Ontological modeling of emotion-based decisions

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Abstract. In this paper, we discuss a number of elements for developing an ontological model for representing decision making of human agents. In particular, our aim is to connect the results in cognitive science that show how emotions affect decisions with agent systems and knowledge representation. We focus in particular on the case of regret.

1 Introduction

Modeling real agents’ decisions in real-world scenarios is a challenging problem for multiagent systems, normative systems and knowledge representation studies. When designing formal systems that are intended to provide tools to assist the organization of human agents’ interaction and decision making (e.g. socio-technical systems, organizations, law, [2]), it is important to account for what a real agent would do in order to evaluate the system or to design efficient prescriptions. For example, imagine a security officer in an airport (a typical case of socio-technical system, in which processes are carried out partly by humans and partly by artificial agents), who has to decide whether to check a customers’ belonging or not. This is a decision to be taken under uncertainty and risk conditions, as the officer has to judge, without much information, whether the customer could be a suspect. Moreover, we can associate payoffs to the officer’s decision: the officer’s utility increases if (s)he checks a customer that turns out to be a suspect, it may decrease in case (s)he loosens time in checking regular customers, it may decrease significantly in case (s)he misses a dangerous suspect by not checking him/her. When designing tools to aid or to evaluate decisions in such a scenario, it is important to understand and to represent how real agents face this kind of situations. Decision theory and expected utility theory have been widely studied in economics and they provide prescriptions that represent what an abstract rational agent would do in risky situations. Real agents, however, often exhibit behavior that significantly diverge from expected utility theory prescriptions [3]. Since the works of Kahneman and Tverski [9], models that are able to represent cognitively biased decisions under uncertainty and risk have been developed. Moreover, several results in the decision making field and in behavioral game theory show how emotions affect decisions under uncertainty and risk (e.g. [11],[7],[5],[4],[12], [8]).

For the sake of example, we shall focus on investigations in neuroeconomics that show how emotions like disappointment or regret play an important role in the way in which agents evaluate risk. The distinction between disappointment and regret is significant in order to model in a principled way expectations of what agents would do
in a given scenario. Both emotions are reactions to an unsatisfactory outcome and both arise from counterfactual thinking. In particular, following the analysis in [14], regret is based on *behaviour-focused counterfactuals*, whereas disappointment is based on *situation-focused counterfactuals*. The difference being that regret entails that the agent directly chose a course of actions with an unsatisfactory outcome and a better choice would have been available, whereas disappointment entails that the agent bears no direct responsibility for the choice and its outcome. Or, better, both depend on what the agent believes about his/her responsibility with respect to the negative outcome [17]. Results in neuroeconomics show for example that regret leads to riskier choices [8], whereas, in the case of disappointment, there is no relevant influence on the level of risk of the subsequent choices. In our airport example, suppose the officer checks nearly every passenger and the procedure takes so long that the flight must be delayed. Suppose also that the airline officially complains with the security company. Disappointment may be caused in case an external decision, like a supervisor’s order, has forced the officer to check all passengers. By contrast, regret may be a consequence of the officer’s decision of checking all passengers. The results that we have mentioned state that it is likely that, after (s)he has felt regret, the officer’s behavior on his/her successive choices is going to be riskier, for instance leading him/her to lower security standards. In case of disappointment, his/her behavior does not vary considerably with respect to subsequent choices. The aim of this paper is to introduce a number of important elements in order to develop a model that is capable of representing and accounting for the effects of emotions in decision making. Moreover, the model has to interface such information with the normative specifications of the system the agent is living and acting in.

In order to achieve our goal, we start developing an ontological analysis of the elements that constitute agents’ decisions. The motivations behind our choice to adopt an ontological approach are manifold. First of all, we are interested in applications in socio-technical systems, and in particular in designed systems where multiple artificial agents interact with humans. A well-founded ontological model should, on the one hand, allow humans to better understand the system they are living and acting in and, on the other hand, once embedded in an artificial agent, should enable the latter to automatically reason about the system, and to exchange information with other (human and artificial) agents in a sound and interoperable way. In particular, including the representation of emotions and of their influence on decisions into the ontological model, should provide the artificial agents with means for interpreting, evaluating, and possibly foreseeing humans’ decisions.

