The computational logic of predictive processes: a 25-year perspective

July 9th, 2025

9:30 AM - 5:00 PM

Schedule

9:30 - 9:45	Opening remarks by Abhi Banerjee
9:45 - 10:15	Rohan Rao
10:15 - 10:45	Aurelio Cortese
10:45 - 11:15	Coffee
11:15 - 12:00	Erin Rich
Break	
14:00 - 14:30	Matthias Tsai
14:30 - 15:15	Silvia Maggi
15:30 - 16:00	Coffee
16:00 - 16:45	Andrea Benucci
16:45 - 17:30	Armin Lak
17:30 ~	Closing remarks/discussion

Aims and topic

Predictive processes are ubiquitous in the brain and critical for adaptive behaviours, such as rapid learning and generalisation of tasks and rules. Early works such as the model proposed by Rao and Ballard (1999) have inspired over two decades of theoretical, computational, and experimental research about predictive neural processing. Stemming from these early works, ongoing investigations provide a rich ecosystem extending beyond the notion of predictive coding. Further, thanks to rapidly developing neural recording technologies, large datasets at multiple scales of granularity and resolution are becoming increasingly available. New computational models enable us to gain a mechanistic understanding of how neural circuits learn to implement and deploy predictive computations. Yet, a complete understanding of the underlying computational logic remains fleeting. Different aspects are often studied in separate research programs (e.g., layer circuits vs whole-brain neuroimaging), with little cross-pollination. This symposium will look at predictive processes in the context of modern computational neuroscience. Speakers will discuss new work across species (humans, monkeys, rodents), focusing on high-level, flexible behaviours (reasoning, context changes, learning). The topic addressed in this symposium is central to diverse streams of research in computational neuroscience, e.g., perception, decision-making, learning and memory. We aspire to stimulate interaction among researchers working in different disciplines and highlight the open questions that will shape future research.

Speakers

- Abhishek Banerjee (Oxford University / Queen Mary University of London, UK)

Opening remarks

- Rohan Rao (Newcastle University / Oxford University, UK)

Diverse frontal cortical predictive strategy codes underlie diversity in adaptive learning

Adapting our behaviours to changing contexts is a critical component of flexible learning. Recently, we identified frontal control signals that broadcast contextual switches. But how do frontal-cortical networks support individual diversity during adaptive learning? To investigate this question, participants completed a Go/No-Go reversal learning task in conjunction with EEG recordings. Participant learning trajectories clustered into five performance-ordered groups. Higher-performance groups successfully employed 'lose-stay' strategies in response to misleading feedback, whereas lower-performance groups were unable to do so. Further investigation revealed that dlPFC-ACC and frontal-somatosensory cortical predictive strategy codes underlie higher-performance behaviour. Together, these results elucidate predictive codes across temporal scales that support optimal adaptive behaviour.

- Aurelio Cortese (ATR Institute International, Japan)

Time-dependent transformation of fear memories

Memories are not set in stone. Here, we sought to better understand how memories about events predicting adverse outcomes might be transformed with time. In our original episodic threat conditioning paradigm, participants could concurrently form two memory representations: cue-associations and episodic cue sequences. We found these two distinct memories compete for physiological fear expression, reorganising overnight from an overgeneralised cue-based to a precise sequence-based expression. With multivariate fMRI, we tracked inter-area communication of memory representations to reveal that a rebalancing between hippocampal- and prefrontal control of the fear regulatory circuit governed this memory maturation. Critically, this overnight reorganisation was altered in participants with heightened trait anxiety. Together, we show the brain prioritises generalisable associative memories under recent adverse events but resorts to selective episodic memories 24 h later. Time-dependent memory competition may provide a unifying account for memory dysfunction in stress-related disorders.

- Erin Rich (New York University, USA)

Effects of value predictions on motivated behaviour

The orbitofrontal cortex is traditionally thought to integrate value-related information in order to compute preference decisions. In contrast, its role as a top-down mediator of value-motivated behaviors is less explored. This talk will preview our recent work showing how value predictions bias motivated responding, and how interfering with orbitofrontal function can reduce this bias.

