A Formal Model of Opportunism Based on Situation Calculus

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Abstract. In social interactions, it is common for one party to possess more or better knowledge about a specific transaction than others. In this situation, parties who are more knowledgeable might perform opportunistic behavior to others, which is against others' interest thus leading to relationship deterioration. In this study, we propose a formal model of opportunism based on situation calculus. Specifically, knowledge asymmetry and intention are modeled by adapting the standard possible-world model semantics, and value opposition is specified through defining a value evaluation function on situation based on the perspective of agents. We illustrate how to use our formal model through a simple example. By this model, we show that the judgment of opportunism is subjective since it depends on from which perspective agents evaluate the situation over their value, and it is not the intention, but the knowledge, of opportunistic agents to cause harm to others. Further study on its emergence and constraint mechanism can be carried out based on the formal model.

Keywords: Opportunism, Value, Situation Calculus, Formalization

1 Introduction

Consider a common social interaction. A seller is trying to sell a cup to a buyer. Since it is known by the seller beforehand that the cup is actually broken (e.g. there is a crack at the bottom of the cup), he makes a rule that the cup cannot be returned in any situations. The buyer buys the cup for its good appearance, but of course gets disappointed when he fills it with water. In this example, the seller earns money from the buyer by exploiting the opportunity of knowledge asymmetry about the cup, while the buyer just focuses on the appearance of the cup rather than being leaky or not. Further, the rule no return does not allow the buyer to get any compensation in the transaction. Such a social behavior intentionally performed by the seller is named by economist Williamson as opportunism [1]. Opportunistic behavior commonly exists in business transactions and other types of social interactions in various forms such as deceit, lying and betraying.

Viewing individuals as agents, we may have similar problems in multi-agent system research. From the very beginning, research about multi-agent systems focused on designing a group of cooperative agents to solve difficult problems. Soon after, interacting agents were modeled to behave in a human-like way with characteristics

of autonomy, local views and decentralization [2]. When such agents possess different quantity or quality of relevant information and try to maximize their benefits, they may probably have opportunistic behavior to others, which is against others' benefits or the norms of the system. For example, in a system with the norm of equity, an agent may hide important information to his or her peers for increasing his own payoff. The agent's behavior has negative results for other agents involved in the relationship and strongly affects the cooperative relationship once it is unveiled. However, one may ask: if the system norm allows hiding, the agent could not be said to have done anything wrong. One may also ask: if other agents agree that agents having more important information deserve more payoff, would it be regarded as opportunistic? Both the system's norms and the agents' perspectives can be seen as value systems, which may be different among systems and agents and influence the judgment on opportunism. Therefore, we propose to investigate opportunistic behavior from the perspective of value.

Over the years, a large amount of research from social science was done to investigate opportunistic behavior from its own perspective [3][4][5], providing a descriptive theoretical foundation to the study of opportunism. However, most of the conclusions were put forward based on specific cases and contexts due to the nature of social science, making it difficult to have widely applicable generalization. For the definition of opportunism, there exists no agreed general and scientific one [6], which makes the study on its emergence and constrain mechanism even more difficult.

In order to solve this problem, we need to have a formal model of opportunism which can be applied in any context and serve as a basic framework for future research. Logic-based formalisms are one of the alternatives for its capacity of describing and reasoning. Through the specification by logic, we can understand more clearly the elements in the definition and how they constitute this social behavior. Thus, we are motivated to propose a formal specification of opportunism by mathematical logic based on our definition.

In this paper, we first have a clear definition of opportunism extended from Williamson's, highlighting the key elements we need to model. We then formulize opportunism using situation calculus [7] as our technical preliminary based on our extended definition. Especially, information asymmetry and intention are modeled by adapting the standard possible-world model semantics, value opposition is specified through defining a value evaluation function on situations based on the perspective of agents. The final formal model of opportunism represents the elements of this social behavior and how they relate to each other. By this model, we show that the judgment of opportunism is subjective since it depends on from which perspective agents evaluate the situation over their value, and it is not the intention, but the knowledge, of opportunistic agents to cause harm to others.

