Neural and behavioral mechanisms of action selection in value-based decisions: A computational approach

V N Christopoulos, J Bonaiuto, R A Andersen

Division of Biology, California Institute of Technology, Pasadena, CA

In high-pressure situations, such as the penalty kick in a soccer game, people have limited time to decide. For instance, the goalie could either try to guess the ball's direction prior to the kick, or he might not discard any option waiting until the last second to make a decision. How does the brain select between alternative actions? Economic theories suggest that decisions are made through a comparison of abstract representations of outcomes. When a decision is made, the action planning begins. Despite the attractiveness of this approach, it is limited by the serial order assumption. Recent studies argue against a purely sequential process, suggesting that decisions are made through a competition between potential actions. Our lab has previously presented a framework to model this view, showing how the complex problem of action selection can be decomposed into a weighted mixture of policies related to the alternatives. Although, this framework captures many aspects of behavior, it is limited only to behavioral data and does not provide information about the neural mechanisms underlying action selection.

In the current study, we extend this framework by integrating a dynamic neural field (DNF) model with stochastic optimal control, providing the computational instantiation of the neural and behavioral mechanisms of action selection, Fig.1. The framework architecture consists of multiple DNFs that simulate the neural processes underlying cue perception, expected reward, selection bias and effort. The outputs from these DNFs are inputs into another DNF that integrates the value information and activates the corresponding policy for planning an action to the goal. Once a policy is active, an optimal controller generates an action-plan towards the corresponding direction. The output of the DNF encodes the relative "desirability" of each policy and the fields' activity is used to weight the influence of each policy to the final action. Depending on the inputs to the field and its dynamics, this can result in winner-take-all selection or a weighted average of several competing policies.

We evaluated the performance of this framework in a series of visuomotor decision tasks and found that it predicts many characteristics of neurophysiological and behavioral data (a characteristic example is shown in Fig.2). Consistent with experimental data, we show competitive interactions between neuronal populations related to potential targets prior to movement onset. We also make novel predictions on how neuronal populations interact in reaches and saccadic movements with competing targets.

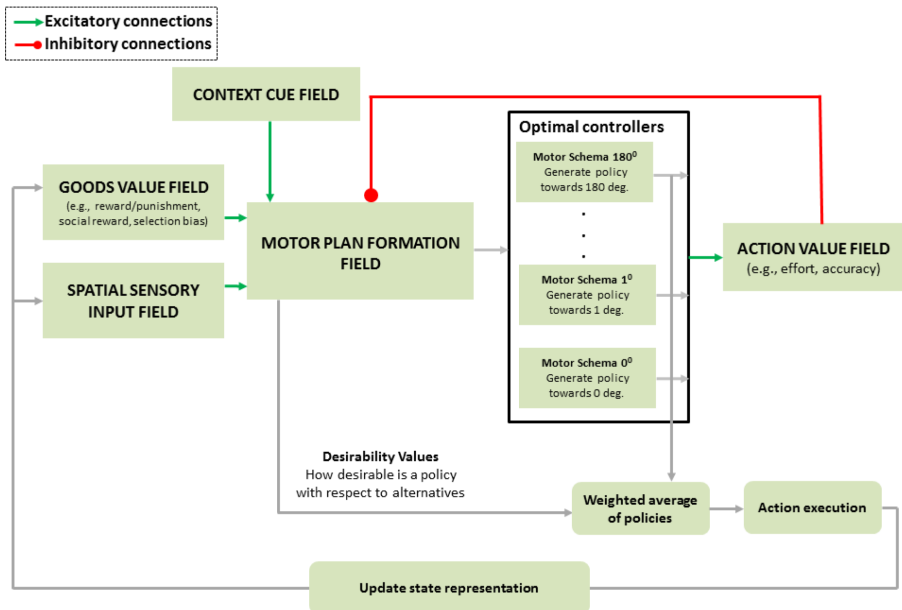

Fig.1: Model architecture: The core component is the motor plan formation field that integrates value information from disparate sources. It receives excitatory inputs from: a) The spatial sensory input field that encodes the angular representation of the alternative goals, b) the goods-based field that encodes the expected benefits for moving towards a particular direction, c) the context cue field that represents information related to the contextual requirement of the task. The motor plan formation field receives inhibitory input from the action value field, which encodes the action cost to move towards a particular direction (see main text for more details).

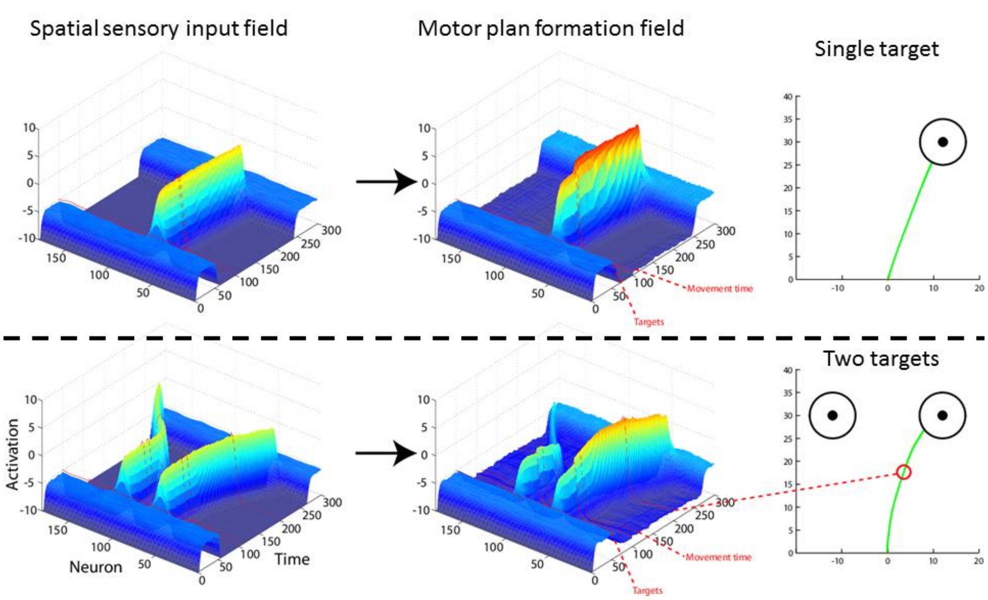

Fig.2: Characteristic examples of the simulated model activity in a single-target and two-targets reaching trials with the corresponding reaching trajectories. Notice that in the single target trial, the model generates a direct reach to the target. However, when two targets are presented, the model generates a curved reach due to the influence of the neurons selective for the direction of the non-selective target.