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Abstract
Trust and deception have been of concern to researchers since the earliest research into multi-agent trading systems (MATS). In an open trading environment, trust can be established by external mechanisms e.g. using secret keys or digital signatures or by internal mechanisms e.g. learning and reasoning from experience. However, in a MATS, where distrust exists among the agents, and deception might be used between agents, how to recognize and remove fraud and deception in MATS becomes a significant issue in order to maintain a trustworthy MATS environment. This paper will propose an architecture for a multi-agent trading system (MATS) and explore how fraud and deception changes the trust required in a multi-agent trading system/environment. This paper will also illustrate several forms of logical reasoning that involve trust and deception in a MATS. The research is of significance in deception recognition and trust sustainability in e-business and e-commerce.

Keywords
Fraud and deception, trust, multiagent trading systems, e-commerce, Inference rule.

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Trust and Deception in Multi-agent Trading Systems: A Logical Viewpoint

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ABSTRACT

Trust and deception have been of concern to researchers since the earliest research into multi-agent trading systems (MATS). In an open trading environment, trust can be established by external mechanisms e.g. using secret keys or digital signatures or by internal mechanisms e.g. learning and reasoning from experience. However, in a MATS, where distrust exists among the agents, and deception might be used between agents, how to recognize and remove fraud and deception in MATS becomes a significant issue in order to maintain a trustworthy MATS environment. This paper will propose an architecture for a multi-agent trading system (MATS) and explore how fraud and deception changes the trust required in a multi-agent trading system/environment. This paper will also illustrate several forms of logical reasoning that involve trust and deception in a MATS. The research is of significance in deception recognition and trust sustainability in e-business and e-commerce.

Keywords

Fraud and deception, trust, multiagent trading systems, e-commerce, Inference rule.

INTRODUCTION

Trust and deception have been of concern to researchers since the earliest research into multi-agent trading systems (MATS). Although much of the research in MATS assumes inherent benevolence, in practice a completely open agent society must allow for the possibility of malevolent behaviour. In an open trading environment, trust can be established by external mechanisms e.g. using secret keys or digital signatures or by internal mechanisms e.g. learning and reasoning from experience. As noted by Ramchurn et al (2004), many current computer applications are following a distributed model with components available through a network e.g. the semantic web, web services and grid computing. The open multi-agent system with autonomous agents has been suggested as the logical computational model for such applications (Jennings, 2001). As a result, the implications of trust and deception have broader relevance than just trading systems.

The logical foundations for conventional reasoning in a trusted environment are well known e.g modus ponens assumes that given a fact (or truth) P and a rule $P \rightarrow Q$ then we can safely assume that Q is true. However in a MATS, where distrust exists among the agents, and deception might be used between agents, we can no longer assume that Q is true with any certainty. We need a different set of reasoning rules to simulate the deceptions or tricks in a multi-agent trading system. Most research into trust and deception in agent societies focuses essentially on heuristic techniques e.g. by learning which agents to trust (Wu et al (2002). However there seems to be little on the form of reasoning used by trustworthy and deceptive agents. We will consider the underlying reasoning from a logical viewpoint.

This paper will discuss multi-agent trading systems, define a model for an MATS, explore how tricks and deceptions change the reasoning required in a multi-agent trading system/environment and will illustrate several forms of logical reasoning that involve trust and deception in a MATS. It looks at a systematic classification of reasoning techniques which can be applied between buyers and sellers. The research is of significance in deception recognition and trust sustainability in e-business and e-commerce. The rest of the paper is organized as follows: Section 2 examines trading activities and proposes an architecture for a multi-agent trading system (MATS). Section 3 discusses trust and deception in the MATS. Section 4

examines the logical foundation for fraud and deception, and then looks at how agents commit fraud and deception in the MATS from a logical viewpoint. Section 5 ends this paper with some concluding remarks.

MULTIAGENT TRADING SYSTEMS

This section will examine trading activities in business and commerce, propose an architecture for a multiagent trading system (MATS), and examine agent behaviors in the MATS.

Trading is the activity of buying and selling, or exchanging, goods and/or services between people or countries. Generally speaking, there are six main different but fundamental trade types: barter, bargaining, bidding, auction, clearing, and brokering (Liang and Huang, 2000, Sun and Finnie, 2004a). Because barter is a trade type in which both sides offer their products for an exchange rather for money, we will not look at it further in the context of e-commerce. In modern business, trading has become a relatively complex mechanism, because trading involve many networked or chained activities such as searching, bidding, negotiating and making compromises with the seller (Sun and Finnie, 2004b). More specifically, the modern trading system consists of activities at three different levels: the market level, contract level, and activity level (Liang and Huang, 2000). At the market level, the agent helps determine the proper trade types. At the contract level, a particular trade type has been chosen. The corresponding agent helps with performing and monitoring the transaction process. At the activity level each agent is capable of performing certain tasks such as information search or alternative evaluation. At the same time, the agents in the trading systems require also some supporting tools such as an order management system, payment management system, decision support system, etc.