- Matthias Tsai (Universität Bern, Switzerland)

Unsigned reward prediction errors inform apical amplification

How do predictions affect sensory processing? Apical dendrites are prominent recipients of top-down projections, which makes them primary suspects to support the integration of predictive signals. Informed by experimental calcium imaging, we present a model of apical dendrite activity encoding unsigned reward prediction errors. Our simulations suggest that the unsigned error signals could inform attentional modulation with the goal of amplifying task-relevant sensory information by conveying feature-specific salience.

- Silvia Maggi (University of Nottingham, UK)

A computational perspective on predictive error processing

Behavioural flexibility—the ability to adaptively shift behaviour when environmental contingencies change—is commonly measured using reversal learning tasks. While extensive training is generally thought to reduce flexibility by promoting rigid response patterns, the overtraining reversal effect (ORE) demonstrates that additional training can sometimes facilitate rather than impair reversal learning. In this talk, we will explore this counterintuitive phenomenon and discuss how computational modelling of learning dynamics might inform our understanding of the mechanisms underlying adaptive behaviour. We used a combination of repeated reversal learning tasks, Bayesian strategy analysis, and reinforcement learning modelling to investigate how extended training alters learning mechanisms in rats. Our findings suggest that overtraining alters how animals process feedback, resulting in more efficient updating and rapid strategy shifts. Finally, we identified the boundaries between flexible and inflexible behaviour by determining how much experience enhances or impairs adaptive responding. These results challenge traditional views of learning and flexibility, potentially informing our understanding of when and why extended experience can paradoxically improve rather than hinder adaptive behaviour, with implications for both theoretical models of learning and practical training protocols.

- Andrea Benucci (Queen Mary University of London, UK)

Unifying Sensory, Cognitive, and Motor Processing Through Hierarchical Predictive Coding in the Mouse Posterior Cortex

Predictive coding, originally proposed for perceptual computations, has been extended to hierarchical generative models supporting inference, learning, and action across sensory, motor, and cognitive domains. Active inference formalises this integration, suggesting that perception and motor control jointly minimise prediction error in dynamic interactions with the environment. Here, we provide experimental support for this framework. First, we show that higher-order visual areas in the mouse ventral stream extract and compress statistical features of natural textures into compact neural subspaces, consistent with internal priors shaped by environmental statistics for redundancy reduction and predictive coding. Second, we identify a distributed decision variable across the posterior cortex, forming a low-dimensional subspace orthogonal to sensory and motor signals and modulated by attention and task demands—hallmarks of top-down inference under uncertainty. Finally, using a hierarchical neural network, we show that combining visual and motor signals enables invariant category representations under self-motion, reflecting predictive visuomotor integration. These findings support a unified account of perception, decision making, and action within predictive coding and active inference frameworks.

- Armin Lak (Oxford University, UK)

Dopaminergic computations shaping individual long-term learning trajectories

Striatal dopamine plays fundamental roles in fine-tuning learned decisions. However, when learning from naive to expert, individuals often exhibit diverse learning trajectories, defying understanding of its underlying dopaminergic mechanisms. Here, we longitudinally measure and manipulate dorsal striatal dopamine signals in mice learning a decision task from naive to expert. Mice learning trajectories transitioned through sequences of strategies, showing substantial individual diversity. Remarkably, the transitions were systematic; each mouse's early strategy determined its strategy weeks later. Dopamine signals reflected strategies each animal transitioned through, encoding a subset of stimulus-choice associations. Optogenetic manipulations selectively updated these associations, leading to learning effects distinct from those of reward. A deep neural network using heterogeneous teaching signals, each updating a subset of network association weights, captured our results. Analysing the model's fixed points explained learning diversity and systematicity. Altogether, this work provides insights into the biological and mathematical principles underlying individual long-term learning trajectories.