Having such a formal model of specification to opportunism is of great importance, as we can clarify the crucial elements that form this behavior and how they relate to each other. Further, by this model we prove some properties that have been confusing since the proposal of opportunism. Therefore, we believe that such a research perspective can ease the debates about opportunism in social science (e.g. the above questions). Moreover, future work on its emergence and constraint mechanism can be

conducted by investigating the elements of this formal model, from both ways of research and practice.

2 Defining Opportunism

In this section, we extend Williamson's definition of opportunism and suggest a more explicit one as a prelude and basis to proposing a formal model in the next section.

2.1 Definition of Opportunism

The classical definition of opportunism is offered by Williamson [1] as "self-interest seeking with guile". While this definition has been used in a large amount of research, it only makes two attributes, self-interest and guile, explicit, leaving other attributes for researchers to interpret from different perspectives. For example, Das defined partner opportunism as "behavior by a partner firm that is motivated to pursue its self-interest with deceit to achieve gains at the expense of the other alliance members" [3]. Even though it is elaborated enough, it has the suggestion that opportunistic individuals are meant to harm others, which cannot be derived from Williamson's definition.

In this study, based on the definition of Williamson, we compare opportunistic scenarios with non-opportunistic ones, and redefine this social behavior in a more explicit way.

Opportunism is a behavior that is motivated by self-interest and takes advantage of relevant knowledge asymmetry[1] *to achieve gains, regardless of the principles.* This definition highlights three attributes: self-interest, knowledge asymmetry, regardless of the principles.

First of all, there has been reached consensus that opportunistic behavior is performed with self-interest motivation [3]. We admit that self-interested pursuit is the natural property of human beings, but the motive of opportunism is more than that: individuals with opportunistic behavior do not care more about the relationship with partners and the negative effects on themselves after being opportunistic.

Secondly, relevant knowledge asymmetry provides the chance to individuals to be opportunistic. Opportunistic individuals may break the contracts or the relational norms using the relevant knowledge that others don't have. It is important for opportunistic individuals to use cheating, deceit or infidelity for hiding their self-interest motive. Therefore, individuals with more relevant knowledge will have more potential for opportunistic behavior.

Thirdly, principles are ignored by opportunistic individuals. The reason to use "ignore" here is to distinguish opportunism from accidentally bringing harm to others. Opportunistic behavior is performed on purpose without any compensation to the

[1] Even though many papers in social science use information asymmetry to represent the situation where one party in a transaction knows more compared to another, we would rather revise it as knowledge asymmetry in this paper for the purpose of being consistent with our technical framework situation calculus and its extensions.

victims. Principles can be the value of others, or the contract rules or the relational norms that are used for balancing various interests and already agreed to by a majority of the individuals.

From the above elaboration, we have something important to keep in mind: it is not the intention of opportunistic individuals to harm others even though opportunism is deliberate with self-interest motives. The ignored principles are a specific kind of knowledge about the interest of others that cannot be considered as an intention to be opportunistic. This is one of the properties that we are going to show through our formal model of opportunism.

2.2 Integrating with Value

Even though we did not explicitly declare the result of performing opportunistic behavior in our extended definition, such behavior must result in gains at the expense of others. In this paper, we propose to investigate this important element from the perspective of value.

Value is something that we think is important, and various types of values together with their orderings form a value system. By integrating the notion of value into our model, the result of performing opportunistic behavior is represented as the promotion of opportunistic individuals' value and the demotion of others' value. Furthermore, even though value system is relatively stable, it may differ across different societies. Each society has its own value system as part of the social context and it is the basis for any judgment within the society. In this sense, some behaviors which are regarded as opportunistic in one society may not be considered as opportunistic in another society, if the two societies don't share the same value system. Assume two societies have different levels of belief in collectiveness and individualism. This may lead to rather different judgment about opportunism for the same scenario. A similar idea, although more focusing on opportunistic propensity, can be found in [6]. Given the value system of the society, opportunistic behavior promotes the self-interest which is in opposition with others' value.

