



HAL
open science

An Attractor Model of the Temporal Dynamics of the Songbird's Premotor Nucleus

Fjola Hyseni, Nicolas P. Rougier, Arthur Leblois

► **To cite this version:**

Fjola Hyseni, Nicolas P. Rougier, Arthur Leblois. An Attractor Model of the Temporal Dynamics of the Songbird's Premotor Nucleus. CNS 2023 - 32nd Annual Computational Neuroscience Meeting, Jun 2023, Leipzig, Germany. . hal-04444204

HAL Id: hal-04444204

<https://hal.science/hal-04444204v1>

Submitted on 7 Feb 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

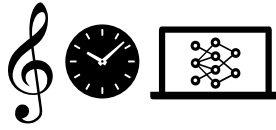


An Attractor Model of the Temporal Dynamics of the Songbird's Premotor Nucleus

FJOLA HYSENI

NICOLAS ROUGIER

ARTHUR LEBLOIS

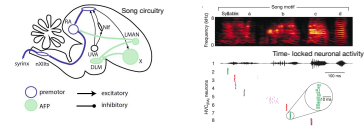


Introduction

Temporal control is crucial for the generation of coordinated movements during sensorimotor tasks.

What do songbirds tell us about timing?

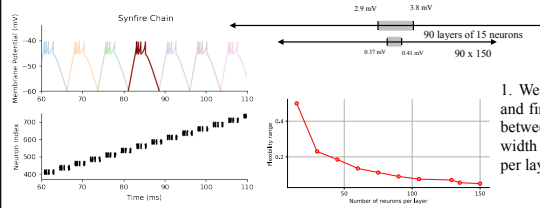
In male zebra finches, the premotor nucleus HVC (proper name) is responsible for the precise control of song tempo, becoming as such an ideal model for action timing.



How to model motor timing in HVC, in accordance with - electrophysiological (3-6 spikes, 6-10 ms burst) and - behavioral (specificity in adaptive learning) evidence?

Current computational models of HVC rely on synfire chains. We propose attractor models as an alternative.

1 Modelling motor timing in songbirds: Synfire Chain vs. Ring Attractor.



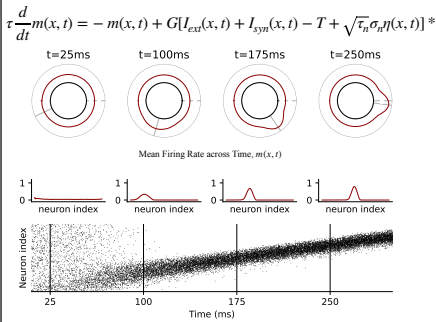
1. We implement a synfire chain with adaptive leaky integrate and fire neurons with synaptic delays and show that the weights between layers can be modified only within a narrow range, the width of which decreases as we increase the number of neurons per layer.

2. An alternative hypothesis is that the gradual propagation of an activity bump is driven in HVC by attractor dynamics. In particular, a linear attractor, also referred to as ring attractor, can drive a drifting activity bump with robust and resilient properties thanks to recurrent connections.

$$W(x-x') = W_0 + W_2 \frac{1}{\sigma\sqrt{2\pi}} e^{-\left(\frac{x-x'}{\sigma}\right)^2}$$

2 Reproducing HVCRA dynamics

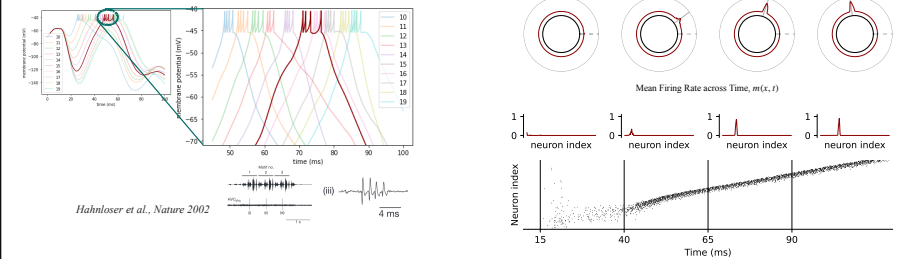
Rate Based Model:



* $m(x,t)$: mean firing rate of neuron x at time t , G : semi-linear gain function, τ : membrane time constant, I_{ext} : external input, I_{syn} : synaptic input, T : threshold, $\sqrt{\tau}\sigma_n\eta(x,t)$: zero mean Gaussian white noise.