Multi-agent systems (MAS) for electronic commerce probably had their origins in the pioneering work of the Autonomous Agents group of the MIT Media Lab led by Pattie Maes which resulted in the Kasbah trading agent and Market Maker (Chavez and Maes, 1996). Other simple on-line shopping agents followed e.g. shopping bots like “Ask Jeeves”. More and more MATSs are being developed in order to realize the transformation from conventional trading to e-trading taking advantage of the internet and e-commerce technology. In what follows, we propose an architecture for a MATS based on MAS techniques, as shown in Fig. 1.

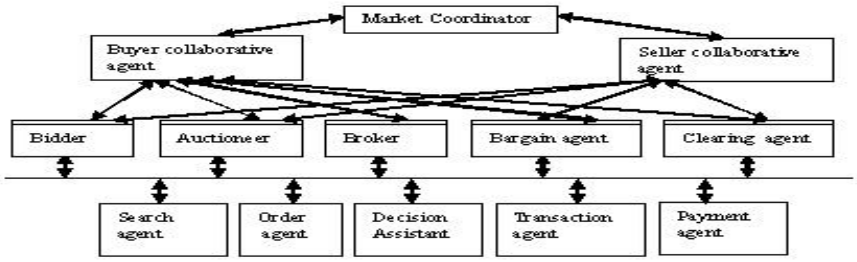

Fig. 1. An architecture of MATS.

In this architecture, the market coordinator helps the buyer or seller or their agents to enter the multi-agent trading market, where the bidder, auctioneer, broker, bargain agents, and clearing agents are the main players. Each of them is responsible for a corresponding trading type, for example, a bidder is responsible for bidding on behalf of the buyer agent to sell a commodity, while the auctioneer is responsible for auction of a commodity on behalf of the seller agent. The search agent, order agent, decision assistant, transaction agent and payment agent are common agent resources for the multi-agent trading market. They serve every trader, buyer and seller in the market. The trading activity here follows a trading cycle (Wittkowski and Pitt, 2000;Liang and Huang, 2000): First, the **bid** step, in which the buyer agent receives demands and asks the bidder to issue bids to seller agents to meet that demand. This step is the most difficult for any trading. The search agent and decision assistant play an important role in this step. Secondly, the offer step, in which the buyer agent asks the bargain agent, or auctioneer, or broker to make offers of the units in response to the bids they have received. Third, the **transaction** step, as soon as the buyer agent accepts the offer, the offer will be processed with the help of the order agent, transaction agent, and payment agent. Fourth, the utilization step, in which the buyer agent distributes the units offered to his/her buyer, and notifies the seller or seller agent that offered them units whether they utilized all the allocation they were offered. In any practical environment, several of these agent activities may be merged into a single agent.

TRUST AND DECEPTION IN MATS

As in any other form of society, agents can exhibit malevolent behavior in the multiagent trading environment. With the focus moving to the distributed systems paradigm and the multi-agent programming model, the study of trust and deception in agent interaction has significant implications for the operation of these systems.

Ramchurn, Huynh and Jennings (2004) provide an extensive review of research into trust in multi-agent systems. They define trust as follows: "Trust is a belief an agent has that the other party will *do what it says it will* (being honest and reliable) or *reciprocate* (being reciprocative for the common good of both), given an *opportunity to defect* to get higher payoffs". The authors conceptualise trust as (a) individual-level trust (agent believes in honesty or reciprocation of interaction partners) and (b) system-level trust (the agents are forced to be trustworthy by the system). They further characterise individual level trust models as learning (evolution) based, reputation-based or socio-cognitive based. Learning models are based on interactions with other agents. Reputation based models work by asking other agents of their opinion of potential partners, often based on some form of social network (Sabater and Sierra, 2002). Rather than relying on interaction with other agents, socio-cognitive models operate on subjective perceptions of opponents. Wong and Sycara (1999) address two forms of trust i.e. trust that agents will not misbehave and trust that agents are really delegates of whom they claim to be. Vassileva et al (2002) consider the formation of long term coalitions of customer and vendor agents using an agent trust model. Others have done research on agent learning in an untrustworthy environment i.e. agents who will attempt to cheat or trick each other in trading. For example, Wu et al (2002) show that trust can be established if agents learn which other agents exhibit poor behavior and hence which agents not to trust.

