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RESEARCH ARTICLE

Emotions as a vehicle for rationality: Rational decision making models based on emotion-related valuing and Hebbian learning

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Abstract
In this paper an adaptive decision model based on predictive loops through feeling states is analysed from the perspective of rationality. Hebbian learning is considered for different types of connections in the decision model. To assess the extent of rationality, a measure is introduced reflecting the environment's behaviour. Simulation results and the extents of rationality of the different models over time are presented and analysed.

Introduction

Decision making usually involves considering different options and comparing them in order to make a reasonable choice out of them. Each option has an associated emotional response, related to a prediction of a rewarding or aversive consequence of a choice for that option. The extent to which such an emotional response associated to an option is felt as positive, is often seen as a form of valuing of the option. In decisions such valuing plays an important role, and can be seen as a grounding for the decision. Decisions that are not solidly grounded by having a positive feeling about them often do not last long, as any opportunity to get rid of them will be considered to cancel the decision.

In recent neurological literature this idea of emotional valuing (and grounding) of decisions has been related to a

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notion of value as represented in the amygdale; e.g., (Bechara, Damasio, & Damasio, 2003; Bechara, Damasio, Damasio, & Lee, 1999; Montague & Berns, 2002; Morrison & Salzman, 2010; Ousdal et al., 2014; Pessoa, 2010; Rangel, Camerer, Montague, 2008; Rudebeck & Murray, 2014). A question that may be put forward is whether such decisions based on emotional valuing are not in conflict with rational behaviour. Indeed, there is a long tradition in considering emotions and rationality enemies of each other. It is this theme that is the focus of this paper. It will be discussed and computationally evaluated how emotions are not an enemy but a vehicle for rationality. It will be investigated in what sense emotional valuing as a basis for decision making satisfies some rationality criterion.

Making a decision is not just an instantaneous process in the present. Instead, decision making has an embedding in the temporal dimension; earlier situations are relevant as well, and it also has implications for future situations. More specifically, experiences with (outcomes of) decisions made within the given environment from the past play an important role. Learning processes adapt the decision making mechanism to such experiences. In this way the decisions become more reasonable, or in some way rational, given its increasing knowledge about the environment built up by these past experiences. The question to which extent such learning based on specific biologically plausible learning models leads to decision making satisfying some rationality criterion will be addressed in this paper.

The computational model for decision making considered here, for a given (observed) situation first generates preparations for a number of options, relevant for that situation. Next, based on predictive as-if body loops, associated feeling states are generated, in order to obtain emotional valuations of the options; e.g., (Damasio, 1994, 2004, 2010; Janak & Tye, 2015; Ousdal et al., 2014; Pearson, Watson, & Platt, 2014; Pessoa, 2010; Rangel et al., 2008). The extent to which such a feeling state is positive, strengthens the preparation for the related option. Through this process a strongest option emerges which can become the outcome of the decision. For this selection process mutual inhibition relations may be added. The type of biologically inspired learning considered is Hebbian learning (cf. Gerstner & Kistler, 2002; Hebb, 1949), in four different variations by applying it to different types of connections in the decision model.

In order to assess whether a specific decision making model can be considered as being rational, first a notion of rationality is needed. Such a notion strongly depends on characteristics of the environment. What is rational in one environment may be totally irrational in another environment vice versa. For example, throwing a ping pong ball (for table tennis) to hit something can be quite rational in an indoor environment without wind, but totally irrational in a stormy environment outdoor, as the effects of such an action will be totally different. Therefore a rationality measure needs to reflect the environment's characteristics in the sense of its behaviour when actions are performed. Two examples of such a rationality measure will be defined and applied to assess the computational decision model. The point of departure for the underlying notion of rationality here is that the more the agent makes the most beneficial choices for the given environment, the more rational it is.

In this paper, in Section 'The adaptive decision model addressed' the decision model and the different variants of adaptivity considered are introduced. Sections 'Simulation results for a deterministic world', 'Simulation results for a stochastic world', and 'Simulation results for a changing stochastic world' present a number of simulation results for a deterministic world, a stochastic world and a changing world, respectively. In Section 'Evaluating the models on rationality' measures for rationality are discussed, and the different models are evaluated. Finally, Section 'Discussio n' is a discussion.

The adaptive decision model addressed

Traditionally an important function attributed to the amygdala concerns the context of fear. However, in recent years much evidence on the amygdala in humans has been collected showing a function beyond this fear context. In humans many parts of the prefrontal cortex (PFC) and other brain areas such as hippocampus, basal ganglia, and hypothalamus have extensive, often bidirectional connections with the amygdale; e.g. (Ghashghaei, Hilgetag, Barbas, 2007; Janak & Tye, 2015; Likhtik & Paz, 2015; Morrison & Salzman, 2010; Salzman & Fusi, 2010). A role of amygdala activation has been found in various tasks involving emotional aspects; e.g., (Lindquist & Barrett, 2012; Murray, 2007; Pessoa, 2010). Usually emotional responses are triggered by stimuli for which a prediction is possible of a rewarding or aversive consequence. Feeling these emotions represents a way of experiencing the value of such a prediction: to which extent it is positive or negative for the person. This idea of value also plays a central role in work on the neural basis of economic choice in neuroeconomics. In particular, in decision-making tasks where different options are compared, choices have been related to a notion of value as represented in the amygdale; e.g., (Bechara et al., 1999, 2003; Montague & Berns, 2002; Morrison & Salzman, 2010; Ousdal et al., 2014; Pessoa, 2010; Rangel et al., 2008; Sugrue, Corrado, & Newsome, 2005).

Damasio (1999, 2010) distinguishes an emotion (or emotional response) from a feeling (or felt emotion); see for example:

> 'Seen from a neural perspective, the emotion-feeling cycle begins in the brain, with the perception and appraisal of a stimulus potentially capable of causing an emotion and the subsequent triggering of an emotion. The process then spreads elsewhere in the brain and in the body proper, building up the emotional state. In closing, the process returns to the brain for the feeling part of the cycle, although the return involves brain regions different from those in which it all started.' (Damasio, 2010, p. 111)