Inverse Models Predict Mirroring Offsets and Explain the Acquisition of New Syntax in a Sequential Song Learning Task

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Control-theoretic inverse models are very useful for learning and generating flexible sensory-goal directed motor behaviors. We have recently proposed a simple eligibility-weighted Hebbian learning rule capable of provably forming inverse models in high dimensional linear networks by associating random motor explorations with their future sensory consequences [1]. In this theory the inverse model forms in the synaptic connections from sensory to motor neurons, allowing the conversion of a sensory memory (for example a tutor song template) into the necessary motor pattern required to reproduce the sensory memory. Mirror neurons naturally arise during inverse model learning. Mirroring of motor and sensory evoked activity is either in precise temporal register, reflecting predictive inverses associated with stereotyped motor codes as in HVC, or temporary delayed, reflecting causal inverses associated with variable motor codes as in LMAN.

Causal inverse models predict a rapid/instantaneous reproduction of new motor targets without exploration if the inverse is omniscient. To test this we presented young zebra finches with song learning tasks using consecutive training with playbacks of two different tutor songs [2]. Birds were first trained with one song, and once it was learned, were introduced to a second song, in which we manipulated both the local structure (pitch) and the global structure (syllable order) of individual syllables: ABC $\rightarrow$ $A^{+}C^{+}B$. Both changes were gradually learned and the most acoustically similar target in the tutor song was matched irrespective of the syllable context. The gradual learning of syllable structure together with the high variability of the pitch points towards ongoing comparison of the bird's own song (BOS) to a memorized sensory representation of a target song (template) instead of a one shot imitation with the learned inverse map. Only after matching the pitch, birds started to rearrange syllable order. Here, we observe no exploration behavior and thus the song syntax learning can be naturally explained by an inverse model. The new syntax is probably constructed by refining links between syllable representations [3] and/or links between auditory areas and motor areas [4].

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