The research in this paper relates to individual level trust as defined by Ramchurn et al (2004). However all the models above rely on establishing a numerical metric of trust that can be used to rank or select partners. The current research is more interested in establishing a logical framework for viewing trust and deception rather than establishing an actual measure of the degree of trust.

Trust and deception are twins in MATS. Trust in MATS can be sustained only if we can understand how agents commit fraud and deception in a MATS. Furthermore, how will agents in a MATS operate autonomously in such an environment and what precautions will they need to take to protect their "owners" from fraudulent or malevolent acts? In human trading systems, "caveat emptor" or "let the buyer beware" is a well known trading rule of thumb. Humans expect the possibility of fraud and deception in trades and accordingly take whatever precautions are possible. Less well know is the Latin maxim "caveat mercator" or "let the merchant beware". The latter is particularly relevant with the increase in internet fraud with on-line merchants carrying the cost of fraudulent transactions. If this is the norm in conventional trading systems, why should it be any different in multi-agent systems?

In what follows, we will use the following general definitions, which are taken from the Cambridge International Dictionary of English:

"Fraud is a person or thing that is not what is claimed; or a crime of obtaining money by deceiving people."

"Deception is an act of hiding the truth, especially, to get an advantage."

In business and social activities, fraud depends on deception, while deception is realized through fraud. Further, the aim of both fraud and deception is to get advantage in an environment with conflict of interests. Therefore, in what follows, we only refer to deception rather than fraud and deception, if necessary.

With the development of the Internet, we find ourselves in hybrid artificial societies, where real world assumptions and the whole range of possible behaviors including deception must be taken into account (Ramchurn et al, 2004; Wooldridge and Jennings, 1994). From an e-commerce viewpoint, there are three different kinds of deception in hybrid artificial society: fraud and deception between humans (via computers), deception between humans and intelligent agents and deception between agents in multi-agent societies such as multi-agent e-commerce. In what follows, we focus on deception in MATS.

From the architecture proposed in Section 2, we can see that there are many agents operating in the multi-agent trading market. Some agents are trustworthy, for example, the market coordinator, search agent, order agent, transaction agent, and payment agent. All these agents are working as a lubricant for a healthy multi-agent trading market. These agents work for buyer agents, seller agents and others such as brokers and bidders in a neutral way in order to maintain the market trading order. However, the buyer agents, seller agents, bidders, auctioneers, brokers and bargain agents may not be trustworthy. These agents may deceive other agents in the MATS in order to obtain the maximum advantage or profit, just as buyers, sellers and brokers may use deception in a traditional trading market. In fact, the internet and information technology (IT) techniques provide new opportunities and ways to deceive, because intelligent agents in MATS will also participate in fraud and deception, and agents are and will be designed, selected or trained to deceive in MATS, and people will be also be

deceived by intelligent agents (Sun and Finnie, 2004a). Deception in the MATS can take a variety of forms e.g. pretending to be someone else, offering goods for sale which they don't have, buying goods but not paying, etc. This is one of the reasons why many people fear to trade in the MATS or in online trading. However, we usually would not stop driving because we saw a fatal car accident on the highway. Similarly, we cannot stop developing online trading and MATS, although we find some fraud and deception cases in online trading and e-commerce. The most important issue for us is recognizing and preventing fraud and deception in MATS. To this end, it is necessary to answer: What is the logical foundation of fraud and deception, because the essence of fraud and deception depends on its logical foundation.

A LOGICAL VIEWPOINT FOR FRAUD AND DECEPTION IN MATS

This section will examine the logical foundation for fraud and deception, and then look at how the agents commit fraud and deception in the MATS from a logical viewpoint.

Inference rules play a pivotal role in any reasoning paradigm, because any reasoning is based on an inference rule or a couple of inference rules (Sun and Finnie, 2004a). For example, *modus ponens* and *modus tollens* are central to deductive reasoning. Sun and Finnie have proposed eight basic inference rules for performing experience based reasoning (EBR) (Sun and Finnie, 2005), which are summarized in Table 1, and cover all possible EBRs, and constitute the fundamentals for all natural reasoning paradigms at the first level. The eight inference rules are listed in the first row, and their corresponding general forms are shown in the second row respectively.

