Natural action selection, modeling

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Put simply, action selection is the task of deciding 'what to do next'. As a general problem facing all autonomous entities—whether animals or artificial agents—action selection exercises both the sciences concerned with understanding the biological bases of behaviour (e.g., ethology, neurobiology, psychology) and those concerned with building artefacts (e.g., artificial intelligence, artificial life, and robotics). The problem has two parts: what constitutes an action, and how are actions selected?

Models of natural action selection allow us to test the coherence of proposed social and biological theories. Although models cannot generate data about nature, they can generate data about theories. Complex theories can therefore be tested by comparing the outcome of simulation models against other theories in their ability to account for data drawn from nature. Each model attempts to account for transitions among different behavioural options. A wide range of modelling methodologies is currently in use. Formal, mathematical models have been complemented with larger-scale simulations that allow the investigation of systems for which analytical solutions are intractable or unknown. These include models of artificial animals (simulated agents or robots) embedded in simulated worlds, as well as models of underlying neural control systems (computational neuroscience and connectionist approaches). A potential pitfall of more detailed models is that they may trade biological fidelity with comprehensibility.

General challenges facing models of action selection include: Is the model sufficiently constrained by biological data that it captures interesting properties of the

target natural system? Do manipulations of the model result in similar outcomes to those seen in nature? Does the model make predictions? Is there a simpler model that accounts for the data equally well? Or is the model too abstract – are its connections to data trivial, making it too obvious to be useful?

Models of natural action selection have delivered new insights in many domains. What follows is a review of several: the relationship between evolved behaviour and optimality, biological mechanisms of action selection, whether or not sequencing behaviour can require special representations, the role of perception, explanations of disability or disease, and finally individual action selection in a social context.

Action selection and optimality

When an animal does one thing rather than another, it is natural to ask 'why?' A common explanation is that the action is optimal with respect to some goal. Assessing behaviour from a normative perspective has particular value when observations deviate from predictions, because we are forced to consider the origin of the apparently suboptimal behaviour. One approach is via the notion of 'ecological rationality': cognitive mechanisms fit the demands of particular ecological niches and may deliver predictably suboptimal behaviour when operating outside these niches. Models assist this approach by determining the behavioural consequences of hypothesized 'optimal' mechanisms. Modellers can also use automated optimization techniques such as genetic algorithms (a machine learning technique inspired by Darwinian selection) to find mechanisms delivering near-optimal behaviour in specific contexts.

Neural substrates

An important open question is whether there are specialized mechanisms for action selection in brains. Arguably, such a mechanism should have properties including (i) inputs that signal internal and external cues relevant to decision-making, (ii) some calculation of urgency or 'salience' appropriate to each available action, (iii) mechanisms

enabling resolution of conflicts between competing actions based on their relative salience, and (iv) outputs that allow the expression of winning actions whilst disallowing losers. Recent computational modelling has focussed attention on the *basal ganglia* (a group of functionally related structures in the vertebrate midbrain and forebrain) as meeting these criteria. Other large-scale models encompass both cortical and sub-cortical mechanisms, indicating that in animals there may be a range of selection mechanisms interacting at different levels of the neuraxis.

Behavioural sequencing

Adaptive action selection requires generating behavioural sequences appropriate to achieve longer-term outcomes. Such sequences often appear to have a hierarchical decomposition, with selection taking place at multiple levels of abstraction – from choosing among high-level objectives (e.g. whether to eat, drink, or rest) through to selecting specific movements implementing the same immediate goal (e.g. which grasp to use in picking up a cup). Computational models have explored not only this approach, but also the alternative – that apparently hierarchical behaviour may be implemented by a framework without a hierarchical decomposition.

Perceptual selection in decision-making

Action selection is mediated by perception as much as by motor control. For example, selective attention can guide action by linking specific motor outputs to one among a range of stimuli. Recent models such as the 'leaky competing accumulator' show that noisy sensory evidence supporting each of a range of alternatives can be accumulated until one option passes a threshold, triggering an action. This model explains experimental data and is mathematically optimal in some conditions. More generally, action selection is sometimes modelled via competing, nested, sensorimotor loops with no clear decomposition into 'sensory' or 'motor' components.

Disorders of action selection

The normal flow of integrated behaviour can become disrupted following neurological damage or disease. Models have suggested that conditions including Parkinson's disease, schizophrenia, Huntington's disease, and obsessive-compulsive disorder, can be linked to the same cortico-basal ganglia circuits that have been identified as possible substrates for action selection. Computational models of these substrates have been used to provide improved explanations for how these disorders arise and to investigate possible avenues for treatment.

Action selection in social contexts

In nature, action selection usually involves a social context. Agent-based models of social action selection explore interactions among individuals mediated both directly and indirectly via, for example, resource consumption. Examples include minimalist models of factors that influence the troop structure of primate species and models of how ants determine when and where to move a colony to a new nest; models can even explore patterns of voting in a democratic society. Modeling also allows examination of evolutionary mechanisms operating on individuals that lead to social outcomes.

Summary

The study of action selection integrates a broad range of topics including, but not limited to, neuroscience, psychology, ecology, ethology, and even political science. These domains have in common a complexity that benefits from advanced modelling techniques, exemplifying the notion of 'understanding by building'. These techniques can help answer many important questions such as: why animals, including humans, sometimes act irrationally; how damage to neural selection substrates can lead to

debilitating neurological disorders; and how action selection by individuals impacts on the organisation of societies.

Anil K. Seth*

Department of Informatics

University of Sussex

Brighton BN1 9QJ, UK

a.k.seth@sussex.ac.uk

www.anilseth.com

+44 1273 678549

Joanna J. Bryson

Department of Computer Science

University of Bath

Bath BA2 7AY, UK.

+44 1225 383934

See also

Action selection, computational perspectives; Decision making, computational perspectives; Decision making, neural underpinnings; Decision-making deficits, models of; Rational decision making, computational perspectives

Further reading

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