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Problem Statement

The Zebra Finches are songbirds which learn the song of their tutor. They learn it from 25 days post hatch (DPH) to 90 DPH [7]. Zebra finches are commonly used as a model of speech acquisition.

Derégnaucourt et al. [6] showed that sleep plays an important role in the learning of tutor songs. Indeed, they showed that sleeping has a negative impact on song restitution by zebra finches in the short term but a positive impact on the long run. Song restitution is less complex and less similar to the tutor song from one morning to the previous day evening, but the greater this loss in performance was overall for one bird, the better this bird was able to reproduce the tutor song at the end of its learning.

Dave and Margoliash [4] have found neurons in the motor cortex which fires sequences during sleep that correspond to their activity pattern when the birds sing in adult zebra finches. This shows that motor neurons that are highly correlated with bird's own song (BOS) are activated during the night. These identified replays suggest that some learning may occur during sleep that use past experiences.

Our hypothesis is that during its sleep, the zebra finch restructures the knowledge it has acquired so far thanks to replay mechanisms. We hypothesize that this restructuring can account for the loss of performance in the short term and an improvement of performance in the long term.

The goal of this internship is to offer a model of the zebra finch song learning which can explain different behavioral data observed such as the correlation between the loss of performance every night and the overall performance at the end of learning.

Investigation/Research

Our goal is to build a biological plausible model. We will use a bird song synthesizer made by Boari et al. [2]. This synthesizer is a biophysical model of zebra finch vocal apparatus. It can be parameterized with relatively few values to produce realistic bird songs. As it models the zebra finch vocal apparatus, it is likely that the parameters we send to this synthesizer are similar to the instructions sent by the zebra finch motor cortex to vocal apparatus muscles. Zebra finches song have already been reproduced using this synthesizer and a look up table [2]. The synthetic songs they produced activated neurons which are highly selective to the bird's own song (BOS). This shows that the synthesized songs are accurate reproductions of BOS.

The authors of the synthesizer have found that what can be seen as syllable in the sensory space can be seen as one or several "gestures" in this parameters space [1, 2]. Gestures are continuous and monotonous variations in the parameter space. These gestures can represent the real motor representation of the song. They define the notion of gesture trajectory extrema (GTE), which are the period in which the bird switch from a gesture to another. We hypothesize that gesture and therefore GTE identification may play an important role in song learning, as they signal changes in the progression of the parameters through time.

Our hypothese is that during the day, the bird is optimizing its sound reproduction toward subparts of the song. During the night, it uses the knowledge acquired during the day to restructure its song decomposition which will determine its new goals. The song decomposition will be the one for which the bird knows the gestures that yield the closest sound for each part. It suggests the presence of replays of already known gestures during sleep.

The restructuration of the song decomposition during the night will have a short term negative impact as the bird will have to optimize new goals but will choose more and more adaptive segmentation that lead to an overall better performance.

Proposed Solution

Our goal is to design a simple optimization algorithm that fits one specific gesture and a gesture identification algorithm. The gesture identification algorithm will try to segment the tutor song in efficient gestures based on the bird current knowledge acquired by the optimization algorithm. This two-step algorithm is similar in some points to an Expectation-Maximization algorithm [5].

This part will only cover the learning of gestures, but not the transitions between these gestures. We have yet to find how to learn the pattern of the syllables and the song. This new algorithm should be able to use the knowledge built by the gesture learning system. The algorithm that learns the syllable transition should also be able to reproduce the different learning strategies that a zebra finch can have: a serial strategy, where it only learns one specific syllable at a time, or a motif strategy, where it tries to reproduce the whole tutor song at every try.

Expected Implementation

We have already implemented the Python binder to the compiled synthesizer by Boari et al. [2]. These sound-waves will then be processed by an auditory system. We plan to use Mel-Frequency Cepstrum Coefficients (MFCC), which are used in speech recognition for Humans. MFCC have already been used to classify birdsongs [3].

We plan to use a Nearest-Neighbor algorithm to hill climb toward the goals the algorithm defines and remember each try it makes for the segmentation algorithm. The segmentation algorithm will try to do cuts in the tutor song so that each cut is the closest possible to a sound the bird can already make according to its previous tries.

Analysis & Testing

To assess the quality of our model, we have selected two criteria to meet. First, we want our algorithm to reproduce the results from Derégnaucourt et al. [6]. This includes observing the increase of song similarity [8] over the development of the bird, that the song similarity decreases overnight, but that this decrease is positively correlated with the song restitution at the end of the learning. To do that, we will use the same statistical tests that Derégnaucourt et al. [6] have done on the same set of features: Amongst other tests, we will measure the signed song similarity between the last 100 songs produced and the first 100 songs produced the next day, and see if the difference is negative (going against overall developpement). We will then do a correlation of pearson test between the overall magnitude of post-sleep deterioration and the eventual similarity to the model song, we expect to see a positive correlation between the two.

Then, we want that our algorithm identifies similar GTE distribution as the identified ones by the automatic GTE extractor made by Boari et al. [2]. We expect the mean amount of GTE per syllable inferred by our algorithm and Boari's algorithm to be equal.

Final Evaluation

Once the model is fully working and respond to our expectations in reproducing the literature, we will study its behaviors to design new hypotheses that can be tested on real zebra finches. For instance, we can make postulates about the replay neural pattern in the night during its development. We can also make the hypothesis that the bird use the same song decomposition through out the day.

Contributions

S. Derégnaucourt provided us behavioral data for model comparison and will help us reproducing his analyses.
S. Boari and his colleagues built the song synthesizer and a GTE detection algorithm.
I will code the model and the analysis with the supervision of Stéphane Doncieux and Benoît Girard.

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