3 Technical Preliminary: Situation Calculus

Situation calculus provides a formal language for representing and reasoning about dynamical domains based on first-order logic. There are three types of sorts: actions that can be performed by agents, situations representing a history of action occurrences and objects for everything else. Situation S_0 represents the initial situation that no action can result in. The special predicate $do(a, s)$ denotes the unique situation that results from the performing of action a in situation s. The properties of situations are specified through relational and functional fluents taking a situation term as their last argument, which means their value may vary from situation to situation. The effects of actions on fluents are defined by successor state axioms.

With situation calculus, we can reason about how the world changes as the result of the available actions. A Basic Action Theory from Reiter [8] is defined as

$$D = \Sigma \cup D_{ap} \cup D_{ss} \cup D_{so} \cup D_{una}$$

Σ: the set of foundational axioms,

1. $do(a_1, s_1) = do(a_2, s_2) \rightarrow a_1 = a_2 \wedge s_1 = s_2$;
2. $(\forall Q).\, Q(S_0) \wedge (\forall s, a).\, [Q(s) \rightarrow Q(do(a, s))] \rightarrow (\forall s) Q(s)$;
3. $s \sqsubset do(a, s') \equiv s \sqsubseteq s'$;
4. $\neg s \sqsubset S_0$;

D_{ap}: the set of actions preconditions, one for each action type,

$Poss(a(x), s) \equiv \pi_a(x, s)$;

D_{ss}: the set of successor state axioms, one for each fluent;

$F(do(a, s)) \equiv \gamma_F^+(a, s) \vee (F(s) \wedge \neg \gamma_F^-(a, s))$

Here $\gamma_F^+(a, s)$ and $\gamma_F^-(a, s))$ are two formulas expressing the conditions for the fluent F becoming true and false, respectively;
D_{so}: the sentences uniform in S_0 describing the initial situation;
D_{una}: the unique name axioms for actions.

This is a brief overview of situation calculus, which is the technical preliminary of our formalization. After John McCarthy's introduction of this theory, people made extensions capable of representing knowledge and belief in order to better reason about actions and their effects on the world [9,10,11]. We will introduce and adopt those extensions in the following sections as appropriate. Since in situation calculus the last argument is always situation, we will follow this convention in this paper for any definition of fluents and predicates.

4 Formalizing Opportunism

4.1 Knowledge Asymmetry

We adopt the approach of Scherl to formalizing knowledge, which is to add agents' possible-world model of knowledge to situation calculus [10]. To treat knowledge as a fluent, we have a binary relation $K(s', s)$, which denotes the epistemic accessibility relation of an agent. It is reflexive, transitive and symmetric.

Definition 4.1.1

$$Know(\phi, s) \stackrel{\text{def}}{\equiv} (\forall s') K(s', s) \rightarrow \phi[s']$$

This definition shows that an agent has knowledge about ϕ if and only if ϕ holds in all the epistemic possible situations of the agent. Then we can have the definition of Knowledge asymmetry.

Definition 4.1.2

$$KnowAsym(i, j, \phi, s) \stackrel{\text{def}}{=} Know_i(\phi, s) \wedge \neg Know_j(\phi, s) \wedge Know_i(\neg Know_j(\phi, s))$$

KnowAsym is a fluent in situation s where agent i has knowledge about ϕ while j does not have. Actually it can be the other way around. But for defining opportunism, we only limit this definition to be one situation. Note that ϕ can represent any proposition in this definition.

4.2 Value Opposition

From the definition of opportunism, we know that agents have different evaluation on the same state transition. For agent i who performs opportunistic behavior, his value gets promoted, while the value of agent j gets value demoted. This is because they make the evaluation from their own perspective. We name this property of state transition value opposition in this study. Since our basic framework, situation calculus, does not include to the notion of value, we first define a set V of value to specify how agents compare situations based on their value system.

