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George Mengov

Decision Science: A Human-Oriented Perspective

Springer

George Mengov
Faculty of Economics and Business Administration
Sofia University St. Kliment Òhridski
Sofia
Bulgaria

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For my students from Sofia University
St. Kliment Òhridski
For my friends

Preface

How people take decisions is an enticing enigma. Humanity has sought to crack it for millennia but apart from the occasional insight by a sage, little was achieved until the enterprise of science became strong enough to take up the issue. With the invention of probability theory in the seventeenth century and the concept of subjective utility in the eighteenth, decision analysis was put on a pragmatic basis. Yet, its success ever since has been very modest compared with the accomplishments of the natural sciences. The main reason is of course the difficulty to conduct research on such an elusive subject. Decision—understood as making up one's mind about a new belief or about an act to be carried out—is indeed tricky to study.

At any moment in history, scientific advancement in this field depended crucially on the available methods to analyse human mind and behaviour. Initially, scholars had to resort only to observation and philosophising. Armed with calculus and probability, the Renaissance mathematicians were taken by the idea to examine the behaviour of gamblers. Soon, however, their attention shifted to the seafaring risks and insurance calculations. Thus, decision analysis developed a strong affinity for economics which lasts to this day. In the meantime, psychophysics—later subsumed by psychology—made a powerful entry into the scene, bringing in the experimental method with empirical data gathering. As all of these streaks seemed to be converging into a loosely coherent framework around utility theory, twentieth century psychology began discovering instances of human irrationality at a rate, by far outclassing the decision theorists' struggle to accommodate them. There is yet no sign that this state of affairs will change soon. Finally, the new and powerful influence of neuroscience—both as neural modelling and as scanning technologies—reshaped the field by adding vast new territories to it. The brain was no longer a black box and decision-making could now become the object of more or less direct observation.

However, seeing something and understanding it may be two quite different things. When we marvel at real-time fMRI and other imaging, and establish statistical links among brain area activations, we only begin to realize how modest our intellectual grasp over human cognition is, and how much more theoretical our approach must be. That is why some of the contributions of mathematical and computational neuroscience that deal with human decision-making take centre stage in this book. They occupy its entire Part III, but the ground for them is prepared by the preceding two parts.

Part I carefully examines the merits and deficiencies of the classical utility paradigm, outlined in Chaps. 1 and 2. It begins with Daniel Bernoulli's seminal idea about subjective utility as a factor, influencing human motivation and choices. Further, Chap. 1 provides a concise discussion on the methodology of science in general, and explains the nature of scientific concepts, measurements, axioms, models and theories, all of them outlined in an accessible manner. The aim here is to facilitate the reader's orientation in the interdisciplinary territory of decision science.

Chapter 2 presents in sufficient detail the accomplishments as well as the weaknesses of the von Neumann–Morgenstern axiomatic system for economic rationality. Another highlight in the exposition is the Arrow–Pratt formula for individual risk-taking attitudes. The chapter closes with a twenty-first century review of the most important rationality principles, as they were ably examined by Busemeyer, Rieskamp and Mellers. By the end of Part I it becomes clear that a chain of events where, time and again, a new paradox of "irrational" behaviour is resolved by a new theory, which is soon challenged by yet another paradoxical finding, is not much of a success story. It must be recognized that deeper methodological obstacles exist that prevent universal solutions.

Part II begins with new hopes, raised by the foray of psychology and cognitive science into some of the outstanding problems in decision-making. The entire Chap. 3 is dedicated to the milestone contributions to the field by Tversky and Kahneman as seen from the standpoint of a scientist with a twenty-first century perspective. Chapter 4 outlines the Griffiths–Tenenbaum experiments that established exactly how people are optimal Bayesian statisticians in everyday judgements. The mastery of that study outlines some of the limits of the traditional—non-neural—mathematical modelling in cognitive science.

Finally, the entire Part III is dedicated to mathematical and computational neuroscience. A particular emphasis is put on the theories of the field's most prominent leader, Stephen Grossberg and his school of thought, somewhat at the expense of others. The approach is explored both theoretically and with experimental work. It begins with Chap. 5, which outlines the foundations of neuromodelling and clarifies its importance for decision-making. There, the Grossberg–Schmajuk theory of classical and operant conditioning and the Grossberg–Gutowski theory of cognitive-emotional interactions, together with their workhorse—the recurrent gated dipole—are summoned to explain how humans act when facing economic choices. In addition, some of the established concepts of the more traditional decision analysis are examined in the light of computational neuroscience. The outcome of this cross-paradigm exercise is a number of conclusions about the relevance of old concepts for new scientific approaches.