We shall use the approach to ontology provided by DOLCE [10] as it is capable of specifying some of the essential elements that we need for our analysis; in particular, we will focus on the notions of agent (inspired by the belief-desire-intentions (BDI) model), of course of actions, decision, outcome, and notions describing the emotions that may affect the decision. The remainder of this paper is organized as follows. In Section 2, we discuss the elements of the ontological model we are interested in developing and we present our discussion of emotion-based decisions. In Section 3, some final remarks are drawn.
2 Ontological analysis: DOLCE

We present some features of DOLCE [10], the ground ontology, in order to place the elements of our analysis within the general context of a foundational ontology. The ontology partitions the objects of discourse into the following basic categories: endurants (intuitively, objects) ED, perdurants (intuitively, events) PD, individual qualities Q, and abstracts ABS. Individual qualities are entities that agents can perceive or measure or evaluate that inhere to a particular. For example, “the color of my car”. They are partitioned into quality kinds Qk, such as the color, the weight, the length. Examples of abstracts are provided by the categories of spaces. Spaces intuitively represent values for quality kinds. The relationship between quality kinds and spaces is modeled by the location relation \( \text{loc}(q_k, s_k) \) that means, for example, that the redness of John’s car is located at a certain point in the space of colors.

Figure 1 shows the categories we are interested in. We restrict our presentation to the case of endurants, namely we focus on the objects of emotions or decisions.

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1 We present the descriptive features of DOLCE. For implementability issues, see [10].
2.1 Plans and decisions

We follow the analysis of plans and norms provided by [1], that introduces a new basic category of situations. Situations may be viewed as complex perdurants and they may be also considered a type of (possibly partial) events. Ho let to queste cose 100 anni fa e non ricordo null6 davvero le situazioni possono essere sia endurant che perdurant? Ti credo che a ]icola non sono mai piaciuteh evo guardarmi il paper :gents refer to or think about situations by means of \( S \)-Descriptions (descriptions of situations). Plans are thus a subcategory of \( S \)-Descriptions, they are the way in which agents think about situations. Plans are complex objects as they may be composed of a number of tasks, they have preconditions, post-conditions, and so on [1]. An agent may think about several plans (i.e. several courses of action). Following the BDI model [15], we represent an agent that is willing to bring about a particular plan \( p \) by means of the relation \( \text{has}_{\text{BDI}}(i, p) \) which holds between an agentive object \( i \) and a plan \( p \) when the agent has the relevant beliefs, desires, intentions to bring about the plan: \( \text{has}_{\text{BDI}}(i, p) \).

In order to evaluate the consequences of a plan for an agent, we consider the situation that is the outcome of the plan: \( \text{Out}(s, p) \). We introduce a preference relation on situations \( \text{Pref}(s, s', i) \) meaning that the agent \( i \) prefers situation \( s \) to situation \( s' \). Moreover, we introduce a preference relation on plans: an agent \( i \) prefers the plan \( p \) to \( p' \), \( \text{Pref}(p', p, i) \), iff the outcome of \( p \) is preferred to the outcome of \( p' \) by \( i \). In our model, a decision that an agent takes is a choice between plans. According to expected utility theory, we denote \( u_i(s) \) the utility for agent \( i \) of situation \( s \) and the expected utility of \( s \) as \( u_i^e(s) = u(s) \cdot \pi(s) \), where \( \pi(s) \) is the probability of \( s \) to be the case.

Riscritto un po’ In order to represent uncertainty in our ontological model, we introduce a quality kind \( Q_L \) for the likelihood of situations, that is used to express the extent to which the agent views the situation as likely. Moreover, we assume a quality space \( S_{1_L} \) to represent probability values. By modeling the likelihood of a situation as an individual quality, we are assuming that human agents can measure or evaluate the likelihood of situations and this is compatible with the psychological literature, see for example [9]. We define the location relation \( \text{loc}(q_s, l_s, i) \) that associates the likelihood quality \( q_s \) of the situation \( s \) with the probability \( l_s \) according to agent \( i \)’s view. The relationship with decision theory is the following: we can view situations as the space of events and the quality as the mapping of values of a probability distribution that \( i \) defines on events. Note that, since a plan describes a complex situation, the probability of the execution of the plan has to be computed taking into account conditional dependencies of sub-situations that occur in the plan. We are not going to go into the details of computing the probability and we abstractly represent the likelihood of a plan by means of the likelihood of its outcome: \( \text{Out}(p, s) \wedge \text{loc}(q_s, l_s, i) \). According to expected utility theory, the abstract rational agent would choose the plan \( p \) that maximizes the expected utility \( \text{has}_{\text{BDI}}(i, p) \leftrightarrow \neg\exists p' \text{Pref}(p, p', i) \), where \( i \)’s preferences are defined as: \( \text{Pref}(p, p', i) \) iff the expected utility of \( p \) is greater than the expected utility of \( p' \). However, as our discussion is centered on human agents, there may be several reasons that prevent it to be the case (besides not knowing what the best plan is), as recent studies

\[ ^2 \text{Agentive objects allow for distinguishing decisions taken by agentive physical objects, e.g. a person, and agentive social objects, e.g. a person in the role of an officer.} \]
in behavioral decision [18] making have already pointed out. As we have seen, in the context of risky choices, regret is one of these reasons.

