A Formal Framework for Reasoning about Opportunistic Propensity in Multi-agent Systems

JAAMAS Track

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1 INTRODUCTION

In the electronic market, buyers are cautious that they will receive products in bad quality. This is because only sellers on the other side of the market know whether the products are good enough before buyers receive them. The sellers can exploit the situation of knowledge asymmetry between seller and buyers to achieve their own gain at the expense of the buyers. Such behavior, which is intentionally performed by the sellers, was named opportunistic behavior (or opportunism) by economist Williamson [6]. We interpret it as a selfish behavior that takes advantage of relevant knowledge asymmetry and results in promoting one's own value and demoting others' value [2]. It is important to eliminate such selfish behavior in multi-agent systems, as it has undesirable results for the participating agents. In order for monitoring and eliminating mechanisms to be put in the right place, it is needed to know in which context agents are likely to perform opportunistic behavior. In this paper, we develop a formal framework to reason about agents' opportunistic propensity. Opportunistic propensity refers to the potential for an agent to perform opportunistic behavior. In particular, agents in the system are assumed to have their own value systems and knowledge. Based on their value systems and incomplete knowledge about the state, they choose one of their rational alternatives to perform, which might be opportunistic behavior. We then characterize the situation where agents are likely to perform opportunistic behavior.

2 FRAMEWORK

We use Kripke structures as our basic semantic models of multi-agent systems. A Kripke structure $\mathcal{M}$ is a directed graph whose nodes represent the possible states of the system and whose edges represent accessibility relations. Within those edges, equivalence relation $\mathcal{K}(\cdot) \subseteq S \times S$ represents agents' epistemic relation, while relation $\mathcal{R} \subseteq S \times Act \times S$ captures the possible transitions of the system that are caused by agents' actions. Note that, because in this paper we only consider opportunistic behavior as an action performed by an agent, we do not model concurrent actions. We require that for all $s \in S$ there exists an action $a \in Act$ and one state $s' \in S$ such that $(s, a, s') \in \mathcal{R}$. Since we assume actions are deterministic, sometimes we denote state s' as $s\langle a\rangle$ for which it holds that $(s, a, s\langle a\rangle) \in \mathcal{R}$. The set of an agent's epistemically accessible states from state s is called the knowledge set of the agent, denoted as $\mathcal{K}(i, s)$. We also use $Ac(s)$ to denote the available actions in state s. We extend propositional logic with knowledge modality and action modality as our language.

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3 VALUE SYSTEM AND RATIONAL ALTERNATIVE

Agents in the system are assumed to have their own value systems and knowledge. Based on that, agents form their rational alternatives for the action they are going to perform. A *value* can be seen as an abstract standard according to which agents define their preferences over states. For instance, if we have a value denoting *equality*, we prefer the states where equal sharing or equal rewarding hold. See the use of values in argumentation in [1] [5]. Because of the abstract feature of a value, we interpret a value in more detail as a state property, which is represented as a formula v in our language. We then define a *value system* as a strict total order over a set of values, representing the degree of importance. When $v \prec v'$, we say that value v' is more important than value v. Given a state transition (s, a, s'), a value v is promoted if and only if $s \models \text{promoted}(v, a)$, and v is demoted along this transition if and only if $s \models \text{demoted}(v, a)$. Since agents can compare any two different values, we can specify agents' preference over two different states. Given two different states s and s', we use highest(i, s, s') to denote the value that agent i most care about when going from state s to state s'. Therefore, agent i weakly prefers state s' to state s, denoted as $s \precsim_i s'$, if and only if $\mathcal{M}, s \models \text{highest(i, s, s')} \Rightarrow \mathcal{M}, s' \models \text{highest(i, s, s')}$, which means agent i's most preferred value does not get demoted (either stays the same or gets promoted).

Before choosing an action to perform, an agent think about which actions are available to him. We have already defined that for a given state s, the set of available actions is $Ac(s)$. However, since an agent only has partial knowledge about the state, we argue that the actions that an agent knows to be available is only part of the actions that are physically available to him in a state. For example, an agent can call a person if he knows the number of the person; without this knowledge, he is not able to do it, even though he is holding a phone. Knowledge and actions have been together investigated in [3] [4]. Given an agent's partial knowledge about a state as a precondition, an agent's subjectively available actions is denoted as $Ac(i, s)$, which is the intersection of the sets of actions physically available in the states in his knowledge set $\mathcal{K}(i, s)$. Based on an agent's rationality assumptions, he will never perform an action which is dominated by (strictly worse than) another action. This notion gives rise to the following definition:

Definition 3.1 (Rational Alternatives). Given a state s and an agent i, the set of *rational alternatives* for agent i in state s is given by the function $a_i^* : S \rightarrow 2^{Act}$, which is defined as follows:

$$a_i^*(s) = \{a \in Ac(i, s) \mid \neg\exists a' \in Ac(i, s) : a \neq a' \text{ and } a' \text{ dominates } a \text{ for agent } i \text{ in state } s\}.$$

The set $a_i^*(s)$ are all the actions for agent i in state s which are available to him and are not dominated by another action which is available to him. In other words, it contains all the actions which are rational alternatives for agent i. We can see that the actions that are available to an agent not only depend on the physical state, but also depend on his knowledge about the state. The more he knows, the better he can judge what his rational alternatives are. In other words, agents try to make the best choice based on their value systems and incomplete knowledge about the state.

