Decision Making as a Closed-Loop Process

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Abstract

The theory of decision making has largely been developed as a disembodied open-loop process, however there is growing recognition that ecologically valid scenarios require integration of movement dynamics into current decision making theory, and a revision of what are considered to be core/fundamental decision components.

Here we develop the theory of decision making as a closed loop process, first exploring the role of confidence both as a neural computation within the loop, affecting movement dynamics and as a property of the egocentric frame with a causal influence on cognition. Secondly, we consider the relationship between closed-loop components/processing and stability — in embodied systems action is accumulated and so physical restrictions limit volatility, moreover the reciprocal relationship between movement and evidence processing means that this stabilisation may also happen on a neural level in the form of a biased gain during evidence accumulation, improving stability/convergence.

Finally, we examine closed-loop embodied decision making in the context of optimality — it is generally accepted that open-loop decision making is optimised to maximise reward via some form of Bayes' Risk, prescribing a speed-accuracy tradeoff in so doing. For closed-loop decision making however, the form of the 'objective function' is unknown, as such we consider higher level, ecologically inspired ideas of optimality such as adaptability to e.g. moving targets or nonstationarity, to explore this fundamental aspect of embodied decision making. Our results build on a growing body of work which points to embodiment as fundamental to understanding both behavioural and neural aspects of decision making.

Framework & Background

To explore the general principles of embodied decision making, we adopt the framework used by Lepora and Pezzulo (2015) based around a simple mouse-tracking 2-choice experiment. This framework separates distinctly the neural mechanisms from the behavioural – neural, in the form of evidence accumulation, and behavioural, in the form of spatial information; position and movement.

Under this framework, Lepora and Pezzulo (2015) find embodiment to have the key implication that a decision is not made simply when neural populations reach a threshold of activity, as has been recorded in immobilised decision making tasks in e.g. area LIP (Churchland, Kiani, & Shadlen, 2008), but when the action is complete, e.g. the cursor is placed on a target indicating the choice. To allow convergence to choice in a manner consistent with experimental data they consider two concepts – action preparation, and commitment – these bidirectionally connect the neural and behavioural components by utilising neurally represented evidence in movement modification (action preparation), and incorporating positional information into evidence accumulation (commitment), doing so renders the model entirely embodied and 'closes the loop'.

The strength of this model is its explanatory power using only evidence accumulation and spatial information. However, a number of questions remain unanswered; How does confidence affect action accumulation? Does an embodied closed-loop system have profound effects on behavioural and neural stability? Can we think of embodied closed-loop decision making in terms of optimality, as we do with traditional decision making paradigms? Within these broader questions are a number of consequential outcomes, for example, what governs action initiation?

We develop the theory of decision making as a closed-loop process around these questions. With reference to experimental results, we build an intuition for the influence of decision components and the fundamental relationship between neural and behavioural mechanisms.

References

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