# Towards an in-Silico Study of *Sternarchus*

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***Abstract*—Modeling a biological system accurately allows its mathematical and computer representation which allows for prediction of responses under various conditions. The *Sternarchus* is a strange biological system wherein there are two different types of nodes within a single axon length, the length itself being uniquely shaped spatially. In this letter, we look at the *Sternarchus* model in two variations - as a single axon and as a short tract of three axons. We find the expected conduction block by type-two nodes. We also find temperature dependence on the action potential conduction profile for the second model.**

## I. Introduction

In this letter, the authors perform in-silico experiments on axons with a second type of node of Ranvier. The experiments are carried out on the MATLAB software platform. This second type of node was introduced by Waxman et. al. (Waxman *et al.*, 1972) on the basis of their examination of *Sternarchus*. In that paper, Waxman presents a number of interesting images showing the presence of two types of nodes. We find that, as suggested in that paper, when the node is allowed only a capacity-like feature or property, it doesn't re-generate the action potential, effectively blocking conduction. This is in contrast to a normal node which, due to ionic currents flowing in and out, allows re-generation of action potential trains. It was suggested in that paper that such nodes (of the second type) are found at the tapering posterior end of the electric organ of the *Sternarchus*, just before it bends and turns in the opposite direction. The electric organ is a unique organ where axons seem to have a non-communication function. The tapering of the axons and the presence of these type-two capacity-like nodes is consistent with a slowing down and near-stopping of action potential trains.

This letter is organized as follows. In Section II we review the early literature on this fascinating organism. In Section III we discuss the computer simulation methods used to perform our investigations. Finally, we present our simulation results in Section IV. Section V closes the letter with a discussion.

## II. Literature Review

The *Sternarchus* turns out to be a widely studied model organism starting in the 1960s, and as early as 1905 we find an entire book on the *Gymnotidae* family to which it belongs (Eigenmann & Ward, 1905). From 1963, we have (Hagiwara & Morita, 1963). From 1965, we have the paper (Hagiwara *et al.*, 1965). Another paper from the same year and one shared author is (Enger & Szabo, 1965). The research volume on this organism continues to grow (see for example, (Maler *et al.*, 1974; Tokunaga *et al.*, 1980; Anderson *et al.*, 1983)) and it would not be appropriate to cite every paper in the literature.

## III. Methods-in-Brief

In order to replicate our results of Section IV, the reader should first develop the program introduced in detail in (Chawla *et al.*, 2019). This is to be followed by a modification of some of the nodes into type-two nodes. Thereafter the simulations can be run.

## IV. Simulation Results

### A. Single Axon

In this section we look at the *Sternarchus* with regular nodes at positions 20, 30, 60 and beyond and type 2 nodes at positions 40 and 50. We observe that conduction gets blocked at node 40. This is due to the purely capacitive feature of type 2 nodes. In these nodes the ionic and activation variables are all zeroed out and purely diffusive effects under the influence of the large capacitance are allowed. Figure 1 below shows our simulation output.

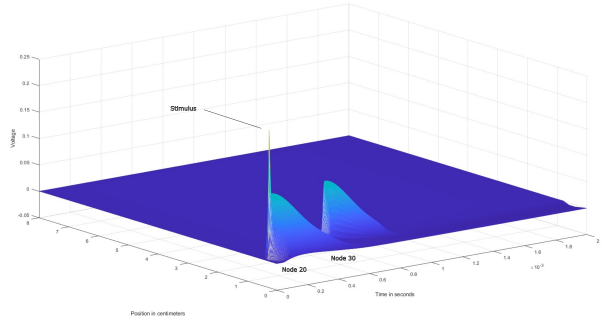


Figure 1. A single axon is stimulated at 29.3 degrees C. After a single additional hop, conduction is blocked by a Type-2 node.