Table 1. Experience based reasoning: Eight inference rules

MP	MT	Abduction	MTT	AT	MPT	IMP	IMPT
$\frac{P \quad P\to Q}{\therefore Q}$	$\frac{\neg Q \quad P\to Q}{\therefore \neg P}$	$\frac{Q \quad P\to Q}{\therefore P}$	$\frac{\neg Q \quad P\to Q}{\therefore P}$	$\frac{Q \quad P\to Q}{\therefore \neg P}$	$\frac{P \quad P\to Q}{\therefore \neg Q}$	$\frac{\neg P \quad P\to Q}{\therefore \neg Q}$	$\frac{\neg P \quad P\to Q}{\therefore Q}$

Four of them, modus ponens (MP), modus tollens (MT), abduction and modus ponens with trick (MTT) are well-known in AI and computer science but the other four need some clarification. First of all, we illustrate modus tollens with trick with an example. We may know that:

1. If Socrates is human, then Socrates is mortal
2. Socrates is immortal.

What we wish is to prove "Socrates is human". In order to do so, let

- $P \to Q$: If Socrates is human, then Socrates is mortal
- P: Socrates is human
- Q: Socrates is mortal.

Therefore, we have P: Socrates is human, based on modus tollens with trick, and the knowledge in the knowledge base (KB) (note that $\neg Q$: Socrates is not mortal). From this example, we can see that modus tollens with trick is a kind of EBR[1].

Abduction with trick[2] can be considered as a "dual" form of abduction, which is also the summary of a kind of EBR. Abduction can be used to explain that the symptoms of the patients result from specific diseases, while abduction with trick can be used to exclude some possibilities of the diseases of the patient. Therefore, abduction with trick is an important complementary part for performing system diagnosis and medical diagnosis based on abduction.

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[1] Because of space limits, we do not introduce any examples in this paper from now on.

[2] If the reader does not like to use trick or deception, he can use "exception" instead. The essence is that such kinds of inferences have not yet examined in computer science and artificial intelligence, although they are necessary for EBR.

Inverse modus ponens (IMP) is also a rule of inference in EBR. The "inverse" in the definition is motivated by the fact that the "inverse" is defined in mathematical logic: "if $\neg p$ then $\neg q$", provided that if p then q is given (Sun and Finnie 2004b). Based on this definition, the inverse of $P \rightarrow Q$ is $\neg P \rightarrow \neg Q$, and then from $\neg P$, $\neg P \rightarrow \neg Q$, we have $\neg Q$ using modus ponens. Because $P \rightarrow Q$ and $\neg P \rightarrow \neg Q$ are not logically equivalent, the argument based on Inverse modus ponens is not valid in mathematical logic. However, the EBR based on inverse modus ponens is a kind of common sense reasoning, because there are many cases that follow inverse modus ponens. For example, if John has enough money, then John will fly to China. Now John does not have sufficient money, then we can conclude that John will not fly to China.

The last inference rule for EBR is *inverse modus ponens with trick* (IMPT). The difference between IMPT and *inverse modus ponens* is again "with trick", this is because the reasoning performer tries to use the trick of "make a feint to the east and attack in the west"; that is, he gets Q rather than $\neg Q$ in the *inverse modus ponens*.

These eight different inference rules provide a logical foundation for any experience-based reasoning paradigms at the fundamental (or atomic) level, so that they can be applied to both benevolent and deceptive agent societies. In what follows, we give several examples to illustrate this view.

We assume that in the MATS, the seller agent, *S*, will offer goods at a specific price while the buyer agent *B* will agree to purchase a specific volume at a specific price. If the MATS provides a trustworthy trading environment, we can assume that conventional reasoning applies i.e. Modus ponens, modus tollens and possible abduction are used in the agents in MATS to conduct any trading activities. For the buyer agent *B*, his trustworthy reasoning could be as follows:

If a seller offers goods at a price then those goods will be available at that price. We assume that *G* and *D* are propositions: *G*: = goods offered at known price, *D*: = goods are available for delivery.

Modus ponens is what the buyer agent or seller agent normally uses in the trading activities: bidding, brokering, negotiation and making compromises, because they believe that If *G*, $G \rightarrow D$ Then *D*. They also use *modus tollens* in the trading activities, i.e. if goods are not available then they will not be offered for sale by an agent.

If not *D* i.e. goods are not available, Then Not *G* i.e goods will not be offered for sale.

Abduction is another common sense inference rule underpinning the marketplace, i.e., if a seller agent, *S*, has goods available for delivery, *D*, he/she will make them available for sale. That is,

D (Goods are available and will be delivered)

$G \rightarrow D$

Therefore, we have *G* (goods will be offered at a known price).

