## Learning by reinforcement

**Cognitive switches and sensory learning using value backpropagation**

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Animals adapt their behaviour in response to variable changes in reward reinforcement. Value-based decision-making involves multiple cognitive maps across distributed brain areas. It is less clear which brain regions are essential and how changes in neural responses flexibly re-map guiding adaptive behaviour. In this talk, I will highlight behavioural-neural interactions between frontal and sensory circuits that implement flexible decision-making. I will present further evidence how some of these functions are disrupted in autism spectrum disorders, arguing for a new conceptual framework based on computational psychiatry to understand cognitive pathophysiology in neurological disorders.

Banerjee A, Parente G, Teutsch J, Lewis C, Voigt FF and Helmchen F (2020) Value-guided remapping of sensory cortex by lateral orbitofrontal cortex. Nature 585:245-250.

Banerjee A, Rikhye RV, Breton-Provencher V, Tang X, Li C, Li K, Runyan C, Fu Z, Jaenisch R, and Sur M (2016) Jointly reduced inhibition and excitation underlies circuit-wide changes in cortical processing in Rett Syndrome. PNAS 113(46):E7287-E7296.

**Reinforcement signals broadcast by neuromodulatory systems during associative learning**

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Neuromodulatory systems have traditionally been associated with signalling rewards and punishments. Specifically, midbrain dopaminergic neurons were shown to transmit reward prediction errors. However, prediction error signalling has been demonstrated in multiple neuromodulatory and other circuits and the division of labour across these areas during associative learning remained unclear. I will present data shedding new light on learning-related reinforcement signaling in the basal forebrain cholinergic and midbrain dopaminergic systems. I will also demonstrate how these signals might change through aging and in the course of neurodegenerative disease.

Laszlovszky T, Schlingloff D, Freund TF, Gulyás A, Kepecs A, Hangya B (2020) Distinct synchronization, cortical coupling and behavioural function of two basal forebrain cholinergic neuron types. Nat Neurosci, 23:992-1003.

Sturgill JF, Hegedus P, Li SJ, Chevy Q, Siebels A, Jing M, Li Y, Hangya B, Kepecs A (2020) Basalforebrain-derived acetylcholine encodes valence-free reinforcement prediction error. bioRxiv 2020.02.17.953141; doi: https://doi.org/10.1101/2020.02.17.953141

**The ubiquity of model-based reward prediction in the dopamine system**

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Phasic activity in dopamine neurons has long been identified as a neural correlate of reward prediction error signals in the brain. Recent findings suggest dopamine prediction error signals reflect more dimensions of an expected outcome than scalar reward value. These features imply a richer learning process in the brain than what is typically assumed in current AI learning models, suggesting instead that neural reward predictions are embedded in learned expectations about the structure of the task environment—a form of 'model-based' reinforcement learning. Using these results, I will highlight a number of intriguing and perhaps surprising implications for the algorithmic understanding of learning in both health and disease.

Langdon A.J., Sharpe M., Schoenbaum G., Niv Y. (2018). Model-based predictions for dopamine. Current Opinion in Neurobiology 49:1-7.
Takahashi Y*., Langdon A.J*., Niv Y., Schoenbaum G. (2016). Temporal specificity of reward prediction errors signaled by putative dopamine neurons in rat VTA depends on ventral striatum. Neuron 91(1):182-193. (*Equal contribution)

**Heterogeneity of cholinergic activities during visual discrimination learning**

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Acetylcholine is known to play a key role in learning and memory. However, it's unclear how cholinergic neurons in the basal forebrain respond to salient events such as sensory stimuli, rewards and punishment, during the course of reinforcement learning. We trained mice to perform a visual discrimination task, and recorded the cholinergic neuronal activities during the learning process. Both the temporal properties and the strength of the cholinergic activities change alongside behavioral performance, and cholinergic neurons show heterogeneous responses to visual stimuli and behavioral outcomes, supporting the notion that cholinergic neurons play diverse roles in learning.

Yang, Y.*, Liu, D-q*, Huang, W, Deng, J, Zuo, Y., Poo MM. (2016). Selective synaptic remodeling of amygdalocortical connections associated with fear memory. Nature Neuroscience, 19(10):1348-55 (*Equal contribution)

Yang, Y. and Zador, AM. (2012). Differences in sensitivity to neural timing among cortical areas. Journal of Neuroscience, 32(43):15142-7.