2.2 Representing emotion-based decisions under uncertainty

An ontological analysis of the BDI model and of emotions has been developed in [13] and [6]. In particular, feelings like disappointment and regret can be categorized as particular complex feelings3, which are in turn particular types of complex percepts. Complex feelings depend on primary feelings (PEL) as well as on beliefs. Our analysis of the distinction between disappointment and regret is then the following. For reasons of space, we omit the subtleties of the analysis in [13] and we define regret and disappointment referred to a situation that is the outcome of a plan. We introduce a dependence relation of a mental object $x$ on a situation $s$, $Dep(x, s)$. At this level of analysis, the relation $Dep$ is very abstract and it may be open to several interpretations: a situation may cause disappointment because of some of the objects that participate in the situation (e.g. the outcome of the plan is an asset for which the agent gets a very low payoff) or because of some property of the situation itself (e.g. the outcome of the plan is an event that entails waiting in line in a long queue). Regret is caused by the negative outcome of a plan that is chosen by agent $i$ in spite of the existence of an alternative plan $p'$ that the agent might have chosen with a better outcome4. Disappointment is caused by a plan whose outcome is dominated by another situation, but $i$ is not responsible.

$$\text{REGO}(x, i) \equiv APO(i) \land PLN(p) \land Dep(x, s) \land Out(p, s) \land has_BDI_on(i, p)$$
$$\land \exists p' \text{pref}(p, p', i)$$

(1)

$$\text{DISO}(x, i) \equiv APO(i) \land PLN(p) \land Dep(x, s) \land Out(p, s) \land \exists p' \text{pref}(p, p', i)$$

(2)

The condition $APO(i)$ specifies that the emotions apply to agentive physical objects and the condition $PLN(p)$ specifies that both emotions are dependent on the outcome of a plan. The distinction shows that, in case of regret, the actualization of the outcome is caused by the agent’s choice, whereas disappointment is caused by the negative outcome deriving from a course of actions triggered by someone else’s choice, namely by another plan. Note that the definition of disappointment is narrower than its intuitive meaning, as it makes the disappointing situation depend on the course of action described by a plan, i.e. decided by someone else. However, our definitions avoid unintuitive cases such as being disappointed by any possible disfavored event. A more precise definition can be formulated by introducing hope or expectations [13]. We can now present our preliminary analysis of how regret that is caused by a particular choice

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3 Disappointment and regret can be more precisely defined as cognitive emotions [16]; here we use the locution “complex feelings” following [13].

4 The responsibility of a choice of a plan is defined by $has_BDI_on$. A closer examination shall single out the role of intentions in taking responsibility. We leave this point to future work.
of \( p \) may affect subsequent choices of plans. We define it as a reason to choose a plan, namely we restate the definition of \( \text{has BDI on} \). We present it in a semi-formal way in order to avoid introducing the relevant elements of temporal analysis and of expected utility theory.

**Definition 1.** An agent \( i \) has BDI on a plan \( p \) at time \( t \) iff either \( p \) is its most preferred implementable plan; or \( p \) is dominated by \( p' \), \( p \) is more risky than \( p'' \), \( p \) has a higher utility value, and there is a precedent time \( t' \), such that the agent has chosen \( p' \) and \( p' \) has caused regret on \( i \).

### 3 Conclusion

We have presented a number of elements that are important to develop an ontological analysis of the role of emotions in decision making. In particular, we have sketched how to integrate in DOLCE decisions as choices between plans, emotions, and risk attitudes. Future work shall provide a tighter connection between the cognitive and the normative modules of DOLCE and the analysis of decisions under uncertainty.

There are several possible extensions of the present work, which is centered on the influence of regret on risk-seeking behavior, for what concerns a single agent. However, in environments populated by more agents, as for instance multiagent systems, understanding and modeling how beliefs, emotions and expectations mutually influence each other becomes particularly important. In such systems agents, while planning, should try to foresee which would be the preferences of the other agents and their propensity to risk, given also the previous history. It is worth noting that, in the specific case of regret, when other agents are involved, the agent who was in charge of the choice may feel regret for him/herself and guilt with respect to the others, who in their turn can feel disappointment for the negative outcome. Furthermore, we could also think about the emotional reactions following collective decisions. In the more specific case of socio-technical systems, decisions can also depend on the performance of technical devices, so not directly from agents, but there may be agents who are responsible of the functioning of such devices (sometimes their designer may be at the same time a participant of the system) and may eventually feel regret. It is exactly in such complex scenarios that the use of the ontological approach is especially useful. Finally, so far we have focused just on a specific emotion, regret (and marginally disappointment), and a specific attitude, propensity to risk, but cognitive science studies have dealt with other emotions, like fear, sadness, happiness, anger, guilt etc. and also with other mental attitudes, like for instance propensity to cooperation, that can affect each other and then influence (individual and/or social) decisions. There are then many possible extensions to this preliminary model that, once complete, could be also implemented in artificial agents, thanks to the use of ontologies.

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