Neural Networks 60 (2014) 232–245

Contents lists available at ScienceDirect

Neural Networks

journal homepage: www.elsevier.com/locate/neunet

Person-by-person prediction of intuitive economic choice

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ARTICLE INFO

Article history:
Received 13 January 2014
Received in revised form 9 July 2014
Accepted 5 September 2014
Available online 16 September 2014

Keywords:
Decision making
Economic choice
Experimental economics
Gated dipole
Intuitive thinking
Differential equations

ABSTRACT

Decision making is an interdisciplinary field, which is explored with methods spanning from economic experiments to brain scanning. Its dominant paradigms such as utility theory, prospect theory, and the modern dual-process theories all resort to formal algebraic models or non-mathematical postulates, and remain purely phenomenological. An approach introduced by Grossberg deployed differential equations describing neural networks and bridged the gap between decision science and the psychology of cognitive–emotional interactions. However, the limits within which neural models can explain data from real people's actions are virtually untested and remain unknown. Here we show that a model built around a recurrent gated dipole can successfully forecast individual economic choices in a complex laboratory experiment. Unlike classical statistical and econometric techniques or machine learning algorithms, our method calibrates the equations for each individual separately, and carries out prediction person-by-person. It predicted very well the behaviour of 15%–20% of the participants in the experiment – half of them extremely well – and was overall useful for two thirds of all 211 subjects. The model succeeded with people who were guided by gut feelings and failed with those who had sophisticated strategies. One hypothesis is that this neural network is the biological substrate of the cognitive system for primitive–intuitive thinking, and so we believe that we have a model of how people choose economic options by a simple form of intuition. We anticipate our study to be useful for further studies of human intuitive thinking as well as for analyses of economic systems populated by heterogeneous agents.
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1. Introduction

General Charles de Gaulle of France once remarked that it was difficult to govern a nation that had 246 different kinds of cheese. Besides the obvious message about developed countries being sophisticated, these words hint that economic choice is not only important but also somewhat frustrating. Economists have studied its more traditional aspects extensively and have come to the understanding that the axioms used in economic and political theory need revision (Sen, 1997). To better explain and predict, they ought to account for the subtle rationality of seemingly irrational decisions as in Amartya Sen's famous example of somebody taking a fruit from a basket with two fruits, but refusing to do so when only one is left. Behavioural economics has addressed the general issue by relaxing its axioms as well as by equipping them with more empirical knowledge about the human being's cognitive characteristics.

In the meantime, psychology has gone a long way in understanding human decision processes. Kahneman and Tversky's research programme enriched economic analysis with findings about the heuristic and emotional aspects of decision making (Kahneman, 2003, 2011; Tversky & Kahneman, 1971, 1981). In our time, it has been established that a decision is reached in the complex interaction of two cognitive systems. Different theories have labelled them in different ways, but in general it is believed that there is one system for "intuitive", "experiential", or "impulsive" reasoning, also called "System I", and another for "logical", "rational", or "reflective" reasoning, also called "System II" (Epstein, 1994, 2003; Kahneman & Frederick, 2002; Schneider & Shiffrin, 1977; Stanovich & West, 2000; Strack & Deutsch, 2004). Recent reviews on the subject can be found in (Alós-Ferrer & Strack, 2014; Brocas & Carrillo, 2014; Dayan, 2009), while some of the recent modelling advances constitute (Andersen, Harrison, Lau, & Rutström, 2014; Fudenberg & Levine, 2006; Fudenberg, Levine, & Maniadis, 2014; Mukherjee, 2010). In this view, the intuitive system is automatic, effortless, emotion-driven, governed by habit, but difficult to change, while the logical system is effortful, controlled and slow, but flexible and able to adopt complex decision rules. Easy tasks are dealt with

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http://dx.doi.org/10.1016/j.neunet.2014.09.002
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predominantly by the former, while complications prompt the intervention of the latter. Buying some cheese would demand mostly intuition – but being not entirely simple – would also need some input from the logical system, while governing a nation would ask for a lot more of it. Therefore, the cognitive load due to every decision can be regarded as a point on a linear segment, with the domains of the intuitive and logical systems located at its ends. Of course this dichotomy is somewhat schematic, as studies of the brain using modern scanning technologies have led to the understanding that the neural basis of emotion and cognition is highly integrated and hardly decomposable (Pessoa, 2008). It has been suggested (Evans & Stanovich, 2013) that it would be better not to speak of "System I" and "System II", but of "Type I" and "Type II" *processes* instead. Hence, it would be more correct to refer to dual-process, rather than dual-system theories.

Somewhat apart from the above family of dual-process theories is fuzzy-trace theory (Reyna & Brainerd, 1991, 2008), which posits that intuition is "gist-based", i.e., resorting to vague memories about the gist of information relevant in a decision situation. In this view, intuition is more advanced than logical reasoning and is more characteristic of experts rather than novices. This theory has successfully explained a variety of empirically established cognitive effects. This is perhaps the only dual-system theory that regards intuition as a sophisticated form of mature reasoning.

