Neural Correlates of Cognitive Models

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Introduction

In recent years, model-based approaches in neuroscience have become more prevalent, providing an answer to the claim that neuroscience is data rich yet theory poor. Indeed, different cognitive models provide predictions that can be empirically validated using neural data, providing new insights into the neural basis of human cognition.

In this symposium four speakers will present new results in the field of model-based cognitive neuroscience. The first two speakers will outline how models that have their roots in machine learning and computer vision can be used to obtain new insights into the neural basis of visual perception. The third speaker addresses how computational models can provide new insights into the neural basis of decision-making. Finally, the fourth speaker complements this work by discussing how neuroimaging data can be used to constrain cognitive models.

This symposium will provide attendants with new insights into this new field of research which promises to bridge the gap between formal models of cognition and their neuronal correlates, as measured by non-invasive imaging techniques.

Brief Description of the Speakers

In the following a brief description of the symposium speakers is given.

Dr. van Gerven is an assistant professor at Radboud University Nijmegen. He is principal investigator of the Computational Cognitive Neuroscience lab and works at the interface between machine learning and cognitive neuroscience. In the past, van Gerven developed new paradigms for brain-computer interfacing based on covert spatial attention and developed new Bayesian techniques for structural and functional connectivity analysis. His current research focuses on the development of statistical approaches for understanding distributed representations in the human brain.

Dr. Ghebreab is an assistant professor at the University of Amsterdam, and head of Studies Social Sciences at the Amsterdam University College. His research combines computational and neural analysis of everyday visual scenes, and aims at understanding what visual information evokes what perceptual and emotional experiences. He teaches several courses on these topics and leads the Brain & Technology Amsterdam lab (BeTA lab).

Dr. Hawkins is a postdoctoral fellow at the Amsterdam Brain and Cognition Center, University of Amsterdam. His research focuses on developing and testing computational and mathematical models of cognitive processes, in particular decision-making. He completed his PhD in experimental and mathematical psychology at the University of Newcastle, Australia. He then commenced a postdoctoral position at the University of New South Wales, Australia, where he used computational approaches to study judgment and decision-making phenomena.

Dr. Borst is a postdoctoral researcher at the Department of Artificial Intelligence, University of Groningen. His research focuses on new neuroimaging analysis techniques, with the goal of providing additional constrains for cognitive computational models. He obtained his PhD in cognitive modeling at the University of Groningen. During his PhD research, he developed computational models of behavioral and neural data of multitasking. Afterwards, he performed post-doctoral research in the lab of Prof. John R. Anderson at Carnegie Mellon University, where he focused on new analysis methods for EEG data.

Symposium Abstracts

Probing Cortical Representations of Naturalistic Stimuli with Deep Learning (Marcel van Gerven)

Recent advances in machine learning have shown that deep learning achieves state-of-the-art performance in visual object recognition. In this talk I outline how we used deep learning to disentangle the functional organisation of the cortical visual stream. Our results show that downstream areas code for features that are also represented in deeper layers of artificial neural networks. Furthermore, the outlined framework can be used as a high-throughput method for analysing how individual stimulus features are represented across the cortical sheet as well as for estimating voxel-level receptive fields. I argue that the marriage of statistical machine learning with cognitive neuroscience yield new insights into human cognition that cannot be easily achieved via more conventional approaches.

FMRI Evidence for Face Recognition by Visual Words (Sennay Ghebreab)

Neuroimaging evidence has shown that a network of face sensitive brain regions underlies the ability of humans to grasp a person's gender, age, race and mood in a single glance. The mechanism to represent faces remains unclear, however. Bag-of-words are effective in the field of computer vision for learning to recognize an object by its type. In this model, a word represents small, mutually similar patches. Images are represented as bags of words by counting the occurrence of each of the thousands different words. We examined the relation between two representations of face images based on a Bag-of-words model and fMRI-responses to these images. The first representation is the similarity distance to the cluster of faces, which we refer too as ordinate bag-of-word representation. The second is the similarity distances with respect to face sub-clusters (males, females, Asians, Africans, Caucasians, children, adults and seniors). Results reveal neural sensitivity in the core-face network (FFA) to ordinate and in the extend face network (aITG) to subordinate bag-of-word face representations. We provide evidence for bag-of-words as a simple yet effective model for face representation in the brain, possible applicable to generic visual object recognition as well.

Behavioural and Neural Evidence for Urgency in Decision-Making (Guy Hawkins)

Most modern accounts of perceptual decision-making assume that evidence is accumulated for one choice option over another until the balance of evidence reaches one of two decision boundaries, triggering a choice. Decision-making models have typically assumed fixed decision boundaries where the amount of evidence required to trigger a decision does not change with time. A more complicated assumption has recently gained popularity in some neurophysiological accounts of decision-making: collapsing boundaries, where decisions are triggered by less and less evidence as time passes. Such dynamic decision boundaries, often interpreted as implementing rising "urgency signals", have attractive normative properties but have not been stringently tested against data. To this end, I will provide an overview of a large-scale analysis of behavioural data from previously published human and non-human primate studies. We found that the use of dynamic decision boundaries depends on task-specific paradigms or procedures, such as extensive task practice or delayed feedback protocols. I will also discuss the neural correlates of urgency in decision-making using an expanded judgment task that induced dynamic decision boundaries in some participants but not others. The amount of urgency evident in individual subject decision strategies was linked with BOLD activity, to investigate the neural bases of urgency. We conclude that various paradigms and procedures can lead decision makers to adopt qualitatively different decision strategies, and individual differences drive the extent to which one uses urgency-related decision strategies.

Using fMRI data to Constrain a Cognitive Model of Working Memory in Multitasking (Jelmer Borst)

Cognitive models are notoriously hard to evaluate. One important requirement for models is that they should be able to predict data of new experiments. However, even if models are capable of predicting reaction times and accuracy data, their complexity often exceeds constraints provided by behavioral data alone. To provide additional constraints, researchers have turned to neuroscience. A prime example of this is the ACT-R cognitive architecture. After a development based on behavioral and eye-tracking data that extends back to the 1970s, in 2003 a mapping was developed from components of the architecture to brain regions. Since then, models developed in ACT-R predict the fMRI BOLD response in several regions of the brain, and can thus be tested and constrained by fMRI data. In this talk, I will show how this approach led us to re-evaluate a model of working memory use in multitasking. Although our initial model matched behavioral data perfectly, a subsequent fMRI experiment indicated that the assumptions underlying the model were incorrect. We adapted the model to both capture the behavioral data, as well as the neuroimaging data. On the basis of this example, I argue that neuroimaging data can provide valuable constraints for cognitive models.