Exponential Integrate & Fire neuron with adaptation (AdEx) and conduction delays:

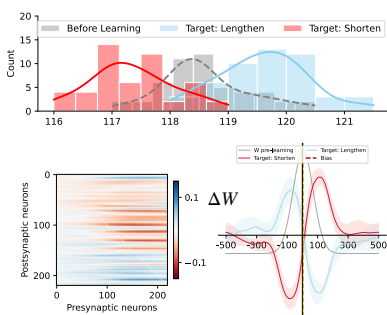
$$C \frac{dV}{dt} = -g_L(V - E_L) + g_L \Delta_T \exp\left(\frac{V - V_T}{\Delta_T}\right) + I_{ext} - w + I_{syn} + \sqrt{\tau_n} \sigma_n \eta(t) **$$



- Using the rate based model, only a short duration bump profile can be generated, but a small membrane time constant (1 ms) is necessary to reproduce the 10 ms burst duration. With the spiking (SNN) model, we acquire results similar to the ones observed in the rate model, but are able to generate experimentally-observed neuronal dynamics with bioplausible parameters.

** V : membrane potential, C : membrane capacitance, g_L : leak conductance, E_L : leak reversal potential, w : adaptation variable, V_T : threshold, Δ_T : slope factor.

3 Behavioral Adaptation with Reinforcement Learning

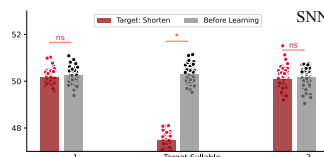
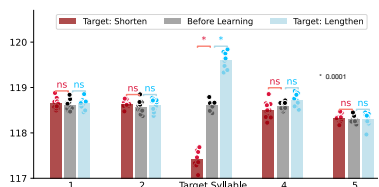


Relying on a reward covariance rule (Williams, 1992), we show that the duration of a syllable can be modified in response to a perturbed reward profile, as implemented in a widely used lab conditioning paradigm.

$$\Delta W_{ij} = \gamma R e_i r_j dt$$

$$e_{ij} = \int_0^t \frac{dt'}{\tau_e} e^{-(t-t')/\tau_e} r_j(t') r_i(t')$$

Consistent with behavioral data, the change in duration is specific to the target syllable. We see no interference with adjacent or non-adjacent syllables, both in the case of targeting for duration increase and decrease.



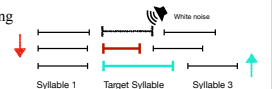
4 Discussion and Conclusion

Song timing: HVC (HVCRA neurons)

Synfire Chain (not robust) ✗
Ring Attractor (robust) ✓

AdEx with delays; 3-6 spikes, 6-10 ms duration (~ HVCRA neurons)

Specific Adaptive Learning (~ behavioral experiments)



References

- [1] Jin et al., J Comput Neurosci, 2007: Intrinsic bursting enhances the robustness of a neural network model of sequence generation by avian brain area HVC.
- [2] Hansel & Sompolinsky, 1998: Modeling feature selectivity in local cortical circuits.
- [3] Egger et al., Cell, 2020: Local axonal conduction shapes the spatiotemporal properties of neural sequences.
- [4] Pehlevan et al., Nat. Comm., 2018: Flexibility in motor timing constrains the topology and dynamics of pattern generator circuits.
- [5] Buonomano & Laje, 2010: Population clocks: motor timing with neural dynamics.
- [6] Williams, Mach. Learn., 1992: Simple statistical gradient-following algorithms for connectionist reinforcement learning.