confidence. Section 5 presents the basic *AgentOpCo* model with an example to demonstrate the model and evaluate its effectiveness. Section 6 concludes the paper.

2. Related work

2.1. Trust

Trust is the subjective probability by which an individual, A, expects that another individual, B, performs a given action on which its welfare depends (Touhid, Josang, & Xu, 2010).

The literature is rich with different approaches to trust detection in MAS. The term "trust" is used in building MAS that may encounter uncertain, incomplete, or incorrect information that had been collected from several sources (Barber et al., 2003). "An agent's trust in another can be understood as a belief that the latter's behavior will support the agent's plan. For rational agents, trust in a party should be based substantially on evidence consisting of positive and negative experiences with it" (Wang & Singh, 2007). Yu and Singh (2002) finds an inverse relationship between conflict and trust.

The degree of trust increases as the amount of information increases and the degree of trust decreases as the amount of information that conflicts with past experience increases. Huynh, Jennings, and Shadbolt (2006a) includes heuristics that merge several information sources for detecting trust. Alfarez and Hailes (2000) models the trust and reputation of agents in an interaction environment (TRAVOS). The study calculates trust depending on past interactions between agents. If there are no available experiences from agents, the model gathers reputation information from third parties. Collecting agent opinions is soliciting the reputation of an agent, which ensures its trustworthiness if they have no personal experiences based on it. They assess the confidence of the agent on the level of trust compared with another agent (certainty of trust). Teacy, Patel, Jennings, and Luck (2005) proposes a model to measure a probability of trust by modeling trust in terms of confidence such that the expected value of trust appears within an indicated error tolerance. In their model, the confidence of an agent increases with the error tolerance. Wang, Mellon, and Singh (2010) uses a reputation system for finding trust estimation, and classifies reputation systems into two types, namely, centralized and distributed.

Fullam, Muller, Sabater, Topol, Barber, Rosenschein, and Vercouter (2005) build a test bed system to test the opinions of several researchers. Each researcher has a separate agent that represents his/her strategy for solving a specific game problem. An evaluator agent then gathers the opinions of researchers to select the best opinion depending on two developed models, which are competition and experimentation. The system proposes methods depending on the social welfare, which allows researchers to define several metrics. Huynh, Jennings, and Shadbolt (2006b), Ramchurn, Sierra, Godo, and Jennings (2003), and Sabater and Sierra (2001) build their trust model by using agent confidence and reputation. An agent's reputation depends on past experience, and in case there is no past experience about an agent, their model asks other agents. Hence, measuring agent confidence depends on the experience of other agents about the specific agent.

2.2. Certainty

Certainty "is a measure of the confidence that an agent may place in the trust information", they are mentioned that measuring a certainty can filters out insufficient information even with high trust degree (Bilgin et al., 2012).

It is defined as a mathematical value that is equal to the probability of right and complete information. One of the important features of information is its indistinctness, which Imam (2010) termed as "uncertainty". Berenji (1988) defines uncertainty as a lack of complete information, or randomness. Douglas (2010, chap. 4, 5, & 6) defines uncertainty as "the lack of certainty, a state of having limited knowledge where it is impossible to exactly describe existing state or future outcome, more than one possible outcome." Information can be certain or uncertain, may come in different degrees, and different degrees of certainty affect the beliefs of an agent (Paggi & Amo, 2010). Wang et al. (2010) defines certainty as "a measure of the confidence that an agent may place in the trust information." The study mentions that measuring certainty can filter out insufficient information even with a high degree of trust. Paggi and Amo (2010) discusses the concepts of uncertainty, and shows the relation between uncertainty and the effects on system design. Wu, Su, Luo, Yang, and Chen (2009) extends the concepts of knowledge, belief, and certainty for MAS. The study introduces a merging of the logic of knowledge, belief, and certainty in MAS. They present a dynamic logic of knowledge, belief, and certainty for MAS (CDKBC logic). Halpern (1991) uses the relation between knowledge and certainty to build his model. He defines fact and certainty as "known if it is true at all worlds an agent considers possible, and is certain if it holds with probability 1."

Wang et al. (2010) uses certainty to describe the degree of trust of each agent for another agent in the system. He proposes a concept of trust in which "an agent Alice's trust in an agent Bob in terms of Alice's certainty in her belief that Bob is trustworthy." We, however, propose a different meaning, which is "an agent Alice's trust in an agent Bob, but Alice is not sure about the certainty of Bob." Thus, Bob is considered a trustworthy source, but we nonetheless need to check the certainty of his information. An example for the difference between certainty and trust, assume that Alice asked Bob about a specific event, Alice trusts Bob. Bob is trustworthy, but he may nonetheless give an uncertain answer due to his uncertainty.

2.3. Evidence

One of the key challenges for the MAS is determining trust based on information from different sources that have different degrees of trust. Wang et al. (2010) defines evidence as "conceptualized in terms of the numbers of positive and negative experiences." When an agent makes unambiguous direct observations of another agent, the corresponding evidence could be expressed as natural numbers (including zero). Wang and Singh (2007) argues that trust should be dependent on evidence. They offer a theoretical model of trust development such that a trust depends