However, the environment provided by the MATS is not always trustworthy, because some agents (e.g. buyer agents, seller agents, bidders, auctioneers, brokers, and bargainers) may have a conflict of interests so that they will try to deceive their trading partners. In what follows, we look at several scenarios in the simple buyer/seller context where deception or fraud could apply and consider the variations on traditional logic which could provide a logical base for the reasoning. More detail on these inference rules and their coverage of all forms of experience based reasoning is available in Sun and Finnie (2004c). A number of scenarios will be proposed where the buyer agent is misled in their dealings with the seller agent in the MATS.

(1) A seller agent may offer goods at a price, *G*, but those goods are not available, which case is a obvious fraud. An example could be malevolent or fraud behaviour by a competitor of the buyer company e.g. to delay production by ensuring that materials in the supply chain are not delivered. This could also apply to competitors of the supplier e.g. to reduce the chances that a competitor does not achieve the deal by offering goods at a lower price. This scenario could be described as *modus ponens with trick* (MPT) (see Table 1 above). It takes the form

G **(**goods at known price),

$G \rightarrow D$

Therefore, Not D (goods are not available for delivery).

The essence behind this fraudulent behavior is that the seller agent has used the inference rule with trick, which deceives the buyer agent.

(2) A second form of deception could arise in the MATS, if a seller agent does not offer goods at a price but the goods are in fact available at that price. This could arise if there are limited goods available and a seller wishes to preference another buyer (agent). This is referred to as *inverse modus ponens with trick* (IMPT) and takes the form:

Not *G* (not offer goods at a price)

$G \rightarrow D$

Therefore, *D* (goods are in fact available at that price).

(3) We could also have the situation where goods are not available but are offered at a specific price. This varies slightly from case (1) above in that the starting point is that the goods are not available. This could for example be a negotiating tactic if goods will be available within a short time. This is called *modus tollens with trick* (MTT) and takes the form:

Not *D* (goods are not available),

$G \rightarrow D$

Therefore, G (goods are offered at a specific price).

(4) We could have the situation where goods are available for delivery but not at that price. This could be used to fool the buyer into intending to make a purchase – again as a possible negotiating tactic or delaying tactic. This could be termed *abduction with trick* (AT) and takes the form:

D (goods are available for delivery)

$G \rightarrow D$

Therefore, Not *G* (goods are not offered at that price).

There are also a number of scenarios of fooling the seller or seller agent in the MATS. As above, the seller assumes that: If goods are purchased at a specific price, the seller will receive the amount in full. The most usual form of fraud and deception would be where goods are purchased but the seller does not receive the full amount (or anything). This is theft or fraud and can be represented as *modus ponens with trick* (MPT). Other forms of inference rules do not apply easily to deceive the seller. *Inverse modus ponens with trick* (IMPT) or *abduction with trick* (AT) suggest that goods are not purchased at a specific price but that the seller receives the full amount, which might be good for the seller but not that likely in practice.

CONCLUSION

In this paper we examined trading activities in business and commerce, and proposed an architecture for a multiagent trading system (MATS). Then we examined agent behaviors in the MATS, in particular trustworthy behaviors, and fraud and deception behaviors of agents in the MATS from a logical viewpoint.

Fraud and deception are an unavoidable phenomenon for engineering MATS. Failure to research and understand deception will lose the "biological" balance in MATS. Benevolent agent societies assume a fundamental basis of the conventional forms of reasoning i.e. modus ponens, modus tollens and abduction. In situations with malevolent or fraudulent agents it is useful to consider other forms of reasoning to better model the processes involved. Although heuristic techniques have been applied to learn which agents could be deceptive, this paper looks at the underlying models of reasoning which might apply with such agents.

It should be noted that what we have examined here is inference-based fraud and deception in MATS. In fact, fraud and deception can be classified into different categories from a knowledge-based viewpoint (Sun and Finnie, 2004a): Knowledge-based fraud and deception, Inference-based fraud and deception, and hybrid fraud deception. For example, if agent *B* and agent *S* possess different knowledge but have the same reasoning methods, then one of them can deceive the other. This is a typical knowledge-based deception. If agent *B* and agent *S* possess the same knowledge but have different reasoning methods, then again one of them can deceive the other. This is a typical inference-based deception. If they have different background knowledge and used different inference rules for reasoning, then we may have hybrid deception. Different categories of fraud and deception require different strategies and methods for detection, recognition and prevention of fraud and deception, in order to sustain a trustworthy MATS environment, which we will examine in future work.

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