Definition 4.2.1

$$Eval: A \times V \times S \rightarrow R$$

This functional fluent returns a real number that represents an agent's evaluation over value about situations. For instance, $Eval(i, v, s)$ denotes agent i's evaluation of value v about situation s from this perspective. Note that the first argument of this functional fluent is an agent, which means the evaluation about situation may be different from agent to agent.

Since function $Eval$ returns a real number, agents can compare different situations and thus have preference ordering. After the performing of action a by agent i, situation goes from s to $do(a, s)$. If $Eval(i, v, s)$ is less than $Eval(i, v, do(a, s))$, agent i's value gets promoted; if $Eval(i, v, s)$ is larger than $Eval(i, v, do(a, s))$, agent i's value gets demoted. Then we can define value opposition for a state transition.

Definition 4.2.2

$ValueOppo(i, j, v, s, s') \stackrel{\text{def}}{=}$

$$Eval(i, v, s) < Eval(i, v, s') \wedge Eval(j, v, s) > Eval(j, v, s')$$

We define value opposition as a property of state transition where a state transition from s to s' can promote value v from the perspective of agent i but demote value v from the perspective of agent j. In other words, agent i has positive effects from the

state transition, while agent j has negative effects. Similar to knowledge asymmetry, we only limit the definition to one situation for defining opportunism.

4.3 Intention

As we highlighted in Section 2, opportunistic behavior is performed by intent rather than by accident. In order to suggest this aspect in our formal model, we adopt the logic of intention in our framework. The definition of *Intend* is as below:

Definition 4.3.1

$$Intend(i, a, \varphi, s) \stackrel{\text{def}}{=} (\forall s')I_i(s', s) \rightarrow done(a, s') \wedge \varphi[s'].$$

$I(s', s)$ denotes the intentional accessibility relation of an agent, and $done(a, s')$ is true when action a is finished in situation s', and φ is an arbitrary formula. An intention of agents i $Intend(i, a, \varphi, s)$ holds if and only if action a is finished and φ holds in all intentional possible situations of agent i. Based on this definition of intention, we have two specification of value promotion and value demotion, which will be later used for providing the final definition and proving its properties.

Definition 4.3.2

$$Intend(i, a, pro(j, v), s) \stackrel{\text{def}}{=}$$
$$(\forall s')I_i(s', s) \rightarrow done(a, s') \wedge Eval(j, v, s) < Eval(j, v, s')$$
$$Intend(i, a, de(j, v), s) \stackrel{\text{def}}{=}$$
$$(\forall s')I_i(s', s) \rightarrow done(a, s') \wedge Eval(j, v, s) > Eval(j, v, s')$$

$Intend(i, a, pro(j, v), s)$denotes that agent i intends to promote the value of agent j by action a in situation s. Similar with $Intend(i, a, de(j, v), s)$. When $i = j$, agent i intends to promote or demote his own value by action a.

4.4 Opportunistic Behavior

The above definitions are pivotal ingredients that we need for having the formal model of opportunism: knowledge asymmetry as a precondition, value opposition as a result, and intention as a mental state. Besides, based on the informal definition we gave in Section 2, there are two more aspects that should be suggested in the definition. Firstly, the Knowledge that the performer has while others do not have should be relevant to the state transition. Secondly, the performer is aware of value opposition for the state transition beforehand but still ignores it.

Definition 4.4 Let D be a Situation Calculus BAT, K and I be the axioms for knowledge and intention representation in the Situation Calculus respectively, V be the set of values and *Eval* be the utility function representing an agent's evaluation over value about situations. Then $(D \cup K \cup I, V, Eval)$ is a situation calculus BAT

extended with knowledge, intention, value and evaluation. Within this system, we have

$$Opportunism(i,j,a,s) \stackrel{\text{def}}{\equiv}$$
$$(\exists v \in V)\big(Poss(i,j,a,s) \equiv KnowAsym(i,j,\phi,s)\big) \wedge$$
$$Intend(i,a,pro(i,v),s) \wedge \phi$$
$$where\ \phi = ValueOppo\big(i,j,v,s,do(a,s)\big).$$

This formula shows a predicate where action *a* is performed by agent *i* in the situation *s* with the asymmetric knowledge about the state transition and the intention of self-value promotion. In this concise formula, knowledge asymmetry is the precondition of action a, and the asymmetric knowledge held by agent i is the knowledge about the state transition from *s* to $do(a,s)$. In this way, the two aforementioned aspects are modeled into the formula. With that knowledge and motivation, it is obvious that agent i will not have any compensation for the negative result to agent j even though the guile is unveiled.

