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Mathematical Models of Decision Making Processes: *State of the Art and Challenges*

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Presentation

Every action comes out of a choice. The cognitive mechanisms that govern these choices and the social, political, and economic patterns that emerge from them have been a subject of interest for behavioral scientists across disciplines. In this context, Psychology is concerned with explaining how decisions are made based on evidence, personal preferences, and individual criteria. Thus, formalizing human decision strategies, including a variety of biases and heuristics, is pivotal in understanding almost any human behavior.

Because of their ubiquity, decision-making processes hold particular relevance in experimental psychology, but they are often overlooked. Observers' responses to experimental tasks are customarily taken as direct measures of the cognitive phenomenon of interest, even though decision processes unavoidably mediate those responses. Disregarding the decisional biases and judgment errors that take place during data collection has been shown to obscure theoretically relevant patterns and to contaminate them via methodological artifacts. Our success in developing meaningful theories about any aspect of human cognition is, thus, heavily dependent on our ability to devise dependable explanations of choice mechanisms. Mathematical modelling has proven to be helpful in disentangling the effects of the various psychological processes that mediate observed performance.

This seminar brings together seven renowned specialists who can offer a state-of-the-art view of quantitative decision-making models across different psychological domains, with a focus on three prominent frameworks within Mathematical Psychology: axiomatic choice models, perceptual decision-making models, and quantum cognition. Presentations will be followed by a discussion aimed at highlighting equivalences, connections, and distinctions among the different frameworks, also acknowledging the different challenges they face.

We hope to provide researchers with tools to address the study of decision processes, as well as present them with promising modeling paradigms that receive little attention in undergraduate and graduate Psychology programs.

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Session I: Axiomatic choice

Median responses, modal choices, prior parameters: How not to test theories of decision making

Michel Regenwetter (University of Illinois)

It is common in behavioral decision research to summarize empirical data or the results of statistical analyses by reporting median responses, modal choices, or summary statistics of parameter estimates. Similarly, in quantitative model competitions, scholars routinely use median parameter estimates from prior studies to reduce a given theory, that they aim to refute, down to a single preference pattern. More generally, it is standard to fit a single set of parameter values to data pooled from many individuals. For example, these practices are common in work that involves Cumulative Prospect Theory, including in the original paper by Tversky and Kahneman (1992). In a theory like Cumulative Prospect Theory, tiny changes in parameters can lead to large changes in predicted behavior, which means that there is disconnect between summary statistics on parameters and summary statistics on preference patterns. Furthermore, social choice theory has long shown that summary statistics about preference patterns can be disconnected from the actual preference patterns themselves. I will review some of the pitfalls associated with these widespread practices.

References

Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and uncertainty*, 5(4), 297-323.

Linking Axiomatic Perspectives on Decision Making to Brain Connectivity

Clintin P. Davis-Stober (University of Missouri)

We present a programmatic perspective that connects axiomatic methods in evaluating choice behavior to neural measures of brain connectivity. As a substantive application, we examine the effects of cognitive aging on decision making processes. In Experiment 1, we investigated whether older adults (ages 60-75) were more likely to utilize compensatory, rational decision making strategies than younger adults (ages 18-25) in a decision making under risk experiment. We found that older adults violated transitivity at a higher rate than younger adults and were more likely to be classified as using heuristic, non-compensatory decision making strategies. In Experiment 2, we replicated the basic design of Experiment 1 but included measures of resting-state fMRI connectivity. For each individual, we generated a brain network from the fMRI data and examined whether efficient neural connectivity was associated with rational decision making. We used the small world propensity measure of Muldoon et al. (2016) to measure the efficiency of each estimated brain network. We report an association between rational choice and efficient brain network organization. We discuss the relative merits of our overall approach and how it interfaces with current neuroscience perspectives.

References

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Session II: Perceptual decision making

Decision processes in psychophysical tasks

Miguel A. García-Pérez (Universidad Complutense de Madrid)

The psychometric function describes how performance on a perceptual task varies with stimulus magnitude, with performance defined as the proportion of times that an observer reports a certain type of judgment across repeated presentations of stimuli at each selected magnitude. Psychometric functions are measured in a broad diversity of contexts, from the study of basic psychophysical processes of detection and discrimination through the study of emotional or attentional influences on them to the assessment of clinical conditions. The analysis of psychophysical data involves fitting a convenient and largely arbitrary function and extracting shape descriptors indicating its location and slope, which presumably capture the sensory components of performance. This is justified on the grounds of an implicit model that purportedly separates out the sensory components of performance, thus eliminating the contaminating influence of decisional and response components. A close look at psychophysical data collected with a broad range of methods nevertheless reveals peculiarities that are incompatible with such model, suggesting that decisional and response components are still present in the data and undermine the interpretation of the location and slope of a psychometric function as measures of the sensory determinants of performance. This talk discusses these peculiarities and presents a process model of performance that accounts for all of them. The model includes sensory, decisional, and response components captured by distinct parameters whose estimation allows effective separation of these components. A formal analysis of various classes of perceptual tasks further reveals that some of them confound these components in an inextricable way, which makes them unsuitable for research. Other types of tasks allow a complete separation, but this can only be achieved when the data are analyzed properly.