### B. Current-coupled Axon Tract; Temperature Variations

The following figures (Figure 2, Figure 3 and Figure 4) show the response of two type 1 nodes followed by two type 2 nodes in a three-axon tract. The tract length is chosen to be a segment that avoids the bending present in the *Sternarchus* geometry. Even though the *Sternarchus* case is not a tract but a single axon, we look at a tract to see if the work can be extended to the ephaptic coupling case. (Hilton *et al.*, 2007) gives the ambient temperature range to be 26.6 degree Centigrade to 29.3 degree Centigrade. We find intriguing variations with temperature changes. The second action potential initiation time gets substantially delayed with temperature.

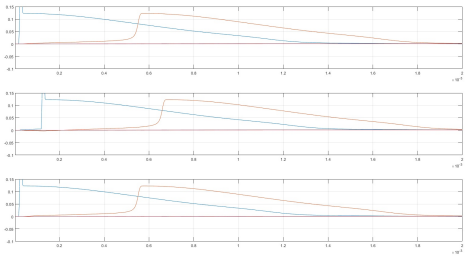

Figure 2. A three-axon tract with current-mediated ephaptic coupling is triply stimulated with delay at 20 degrees C. Axons are numbered 1, 2 and 3 from top to bottom subplot. The x-axis is time in seconds and the y-axis is voltage in Volts.

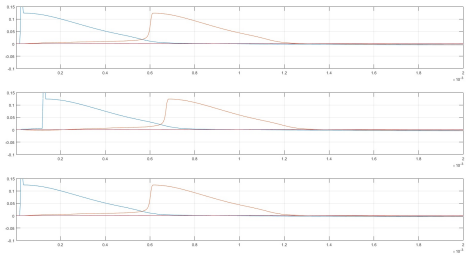

Figure 3. A three-axon tract with current-mediated ephaptic coupling is triply stimulated with delay at 26.6 degrees C. Axons are numbered 1, 2 and 3 from top to bottom subplot. The x-axis is time in seconds and the y-axis is voltage in Volts.

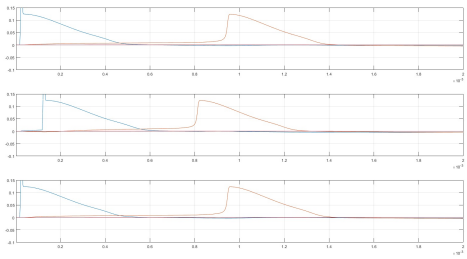

Figure 4. A three-axon tract with current-mediated ephaptic coupling is triply stimulated with delay at 29.3 degrees C. Axons are numbered 1, 2 and 3 from top to bottom subplot. The x-axis is time in seconds and the y-axis is voltage in Volts.

## V. Discussion

Tegmark, in (Tegmark, 2000), looks at a single type of node in a neuron with two states: in and out or firing and not-firing. But if we have two types of nodes, or a continuum of nodal lengths, meaning a continuum of nodal types, then there is effectively a two dimensional manifold of states. One can therefore consider quantum superpositions of states, each of which belongs to this 2D manifold. Nevertheless, we have to keep in mind the caveat that these alternate node types (the so-called type-two in the *Sternarchus*) might not be full-fledged nodes, performing more of a capacity-like function. A direction to extend our present work on the *Sternarchus* is therefore to look at universal quantum computation at both the node types and whether there can be some collaboration or cooperation between the nodes. This would be in the context of (Chawla & Morgera, 2022a).

It would also be interesting to investigate whether we can provide a lower bound to the date of evolution of *Sternarchus*. This might be feasible if we do a model of the *Sternarchus* in an expanding universe and study when the impact of the expansion molds the *Sternarchus* into the form where information processing is done as at present, as presented herein. Similar ideas were proposed in (Chawla *et al.*, 2021).

Finally, (Quick & Waxman, 1978) looks at demyelination in the *Sternarchus* and it would be interesting to include this feature in our models. With two node types, we might expect slightly different results from those presented in our earlier work (Chawla & Morgera, 2022b).

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