It proved worthwhile to approach the issues of intuitive–emotional vs. logical–rational choice in general, and with regard to economics and business in particular, with the tools of mathematical neuroscience. Its ideas have for long translated into a variety of models that look promising for understanding the complexities of decision making. Perhaps the earliest theoretical forays in this direction were made in the 1960–1970s by Stephen Grossberg, with most of his ideas summarized in Grossberg (1980). Not necessarily driven by the needs of economic analysis, further contributions have assisted in developing the field. Affective balance theory (Grossberg & Gutowski, 1987) extended and subsumed Kahneman and Tversky's prospect theory. A cognitive–emotional model, CogEM, of reinforcement learning and motivated attention (Grossberg & Schmajuk, 1987) was used alongside ART neural networks in a theory of consumer motivation (Leven & Levine, 1996). CogEM was further developed and became the precursor of the more general MOTIVATOR model (Dranias, Grossberg, & Bullock, 2008), which explained how cognitive–emotional resonances occur between brain areas that code subjective value and form the basis of behavioural choices. Levine (2006) proposed a neural model for the interaction of selfishness and empathy in economic actions.

This line of research owes a lot to Grossberg's theoretical method, which consists of a number of iterative steps (Grossberg, 2006) when studying a particular cognitive phenomenon. These involve: top-down analysis of behavioural data, discovery of underlying principles, using them to develop mathematical models, refining the latter by computer simulations, and eventually identifying the most adequate theoretical model. The building blocks of all models are three nonlinear ordinary differential equations, characterizing the fundamental neural interactions. Complex brain processes are modelled by recombining the three equations as well as by embedding simpler models into more sophisticated ones in an evolutionary way. This method was adopted by other neuroscientists with interest in economic behaviour (notably, Levine), who carried on using it successfully even in the era of fMRI data.

Indeed, in the 2000s, fMRI studies helped to clarify how elements from the classical psychological theories of heuristic judgement and decision making, including prospect theory, could be mapped on brain processes (Tom, Fox, Trepel, & Poldrack, 2007; Trepel, Fox, & Poldrack, 2005). Complementary theoretical and experimental advancements led to the creation of new and more sophisticated neural models. For example, Levine (2012) proposed an elaborate nonlinear neural network accounting for the biasing effects of emotion on probabilistic choice. It was composed of ART modules and gated dipoles, and was based also on fuzzy-trace theory, findings from fMRI studies, and traditional psychological experiments. Levine (2009) developed a similarly complex neural network that explained a variety of instances of emotionally influenced decision making. It was named DECIDER and combined a neural representation of Maslow's hierarchy of needs with a system of ART modules, conceptually grounded in facts about brain processes.

All of these modelling efforts aimed at producing theoretical knowledge and were generally not intended for direct applications. Trying to use one of Grossberg's or his disciples' theories to guide a novel laboratory experiment or R&D work usually leads to unforeseen obstacles that call for introducing simplifications and ad hoc adaptations, trading off theoretical rigour and beauty for practical viability. This is necessary for at least two reasons: first, the target domain may be quite different from the theory's territory of origin, both conceptually and methodologically, which makes the communication between the two problematic. In that respect, a good example is the attempt to employ instruments from mathematical neuroscience to examine economic decision making. Secondly, in applied science, an essential goal of the knowledge transfer is to create models for prediction, often in real time. However, this is a return to the imperfect empirical world, full of artefacts and contaminating factors, and almost always involving work with noisy data both as calibration and validation sets.

In the present study, we investigate experimentally the abilities of the Grossberg–Schmajuk CogEM model to explain and predict individual economic choice under laboratory conditions close to real markets. The main element in CogEM is a neural network called READ (REcurrent Associative gated Dipole). We suggest that READ may be remotely related to the "intuitive" system, or "Type I" process, as understood by the majority of the dual-process theories, and indeed may be seen as its hypothetical neural substrate. It must be stressed though, that the Grossberg–Schmajuk model is conceptually independent from these theories and can in no way be affected by any controversies around their empirical validation. In fact, when future research clarifies the difference between primitive intuition and gist-based expert intuition, READ could turn out to be just as useful for modelling the former, or may be even both.

Further, because the intuitive and the logical systems (or processes) are locked together in a loop of intensive mutual communication, if READ is to model that, it must be augmented with additional elements, as in Levine's (2009, 2012) approach. However, even as it stands now, this neural network can account for the more primitive aspects of intuitive decision making. Precisely that is what it is used for in the present study.

Previously, READ successfully predicted 87% of people's binary preferences in a simple experiment, thus surpassing some state-of-the-art econometric tools (Mengov, Egbert, Pulov, & Georgiev, 2008). Here we develop a more complex economic experiment, which involves profit maximization by choosing one among four competing suppliers of a good. Our goal is to use READ as a vehicle to connect real people's market behaviour with some of the established theoretical concepts of decision science. Along the way, practical problems call for combining the gated dipole with econometric variables, thus obtaining a hybrid neural model of economic choice. A separate model is calibrated for each individual and is then tested with validation data to establish to what degree personal choices are predictable. In summary, what sets this study apart from many others is that it utilizes a sophisticated neural model to predict real people's economic choices *person-by-person* in a relatively complex economic game.

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