A two-stage diffusion model account for compelled-response task data

Adele Diederich (Jacobs University Bremen)

Recently Salinas, Stanford, and colleagues (Stanford et al 2010, Salinas et al 2010, 2014) developed a paradigm that seems suited in separating the process of perceptual decision making from motor planning and execution. In this compelled-response task the participant has to make an eye movement to a signal occurring either left or right from the fixation point. Crucially, the signal that instructs the subject to start an eye movement (disappearance of the fixation point) is given before the cue that indicates which of two possible choices is the correct one (the target). When the cue is given very late (say, never) the participant must guess and make an uninformed, random choice. In contrast, the earlier the cue is given the more informed the participant will be in making a choice. The idea is that the motor process is initiated early and that perceptual information, once presented, influences a motor plan that is already developing. Probing the paradigm on monkeys, it has been suggested that perceptual performance can be tracked as a function of the amount of time during which sensory information is available (called tachometric curve) independently of motor demands (Stanford et al 2010, Costello et al 2013, Shankar et al 2011).

Stanford and colleagues (Stanford et al. 2010, Salinas et al 2010) have discussed different formal approaches to represent the computational mechanisms elicited in the compelled-response task. Specifically, in their accelerated race-to-threshold model two developing oculomotor plans race to a threshold and the incoming perceptual information differentially accelerates their trajectories toward it. From their model fit they conclude that stimulus information (color identification) needs to be processed for just 25--50 ms to have an impact on behavioral outcome. Here, we extend their results in two ways. First, we demonstrate that the compelled-response task is also well suited for human subjects leading to comparable estimates for perceptual decision time. Moreover, we propose an alternative to the race-to-threshold model, a two-stage diffusion model (Diederich 2016). Arguably, this alternative model has several advantages over the race model. According to the race model, random variability is introduced only across trials, with acceleration of information build-up being constant in the first stage and change of information build-up in the second stage being constant again. In contrast, build-up of information in the diffusion model is stochastic at any point in time within a trial which has made diffusion-type models the primary approach to account both for behavioral and neural data (Smith & Ratcliff, 2004).

References

Costello, M. G., Zhu, D., Salinas, E., & Stanford, T. R. (2013). Perceptual modulation of motor—but not visual—responses in the frontal eye field during an urgent-decision task. *Journal of neuroscience*, 33(41), 16394-16408.

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Session III: Quantum cognition

What Is Quantum Cognition, and How Is It Applied to Psychology?

Jerome Busemeyer (Indiana University Bloomington)

Quantum cognition is a new research program that uses principles from quantum theory as a framework to explain human cognition, including judgment and decision making, and conceptual reasoning. This research is not concerned with whether the brain is a quantum computer. Instead, it uses quantum theory as a fresh conceptual framework and a coherent set of formal tools for explaining puzzling empirical findings in psychology. In this introduction, I will focus on two quantum principles as examples to show why quantum cognition is an appealing new theoretical direction for psychology: complementarity, which suggests that some psychological measures have to be made sequentially and that the context generated by the first measure can influence responses to the next one, producing measurement order effects, and superposition, which suggests that some psychological states cannot be defined with respect to definite values but, instead, that all possible values within the superposition have some potential for being expressed. I will present evidence showing how these two principles work together to provide a coherent explanation for many divergent and puzzling phenomena in psychology.

Empirical Foundations of Quantum Cognition

Zheng Joyce Wang (The Ohio State University)

Quantum theory provides a unified and powerful explanation for a wide variety of paradoxes found in human cognition and decision research ranging from attitude, inference, causal reasoning, judgment and decision, to perception and memory. We will review applications of quantum cognition where classical models fail, including (1) conjunction/disjunction errors that violate rules of classical probability, (2) question order effects that violate commutativity, (3) interference effects that violate the law of total probability, (4) context effects that violate joint probabilities (including violations of "Bell type" inequalities), (5) asymmetric similarity judgments and violations of Euclidean distance models. Quantum cognition provides a new theoretical and modeling approach to a wide variety of empirical cognitive phenomena using a unified, common set of theoretical principles.

The rational (?) status of the conjunction fallacy

Emmanuel Pothos (City, University of London)

The conjunction fallacy has been one of the key empirical findings questioning the rational status of human probabilistic reasoning. Recently, some researchers have provided an account of the conjunction fallacy based on the probabilistic framework from quantum theory: using quantum probabilities, the conjunction fallacy is no longer an incorrect decision. But is it rational? Most researchers (in psychology at least) equate rational decision making with consistency with Bayesian inference and, superficially at least, the conjunction fallacy is at odds with Bayesian inference. I will discuss the quantum approach to the conjunction and explore whether a rational perspective to this important result can be provided.