Another observation from the model is about the subjectivity of opportunism. We can see through the functional fluent $Eval$ that agents always evaluate the situations and consequently the state transition from their own perspectives, which are part of their value systems. If the value systems upon which they have evaluation change to another, the property value opposition may be false. Opportunism is presented as a "problem" in most research. However, the above formal model of opportunism implies that it depends on from which perspective, or more generally value system, we evaluate the state transition. It is positive from the perspective of agent *i*, while it is negative from the perspective of agent *j*. It is not necessarily a good thing or a bad thing; it could be either. In reality and multi-agent systems, people usually take the established norms into consideration when they decide whether it should be prevented, and the result may be different from society to society and from system to system.

After having the formal model of opportunism, we show how the property we informally suggest in text at the beginning is captured by our formalization.

Proposition 4.4.1

It is not the intention, but the knowledge, of opportunistic agents to cause harm to others.

Assume that agent *i* performs opportunistic behavior *a* to agent *j*. With our formalization, we can prove that he knows the performing of this behavior demotes agent *j*'s value, but needs not intend to get this result. Thus, the following property holds:

$$\vDash Opportunism(i,j,a,s) \rightarrow Know_i\big(Eval(j,v,s) > Eval\big(j,v,do(a,s)\big),s\big)$$

$$\nvDash Opportunism(i,j,a,s) \rightarrow Intend(i,a,de(j,v),s)$$

Proof

The first one is already in the definition of opportunism, and we are going to prove the second one. Since the second one means that the implication does not hold in the

model, what we need to do is to find a model where $Opportunism(i, j, a, s)$ is true whereas $Intend(i, a, de(j, v), s)$ is false. The model is given as follows.

Free riding is one of the classic models about opportunism, and it occurs when someone benefits from resources, goods, or services but does not pay for them, which results in either an under-provision of those goods or services, or in an overuse or degradation of a common property resource [26]. Suppose agent *i* is a free rider, then its behavior free riding satisfies the definition of opportunism. We have

$$(\exists v \in V)\big(Poss(i, others, freeride, s) \equiv KnowAsym(i, others, \phi, s)\big)$$
$$\wedge\, Intend(i, freeride, pro(i, v), s) \wedge \phi$$
$$where\ \phi = ValueOppo\big(i, others, v, s, do(freeride, s)\big).$$

Then we have the two sentences below,

$$(\forall s')K_i(s', s) \rightarrow Eval(others, v, s') > Eval\big(others, v, do(freeride, s')\big)$$
$$(\forall s')I_i(s', s) \rightarrow done(freeride, s') \wedge Eval(i, v, s) < Eval(i, v, s'),$$

which mean that agent *i* knows his behavior will demote the value of others, and it is his intention to promote his value by free riding.

However, the following sentence, which means it is agent *i*'s intention to demote the value of others, does not hold in our model,

$$(\forall s')I_i(s', s) \rightarrow done(freeride, s') \wedge Eval(others, v, s) > Eval(others, v, s').$$

It is firstly because, in our formalization, we define K-relation and I-relation are two different types of accessibility relations, and that something holds in the possible situations of knowledge does not mean that it holds in the possible situations of intention as well. Secondly, at the social level, agent *i* does not intend to reduce others' share of public goods. Therefore, $Intend(i, a, de(others, v), s)$does not hold in our model.

