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Phylogenetic Onset and Dynamics of Neuromodulation in Learning Neural Models

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The complexity of modulatory dynamics -- from low to high levels involving a large variety of chemicals and brain function -- is a daunting image to fathom. On a low level, new insights on synaptic plasticity are indeed unveiling the central role of heterosynaptic modulation for stabilizing Hebbian plasticity and memory (relevant data include evidence of heterosynaptic-mediated associative learning in the mollusk *Aplysia)*. Yet, how the cellular mechanisms, activation patterns and neural circuits bring about the system dynamics is still highly speculative.

This issue is investigated here by means of a computational approach that covers both the phylogenetic and the lifetime learning aspects of neuromodulation. Models of modulatory and standard neurons (seen as small and independent computational units) implement hetero- and homosynaptic mechanisms: signals produced by modulatory neurons act on synaptic plasticity (rather than on activations) of target synapses, gating homosynaptic correlation-based Hebbian plasticity with a multiplication factor.

Given the above settings, the system dynamics are sought by means of a Darwinian principle: simulated evolution is employed to breed a population of artificial neural networks that strive to survive in dynamic, reward-based environments. In these simulated scenarios -- characterised by changing reward-conditions such as uncertain food locations or quantities -- learning skills are essential to achieve good performance and guarantee survival.

Following a course of simulated evolution, the topology and neural dynamics of evolved networks are analysed. Research questions principally include: 1) whether the phylogenetic process resulted in the phenotypical expression of modulatory neurons, 2) which environmental conditions appeared to foster the rise of modulatory dynamics, 3) which neural circuitry and dynamics arise from cellular mechanisms in order to achieve learning and memory function.

The results indicate a central role of neuromodulation in many computational aspects of evolving and learning networks. Principal findings suggest that: 1) learning problems foster the phylogenetic onset of modulatory dynamics: modulatory neurons are introduced and preserved by artificial selection to provide an advantage in dynamic conditions, and 2) neuromodulation appears to improve speed in signal propagation and to reduce network size; 3) the interaction between synaptic mechanisms, activation patterns and topology is strongly coupled, often resulting in surprising and non-trivial dynamics even for small few-neuron networks.

In conclusion, this approach is a viable method to observe the autonomous evolution of computational neural dynamics for learning and memory. The analysis of neural circuitry with learning and memory capabilities can provide a ground for hypotheses on their biological counterparts and a valuable insight on computational aspects of neuromodulation.