4 DEFINING OPPORTUNISM

Before reasoning about opportunistic propensity, we should first formally know what opportunism actually is. Opportunism is a social behavior that takes advantage of relevant knowledge asymmetry and results in promoting one's own value and demoting others' value [2]. It means that it is performed with the precondition of relevant knowledge asymmetry and the effect of promoting agents' own value and demoting others' value. Firstly, knowledge asymmetry is defined as formula $\text{KnowAsym}(i, j, \phi)$, which holds in a state where agent i knows ϕ while agent j does not know ϕ and this is also known by agent i. We define opportunism as follows:

Definition 4.1 (Opportunism). Let $\mathcal{M}$ be a muti-agent system and s be a state, given two agents i and j and an action a, the truth of formula $\text{Opportunism}(i, j, a)$ that action a performed by agent i to agent j is opportunism wrt $\mathcal{M}$ and s is defined as:

$$\mathcal{M}, s \models \text{Opportunism}(i, j, a) :=$$
$$M, s \models \text{KnowAsym}(i, j, \text{promoted}(v^*, a) \wedge \text{demoted}(w^*, a))$$

where $v^* = \text{highest}(\text{i, s, s}\langle \text{a}\rangle)$ and $w^* = \text{highest}(\text{j, s, s}\langle \text{a}\rangle)$.

This definition specifies that if the precondition KnowAsym is satisfied in $\mathcal{M}, s$, then the performance of action a will be opportunistic behavior. The asymmetric knowledge that agent i has is that the transition by action a will promote value v^* but demote value w^* along, where v^* and w^* are the values that agent i and agent j most care about along the transition respectively.

5 REASONING ABOUT OPPORTUNISTIC PROPENSITY

Agents will perform opportunistic behavior when they have the ability and the desire of doing it. The ability of performing opportunistic behavior can be interpreted by its precondition: it can be performed whenever its precondition is fulfilled. Agents have desire to perform opportunistic behavior whenever it is a rational alternative. There are also relations between agents' ability and desire of performing an action. As rational agents, firstly they think about what actions they can perform given the limited knowledge they have about the state, and secondly they choose the action that may maximize their utilities based on their partial knowledge. This practical reasoning in decision theory can also be applied to reasoning about opportunistic propensity. Given the asymmetric knowledge an agent has, there are several (possibly opportunistic) actions available to him, and he may choose to perform the action which is a rational alternative to him, regardless of the result for the other agents. Based on this understanding, we have the following theorem, which implies agents' opportunistic propensity:

THEOREM 5.1 (OPPORTUNISTIC PROPENSITY). *Given a multi-agent system $\mathcal{M}$, a state s, two agents i, j and an action a, agent i is likely to perform action a to agent j as opportunistic behavior in state s:*

$$a \in a_i^*(s) \text{ and } \mathcal{M}, s \models \text{Opportunism}(i, j, a)$$

iff

(1) $\forall t \in \mathcal{K}(i, s) : \mathcal{M}, t \models \text{promoted}(v^*, a) \wedge \text{demoted}(w^*, a)$, $\exists t' \in \mathcal{K}(j, s) : \mathcal{M}, t' \models \neg(\text{promoted}(v^*, a) \wedge \text{demoted}(w^*, a))$, *where* $v^* = \text{highest}(\text{i, s, s}\langle \text{a}\rangle)$ *and* $w^* = \text{highest}(\text{j, s, s}\langle \text{a}\rangle)$*;*
(2) $s \prec_i s\langle a\rangle$ *and* $s \succ_j s\langle a\rangle$.
(3) $\neg\exists a' \in Ac(i, s) : a \neq a'$ *and* a' *dominates* a.

Given an opportunistic behavior a, in order to predict its performance, we should first check the asymmetric knowledge that agent i has for enabling its performance. Based on agent i's and agent j's value systems, we also check if it is not dominated by any actions in $Ac(i, s)$ and its performance can promote agent i's value but demote agent j's value. It is important to stress that Theorem 5.1 doesn't state that an agent will for sure perform opportunistic behavior if the three statements are satisfied. Instead, it states opportunism is likely to happen because it is one of the agent's rational alternatives. The agent will perform one action, which might be opportunistic behavior, from his rational alternatives.

6 CONCLUSION AND FUTURE WORK

The investigation about opportunism is still new in the area of multi-agent systems. We ultimately aim at designing mechanisms to eliminate such selfish behavior in the system. In order to avoid over-assuming the performance of opportunism so that monitoring and eliminating mechanism can be put in place, we need to know in which context agents are likely to perform opportunistic behavior. In this paper, we argue that agents will behave opportunistically when they have the ability and the desire of doing it. Based on that, we then developed a framework of multi-agent systems to reason about agents' opportunistic propensity. Agents in the system were assumed to have their own value systems. Based on their value systems and incomplete knowledge about the state, agents choose one of their rational alternatives, which might be opportunistic behavior. With our framework and our definition of opportunism, we characterized the situation where agents are likely to perform opportunistic behavior. Future work can consider issues such as norms, reputation, warranties and contracts in combination with the ability and the desire of being opportunistic. Most importantly, this paper sets up a basic framework to design a mechanism for eliminating opportunism.

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