□

In other words, agent *i* knows the negative result for other agents, but needs not intend to have it. This property about the correlation between knowledge and intention are similar to the perspective of intention from Cohen and Levesque [12], who claimed that agents need not intend all the expected side-effects of their intention.

5 Example: Selling a Broken Cup

Recall the example that we used to introduce opportunism at the beginning of the paper. The scenario is simple but enough to illustrate how to analyze opportunistic behavior with our formal model. We recap it as follows. A seller sells a cup to a buyer. Since the cup is known to have a crack by the seller, he does not allow the buyer to return the cup in any situations. The buyer buys the cup for its good appearance, but gets disappointed when he uses it at home. The seller's behavior is considered to be

opportunistic because he exploits the asymmetric knowledge about the cup to achieve gain in the transition. We are going to use our formalization and definition to analyze it.

We label the seller and the buyer as s and b, who can be in one of the situations: S_0 (the initial situation, before the transaction) and $do(a, S_0)$ (after the transaction). The seller can either sell the cup ($a = sell(x)$) or keep it. If the seller performs the action $sell(x)$ in S_0, then situation will go to $do(sell(x), S_0)$. The successor state axioms for the functional fluents *Eval* are as follows:

$$Eval\big(s, v, do(a, S_0)\big) = x_s \equiv (\exists y_s < x_s)\, Eval(s, v, S_0) = y_s \wedge a = sell(x) \quad (1)$$

$$Eval\big(b, v, do(a, S_0)\big) = x_b \equiv (\exists y_b > x_b)\, Eval(b, v, S_0) = y_b \wedge a = sell(x). \quad (2)$$

Firstly, we need to specify the precondition of performing action $sell$. Staying in situation S_0, the seller knows the cup is broken while the buyer does not know it. Using our definition, the asymmetric knowledge owned by the seller but not the buyer is not only about the broken cup, but also the state transition: once the transaction finishes, the situation will go from S_0 to $do(sell(x), S_0)$, which gets the value of the seller promoted whereas the value of the buyer demoted. We formalize it as below:

$$(\exists v \in V) Poss(s, b, sell(x), S_0) \equiv KnowAsym(s, b, \phi, S_0) \quad (3)$$

$$where\ \phi = ValueOppo\big(s, b, v, S_0, do(sell(x), S_0)\big).$$

Now consider the value for both parties. Apparently both parties go for economic value. However, they have different and contradictory perspectives about the economic value: the seller wants to sell the broken cup, while the buyer wants a good cup for use. Therefore, what the seller looks at is whether the broken cup is sold or not. When the seller knows the broken cup has already been sold, his value v will get promoted. That is, sentence (1) ensures that

$$Eval(s, v, S_0) < Eval\big(s, v, do(sell(x), S_0)\big) \quad (4)$$

holds. Conversely, what the buyer looks at is whether the cup is good or not. So when the buyer knows the cup is broken, his value gets demoted. That is, sentence (2) ensures that

$$Eval(b, v, S_0) > Eval\big(b, v, do(sell(x), S_0)\big) \quad (5)$$

holds. Sentence (4) and (5) ensure that the axiomatization entials

$$ValueOppo(s, b, v, S_0, do(sell(x), S_0)) \quad (6)$$

for these two parties when situation goes from S_0 to $do(sell(x), S_0)$. Further, since it is the seller's intention to sell the broken cup to the buyer for promoting his value, the sentence below also holds.

$$Intend(s, sell(x), pro(s, v), S_0) \quad (7)$$

With the above formalization, we have the formula of opportunistic behavior for this example.

$$Opportunism(s, b, sell(x), S_0) \leftrightarrow \tag{8}$$
$$(\exists v \in V)\big(Poss(s, b, sell(x), S_0) \equiv KnowAsym(s, b, \phi, S_0)\big) \wedge$$
$$Intend(s, sell(x), pro(s, v), S_0) \wedge \phi$$
$$where\ \phi = ValueOppo\big(s, b, v, S_0, do(sell(x), S_0)\big).$$

