Replication of Laje & Mindlin's model producing synthetic syllables

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Abstract

In order to implement a realistic output in a song learning model, we investigated one of the models proposed in the long research quest of Minldin. We were looking for a model with few degrees of freedom, and replicated the RA model proposed in Laje & Mindlin (2002). The model describes three neural populations of RA receiving inputs from HVC: two of which are excitatory and control the syringeal muscles and respiratory muscles (x_k and x_p resp.); one which stands for inhibitory interneurons. This model is able to produce syllables sounds. We implemented this model in Python language and tried to reproduced several figures of the original paper: a bifurcation diagram and three synthetic syllables.

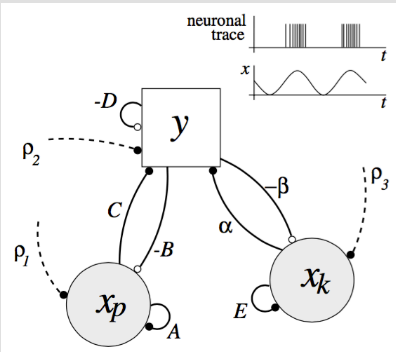
Materials & Methods

Mean-field population model

The interaction between these populations are described by three ordinary differential equations (ODE).

$$\dot{x}_p = 30[-x_p + S(\rho_1 + Ax_p - By)],$$
$$\dot{y} = 30[-y + S(\rho_2 + Cx_p - Dy + \alpha x_k)],$$
$$\dot{x}_k = 120[-x_k + S(\rho_3 + Ex_k - \beta y)],$$

where S denotes a sigmoid function $S(x) = 1/(1+e^{-x})$ and ρ_i are the excitatory inputs from HVC into the sets of neurons with activities x_p (pression), y (inhibitory), and x_k (tension) respectively.



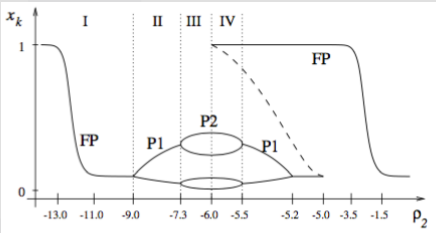
The neural sets within RA: two excitatory sets (shaded circles) connected to a long-range inhibitory one (open square). All sets receive excitatory inputs from HVC, denoted here by dashed lines. Inset: averaged activity of one of the populations (bottom), and spiking activity consistent with the averaged activity (top).

Discussion

We could partly reproduce the results (i.e. figures) of the original paper of Laje & Mindlin (2002). According to our experiments it seems that the original bifurcation diagram was probably interpolated by hand because we obtain a qualitatively similar figure but not a quantitatively similar figure. We could also produce a few different synthetic syllables with the model. However, we were not able to reproduce the same "song" composed of the three syllables as it is shown in the original figure. Moreover, we were not able to find the initial conditions which enable to produce a syllable "right away" when setting a particular ρ_2 value: a transitory period was necessary before the corresponding syllable (of their paper) could be produced. In conclusion, the model can produce a few isolated syllables but, and, as far as we experimented, it seems difficult to produce songs.

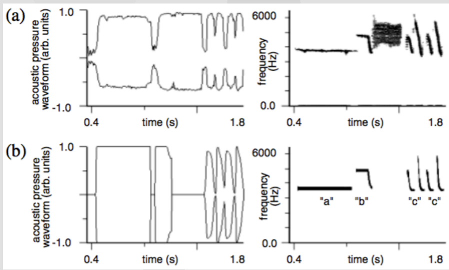
Original figures

Bifurcation diagram



Bifurcation diagram obtained as ρ_2 is varied. $\rho_1 = 0$, $\rho_3 = 6$. FP fixed-point, P1: period-one limit cycle, P2 period-two limit cycle. The P1 oscillation is represented by two points indicating maximum and minimum of the oscillation, and the P2 oscillation is represented by four points indicating two local maxima and two local minima. Solid line: stable solutions; dashed line: unstable solutions.

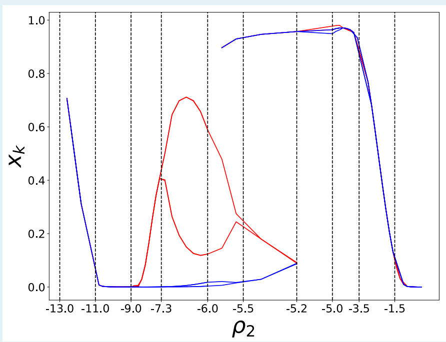
Synthetic syllables



(a) A recorded song of a white-crowned sparrow (Zonotrichia leucophrys), and (b) the synthetic song. One of the syllables cannot be generated by this subpopulation. Values of ρ_2 used for the different syllables: syll. "a": ρ_2 = -11.0; syll. "b": ρ_2 = -11.8; syll. "c": ρ_2 = -7.1;

Reproduced figures

Bifurcation diagram



Bifurcation diagram obtained by two pass iterative simulations. (blue) local minima (red) local maxima. Scale is piece-wise linear in order to keep a similar shape than in the original figure. We used a sampling rate of 63,000 when generating the sounds.

Acknowledgements

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References

Laje, R., & Mindlin, G. B. (2002). Diversity within a birdsong. Physical review letters, 89(28), 288102.

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Synthetic syllables

We show the three syllables obtained when changing sequentially the values of ρ_2 (-11.0; -11.8; -7.1), while keeping $\rho_1 = 0$ and $\rho_3 = 6$. Moreover, we give the corresponding pressure and tension activity. We used a sampling rate of 105,000 when generating the sounds.