Modelling Natural Action Selection

Action selection is a fundamental problem in biology and ecology. It requires determining available alternatives, executing those most appropriate, and resolving conflicts among competing goals and possibilities.

Using advanced computational modelling, this book explores cutting-edge research into action selection in nature from a wide range of disciplines, from neuroscience to behavioural ecology, and even to political science. It delivers new insights into both detailed and systems-level attributes of natural intelligence and demonstrates advances in methodological practice. Contributions from leading researchers cover issues including whether biological action selection is optimal, neural substrates for action selection in the vertebrate brain, perceptual selection in decision making, and interactions between group and individual action selection.

This major integrated review of action selection in nature contains a balance of review and original research material, consolidating current knowledge into a valuable reference for researchers, while illustrating potential paths for future studies.

Anil K. Seth is a Reader in the School of Informatics at the University of Sussex, an EPSRC Leadership Fellow, and Co-Director of the Sackler Centre for Consciousness Science. His research crosses the fields of computational neuroscience, consciousness science, and neurorobotics. In addition to contributing new insights into the mechanisms of action selection, he has developed new ways to link brain activity to conscious experience and he is well known for his research on the statistical analysis of causality.

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Foreword

The sea pen leads a simple life. After floating on the deep-sea currents as a juvenile, it settles down onto a comfortable patch of sand and begins its largely immobile adult life, growing into a feathery shape and swaying in the water while ensnaring whatever edible morsels pass its way. It hardly moves on its own; it just passively filters the world that goes by. No choices need be made, for there are no actions to take. As such, the sea pen will not feature prominently in this book.

For other more active (and more behaviourally interesting) species, life presents a stream of decision points, at which actions must be chosen: stay or move on, ingest or pass by, approach or avoid, wait or strike, court/accept or decline. These are all essentially forms of the exploitation/exploration trade-off that organisms must balance throughout their lives, whenever resources are distributed in space or time and the individual can actively seek them. This is the realm of natural action selection. How do organisms do it?

Action selection mechanisms are decision mechanisms. Like the study of decision mechanisms used for making inferences – a common topic in research on (human) judgement and decision making – the study of action selection mechanisms aims to uncover what the mechanisms are that people and other animals use, how they work, and when and where they work well or do not work – that is, the conditions under which they do or do not produce adaptive (or rational) behaviour. Research on human inference has revealed that there are multiple decision mechanisms that people can use in particular situations – the mind's *adaptive toolbox* – and often several of these can produce similar outcomes. The chapters in this book reveal the range of possible action selection mechanisms that can be used as well. Some of the simple heuristics that have been identified for human inference show that decisions can be made without fully comparing different alternatives on multiple incommensurate dimensions (e.g., by ignoring conflicting dimensions and just deciding on the basis of one factor); some of the models in this book show similar shortcuts or rules of thumb that can work in action selection. One difference between standard decision-making research and that on natural action selection is that, in the former, the possible alternatives that can be selected in an inference task are generally known or specified by the researcher, e.g., which city is larger, Detroit or Milwaukee? The possible actions that an animal might take in nature may not always be explicitly identified and, without knowing precisely the range of possibilities, studying the mechanisms that select among them becomes more difficult.

In the human inference literature, the study of the contents of the adaptive toolbox has led to a further question beyond asking how people choose between alternatives in an inferential task: how do people choose what *mechanism* to use to make their inferences in a particular task? That is, how do people choose which tool to use from the adaptive toolbox? This is an open and challenging question, with different possible answers; sometimes the environment will determine the choice, depending on what types of information are available; other times, individuals may learn through experience or can be taught what decision mechanisms are good to employ in particular settings. If there are multiple competing action selection *mechanisms* in a given situation – not just multiple competing actions themselves – then this kind of meta-selection question will also be important in the study of natural action selection.

Specifying the action selection mechanisms that inhabit the mind's adaptive toolbox means specifying how they work – but how can this be determined? This is also a main theme of this book: exploring the methods that are being employed at the cutting edge of research for understanding the operation of action selection mechanisms. Experiments and field observations are necessary for generating data on action selection in action, but the data must be understood in terms of a theory. Here the theories are instantiated as models, which because they often operate at multiple levels – cognitive, neural, and social – are complex enough that they are best implemented as computer simulations. Ideally, multiple competing models then specify further data to be collected to distinguish between them, and the new data constrain the models (and the theoretical understanding) further, in an ongoing feedback loop. In this book we see multiple stages of that process, and the current state of understanding to which it has led.

This modelling approach can thus be characterised as 'understanding by building'. But once the action selection models have been built and understood, we can also use the models as a way to explore how to change things in important application areas. The applications, like the models, can be at different levels of description. At the neural level, important health implications emerge from understanding clinical conditions such as Parkinson's disease and obsessive–compulsive disorder as disruptions of action selection. And by better knowing how natural action selection works at this level, we can gain better understanding of what is going on when things go wrong – tweaking the models to achieve 'understanding by breaking' – and insights into possible ways of addressing those problems.

At the individual and social level, we may want to help people choose better courses of actions for themselves and others – avoiding the third piece of chocolate cake, or promoting the election of innovative leaders. Again by modelling and understanding the processes of action selection at these levels of description, we can develop, and test, ideas for how to change the action selection process in desired directions, before trying them out in the real world. These methods could involve giving people and groups new ways of selecting their actions – new tools for choosing what and when to eat, or new voting mechanisms, for instance – or could rely on changing the environmental cues that they receive, to 'nudge' people into making different selections. And modelling can help us determine which approach may be more effective, changing environments or changing minds or norms.

Hence, the work in this book is important. And it is incumbent on readers not just to passively filter and accept what is written here, but to actively choose to ingest or pass by, approach or avoid, accept or decline, and above all explore and exploit the ideas presented herein.

Peter M. Todd

Preface

Parts of this book were originally published as an issue of the *Philosophical Transactions of the Royal Society B: Biological Sciences* (Volume 362; Issue 1485) but have been modified and updated. Anil Seth's contribution to the book was supported by EPSRC Leadership Fellowship EP/G007543/1 and by a donation from the Dr Mortimer and Theresa Sackler Foundation. Tony Prescott's contribution was supported by the EU 7th Framework Programme via the projects BIOTACT (ICT-215910) and EFAA (ICT-270490). Joanna Bryson's effort was funded in part by the US Air Force Office of Scientific Research, Air Force Material Command, USAF, under grant number FA8655-10-1-3050.

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