From the above analysis, we can recognize two situations that may not be regarded as opportunism. Firstly, if the buyer buys the cup only for decoration without using it, he will never know the cup is broken. In other words, the perspective of the seller getting the cup sold and the perspective of the buyer that the cup is good for decoration are not contradictory. In this case, the seller's behavior may not be opportunistic from the perspective of the buyer, if the social norms are not taken into account. Secondly, if there is nothing the seller can do except sell the broken cup when staying in state S_0, it might look more like self-defense behavior rather than opportunistic behavior. In our example, however, the options available to the buyer in state S_0 are $\{sell, keep\}$, which means selling the broken cup is not the only action that he can perform. Note that the second situation is not included in our definition, since it is supposed to be analyzed with specific scenarios as what we do here.

Further, with the help of our model, we can gain practical insights into constrain mechanism of opportunism. In our case, one important reason why the seller's behavior is seen as opportunistic is that they evaluate the state transition from two contradictory perspectives based on their value systems. In other words, even though they both go for economic value, they look at different things for evaluation. When applying this approach in collaborative relationship, it is much easier to understand how the relationship ends from defection. Therefore, one deterrence mechanism for partner opportunism is to avoid having contrasted value systems in the relationship. As for the precondition of opportunism, even though it is difficult to prevent knowledge asymmetry in business transactions, we still need to think about how much information we can provide to our partners and how they are going to use the information.

6 Discussion

As it is the first step of our work, we try to propose a simple but elegant model of opportunism by making restricted assumptions. But it also means that the model might not manage to capture every possible scenarios. For instance, the model only considers the interaction between two agents. So in section 4.2 we only investigate the evaluation on the state transition from the perspectives of the two agents who are involved in the transaction. But actually such evaluation can also be done by others. Assume that a person sees the transaction and his value system is incompatible with agent *i*'s. He may get angry with the seller even though he is not involved. In this sense, the behavior that is performed by agent *i* is considered to be opportunistic from

the perspective of the third person. Similarly, what agent i does is regarded as opportunistic by the whole society if it is against the society's value system. Therefore, our model is needed to be extended to have the perspective of others about the behavior. Further, we only consider one action to be opportunistic in our model, but in reality opportunistic behavior may consist of sequential actions, which result in a series of state transitions. Only when we take into account the whole path of the state transitions by those actions is it indeed opportunistic. That is, the symbol a in the formula can be replaced by a sequence $[a_1, a_2, \dots, a_n]$.

By this model, we also propose that the asymmetric knowledge obtained by opportunistic agents is value opposition about the state transition, which not the same as our intuition. The reason can be shown by the example in section 5. Intuitively the asymmetric knowledge that the seller has is about the broken cup. Now we assume that both the seller and the buyer know the cup is broken and the seller sells it with a high price. Once the buyer knows that the broken cup is not worth that price, his value will get demoted. From that we can see it does not matter whether the fact about the broken cup is only known by one party beforehand, but whether value opposition about the transaction is only known by one party beforehand. In other words, the asymmetric knowledge is not about the objective fact, but about agents' evaluation on the state transition.

7 Related Works

Opportunism is not a new topic in social science. Since it was released by economist Williamson, scholars have studied the typical social behavior of economic players from various perspectives i.e. transaction cost economics [13], resource-based view [14], game theory [15], agency theory [16] and strategic management [17]. Even though they are indeed all worthwhile, it is difficult to directly apply their conclusions to MAS for improving the system's behavior because most of them are informal, which makes reasoning about this behavior in MAS impossible, and also not commonly accepted even in their own area.

In the field of artificial intelligence, there is a tradition to devise intelligent artifacts and construct intelligent system using symbolic representation of all factors involved [18]. Especially for mathematical logic, it is a great important approach to this field due to its highly abstract representation and reasoning about social reality. Therefore, a lot of work on logic formalism has been designed for representing and reasoning about dynamical domains such as situation calculus [19], event calculus [20] and fluent calculus [21]. We choose to use situation calculus as our basic framework because it has been well developed and extended with knowledge [10], belief [9] and other model semantics. In [10], an epistemic fluent $Know(P, s)$ is proposed by adapting the standard possible-world model of knowledge to situation calculus. We use this approach to define knowledge asymmetry where agents possess different amount of knowledge.

