Bird song learning without reinforcement: the Hebbian self-organization of sensorimotor circuits.

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How can distributed sensorimotor circuits, using only local synaptic plasticity mechanisms, enable organisms to rapidly learn complicated motor sequences? For example, how can a songbird, exposed only to the sensory experience of a tutor's song, learn to produce complex sequences of muscle activations that generate the same song?

Reinforcement learning (RL), a dominant theoretical framework for song learning, suffers from several problems. All RL models require a comparator circuit that computes a reward signal by comparing auditory feedback of the bird's own song with a template of the tutor song. However, physiological evidence for this comparator is lacking. Furthermore, RL cannot explain one-shot learning of sounds, possible for example in parrots and humans.

We provide a new paradigm for birdsong learning. First, in a sensory phase, tutor song exposure creates a template circuit that can replay an auditory representation of the tutor song. Second, as the bird begins to babble, it learns a forward model that predicts sensory feedback generated by motor activity. Third, the bird exploits the forward model to train an inverse model that maps auditory song representations into appropriate motor patterns required to generate song. Fourth, the bird feeds the output of the sensory template into the inverse model, to generate song and further train motor circuits. We show these phases can all be implemented through local Hebbian plasticity rules, and mathematically prove that the circuit self-organizes to generate tutor song.

Overall, this new paradigm not only explains one-shot learning, obtained by feeding a rapidly learned sensory representation into the inverse model, but also makes several testable behavioral and physiological predictions about the development of the song circuit, including the emergence of mirror neurons. More generally, this non-RL framework uncovers network design principles that could underpin rapid learning in a wide variety of sensorimotor circuits.