Classification decisions in machines and human brains

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Abstract

Our ability to extract abstract information from our experiences and group it into meaningful units (categories) is a fundamental cognitive skill for interpreting the complex environments we inhabit. How does the human brain learn about the regularities and context of novel perceptual experiences that have not been honed by evolution and development and decide on their interpretation and classification? We propose a novel interdisciplinary approach that integrates advanced multimodal imaging (fMRI, MEG, EEG) methods and state-of-the art machine learning algorithms to examine the neural architecture that underlies classification learning and decisions in the human brain. We aim to a) create an electrical-haemodynamic signal space in which neuronal assemblies and their interactions can be characterised, and b) to develop a unified algorithmic method for efficiently analyzing neural imaging and behavioural data. In particular, we will use machine pattern classifiers to define perceptual decision images that reveal the critical stimulus features on which the observers base their perceptual classifications, and neural decision images that reveal the neural selectivity, plasticity and dynamics with which these features are encoded and learnt by the human brain. Our methodological and theoretical developments will provide a) novel and sensitive tools for the assessment of the behavioural and neural signatures of perceptual decisions in neuroscience, and b) novel challenges and insights in machine learning for the optimisation of biologically-constrained algorithms with direct applications for expert recognition systems. Further, our findings will advance our understanding of the link between sensory input, neural code and human behaviour and have potential applications for studying the development of perceptual decision processes across the life span, and their impairment and potential for recovery of function in ageing and disorders of visual and social cognition.

Summary

In our everyday interactions we encounter a plethora of novel experiences in different social contexts that require prompt decisions for successful actions. Extracting the key information from the highly complex input of the natural world and deciding how to interpret it is a computationally challenging task that is far from understood. In particular, our perceptual decisions are determined not only by the sensory evidence available but also by abstract rules that allow us to be flexible in interpreting novel experiences based on our previous knowledge about the likelihood of an event with a desired outcome, its social context, and the magnitude and rate of reward associated with the anticipated action choice. For example, deciding how to act (reserved vs. extroverted) when encountering an acquaintance depends on sensory evidence (we recognise the specific person or they simply appear familiar), our knowledge and feelings about this person based on previous encounters, the social context (business meeting or social event) and the reward associated with this social interaction (new friendship or partnership). We propose to examine the neural basis of perceptual decisions in complex, novel and uncertain environments that map sensory experiences into actions by bringing together interdisciplinary expertise in advanced mathematical approaches (i.e. machine learning), established behavioural methods and multimodal brain imaging (fMRI, MEG, EEG) techniques that allow us to study the human brain at work in real time. Our goal is to understand the neural computations that allow humans to make categorical decisions based on adaptive learning. This challenging problem of visual categorisation is known in engineering as the pattern classification problem. In this framework, we will examine how the human brain extracts important features from complex inputs and classifies them to meaningful perceptual categories by comparing the performance of human observers with that of statistical learning machines. The aim of this interdisciplinary project is threefold. First, we will develop and validate novel analysis methods for psychophysical and multimodal imaging data based on elegant mathematical approaches that test for feature selection and multi-dimensional classification in rich biological data sets. Second, we will use these machine classifiers as sensitive and powerful tools for decoding the internal representation of the physical world in the human brain. Third, we will optimise and constrain these algorithms based on biophysical models (human observers' performance, neural responses) that will allow closer comparison between machine and human classification and have direct applications for the design of artificial systems (e.g. expert systems for face, fingerprint or hand-writing recognition, gene or tumour classification). This collaborative work will initiate a new line of UK collaborative research that will bridge physical and biological sciences and provide novel insights and tools in understanding the link between behaviour and neural plasticity. Further, this research has implications for understanding the development of our social cognition functions, their disruption in ageing and neurological disorders and the potential for recovery of function through learning. In sum, the proposed work has strong potential for building and enhancing interdisciplinary, high-end, competitive research in the UK, improving the long-term quality of life through basic research with potential applications in engineering and medicine, and thus contributing to the general health and wealth in the UK.

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