Chapter 6 presents an experiment on human intuition when doing economic choices. That study is guided by the theories outlined in the preceding chapter and shows how they can be harnessed in a practical application. Here, scientific details about the psychological, economic and computational issues abound in the exposition for two reasons. First, mathematical neuroscience is a young discipline, which is mainly occupied with discovering new knowledge, while using existing knowledge to guide new experimental studies has been rare. Thus, the limits within which neural models can explain empirical data from people's actions in different contexts are mostly untested. Such applications comprise a specific form of feedback and face challenges of their own. Chapter 6 seeks to contribute to their better understanding and to suggest ways to overcome some of them. The second reason for the highly technical discussion in this part of the book involves the very interesting effects related to human intuition that were discovered. However, they can be fully appreciated only in connection with the research methods that produced them.

The book's final Chap. 7 outlines a detailed analogy between the operations in an ART neural network taking place on the millisecond-to-second timescale, and some events and processes in hierarchical social organizations developing over months and years. This fractal-type analogy, alongside some others, forms the basis of a vision about a new kind of social science that could emerge by extending neuroscience modelling to the socioeconomic domain.

As the book is intended for advanced undergraduates and graduates, it had to convey major ideas in a way that would be as approachable as possible. To this end, formulae are kept simple. This meant deriving them in full when it was considered worthwhile, or skipping them entirely when it was justified. The choice in any particular case was guided mostly by a thought about the reader's convenience, but inevitably might have included the author's personal bias.

A bias of much greater proportions must be admitted here. Any writer would have struggled with the task of putting in such a book all the important achievements of decision science. This is simply not possible. Still, I am a little embarrassed that a number of distinguished scholars are just barely mentioned, and the names of many more had to be left out altogether. It is a consolation that a lot of other volumes have extensively presented and discussed what could not be accommodated here. By the same token, here I keep quiet about group decisions, game theory, operations research and other related fields. My topic is the scientific analysis of decision-making as practiced by the individual mind.

If lucky, decision science books sometimes attract the attention of readers from a wider audience besides the researchers in the narrow field. This makes sense because however technical one's profession or job might be, one must interact with other human beings whose choices inevitably affect him/her. Therefore, some knowledge about how people around us take their decisions is always helpful.

The book is intended to be read not only by decision scientists, but also by engineers, computer scientists, software developers, and the likes. These professions are behind some of the most spectacular intellectual triumphs of our time, such as building machines that autonomously explored other planets, beat the world champion in chess, and attained human-level mastery of the Atari computer games.

This successful trend is likely to continue with the advancement of new paradigms such as cognitive computing and of new temptations going along with in-memory computing. In the past, the adjective “deep” has often been favoured in designating those technologies: Deep Thought, Deep Blue, Deep Learning, Deep Neural Networks … . Without using the word explicitly, this book seeks to communicate to the reader another facet of deepness—the one that stems from analysing human choice with the means of computational neuroscience.

Acknowledgments

An author of a book is influenced by many people. Acknowledging them all by name is impossible, which makes writing this section always awkward. Yet I must express my gratitude to at least some of them.

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Professor D.Sc. Mirena Slavova from Sofia University St. Kliment Ohridski suggested the Latin terms Homo Aequanimus and omnium bonum.

Contents

Part II Psychological Insights

Part III Intuition and Decisions

Nomenclature

A, B, C, ...	Alternatives (prospects) containing risk
$A1$, $A2$, $B1$, $B2$, ...	
$\mathrm{A_I}$, $\mathrm{A_{II}}$, $\mathrm{B_I}$, $\mathrm{B_{II}}$, ...	
a_1, a_2, a_3	Constants in neural differential equations
b, b_1, b_2	
c, c_1, c_2	
D	Weighted sum of decision factors
d_1, d_2, d_3	Weights in a decision rule
K	Winning supplier in the omnium bonum experiment
m, N, n	Number
p	Probability
P_a	Asking price
t	Time, or interim point in the accumulation of some stuff
T	Duration of a process or sum of a quantity
T^*	Median of T
u	Utility of a single outcome. In addition, u is used as equivalent to U in the integrands in Eqs. (2.6), (2.7), and (2.10)
U	Utility of an entire risk-containing alternative
U_t	Utility at time t
V	Utility function derived from a neurobiological model
w, w^+, w^-	Decision weighting functions
W, W_0, W_f	Total wealth, initial wealth, final wealth
x, x_i	Outcome in a prospect; any variable
y_i	Neuron activity
z_i	Neurotransmitter medium-term memory

z_{ij}	Long-term memory
ΔP	Difference between asking price and final price
$\pi(p)$	Subjective probability; probability weight in prospect theory
π_i, π_i^+, π_i^-	Decision weights in cumulative prospect theory