We integrate value into situation calculus to represent agents' evaluation on situations and state transitions. However, in logical formalization, people usually use goals

rather than value (e.g. [12][22]) for the same purpose. Only some works in the area of argumentation reason about agents' preferences and decision making by value (e.g. [23] [24]). Even though both goals and values can be used to represent agents' preferences about situations, they have different features. Goals are concrete and should be specified with time, place and objects. For example, to earn 1000 euros next month is a goal. If one agent's goal is achieved in one situation, then he has high evaluation on that situation. Value is described by Schwartz as trans-situational [25], which means that value is relatively stable and not limited to apply in a specific situation. For instance, if honesty is a value of somebody, he will be honest for a long period of time. Since state transition results from the performing of actions, we can evaluate actions by the degree in which our value is promoted or demoted, as what we do in this study. Of course, people always want to promote their value. However, different individuals may have different perspectives and orderings of values, which are important elements of their value systems. People evaluate the same state transition based on their own value systems and may have various results. Thus, we use value variation to represent agents' different evaluation on the state transition by opportunistic behavior.

8 Conclusions

Agents situated with information asymmetry might perform opportunistic behavior to others in their interest. Numerous works about such a social behavior have been seen in social science due to its negative effect on the relationship. However, most conclusions are based on a given form of opportunism, making it hard to build a fundamental theory that can be applied in any contexts. This study took the initiative to propose a formal model of opportunism based on the extended informal definition from Williamson. The modeling work was done based on situation calculus. Through the model, we demonstrated that value opposition is the property of the state transition by an action and comes from different perspectives about the value. Therefore, we proposed that the judgment of opportunism is subjective since it depends on from which perspective agents evaluate the state transition. Moreover, we also showed that the asymmetric knowledge owned by agents is the knowledge about the state transition, which should be differentiated from the intention of opportunism self-interest.

It is important to keep in mind that our aim is not to indicate where opportunistic behavior comes from through the model we propose, as before coming to this part we should have a better understanding of the nature of opportunism. Therefore, the main strength of this study is defining such a behavior in a formal way, so as to specify the crucial elements in the definition and how they relate to each other, and show the properties that were confusing before but are quite useful for future study. Only when all those things are clear can we have further study on its emergence and design constraint mechanism to reduce its occurrence.

One limitation for our current study is about agents' evaluation on the state transition. In this paper, we assume that agents can always evaluate a situation and have preference based on their value system, which means that we can compare any two situations that are linked by actions. However, sometimes it is difficult to have an

answer to a comparison because we don't have any preference for the two things. For example, given a color set {red, white, blue}, one prefers red to white, but has no preference between red and blue, and, white and blue. In this case, the single state transition from red to blue and from blue to white does not mean anything, but the whole path from red to white does demote one's value. Another reason is the lack of information. If the information by which agents evaluate the state transition is blocked, agents may not have an answer to the comparison of the situations. Therefore, it will be fairly interesting and meaningful to include this possible situation for elucidating and generalizing our definition and study the relation among information that agents obtain, evaluation on state transition over value, and opportunism.

Another avenue would be to investigate how opportunism emerges based on the definition of opportunism. As we mentioned in our example, agents are not able to perform opportunistic behavior if the precondition knowledge asymmetry fails. However, such a situation is unrealistic since agents usually stay in different positions where agents possess different amount or quality of information so that knowledge asymmetry is unavoidable. Therefore, we need to think about how much information and what kinds of information we can share with our partners. Moreover, agents' having different perspectives on the same value is the reason to value opposition of a state transition. So it is natural to think about how agents evaluate a situation from their perspectives and how the perspectives relate to their value systems for the study of opportunism emergence. Considerable insights can be achieved from the investigation about the compatibility of different value systems and the co-evolution of agents' value system with social context or environmental changes.

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