Dynamic information routing in *Caenorhabditis elegans*

J. Medina, V. M. Eguíluz, C. Mirasso.

IFISC (CSIC-UIB) Palma de Mallorca – Spain.

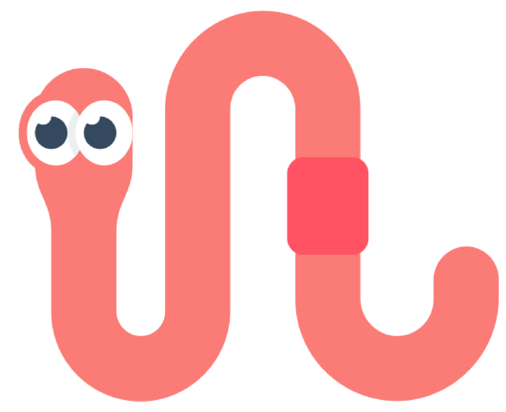
jorgemedina@ifisc.uib-csic.es

Abstract

Caenorhabditis elegans (c. elegans) is a transparent nematode of about 1 mm of length. As of 2021, it is the only organism whose connectome, i.e. the neuronal connectivity diagram, has been fully tracked. Thus, it conforms the **most realistic example of a biological neural network**.

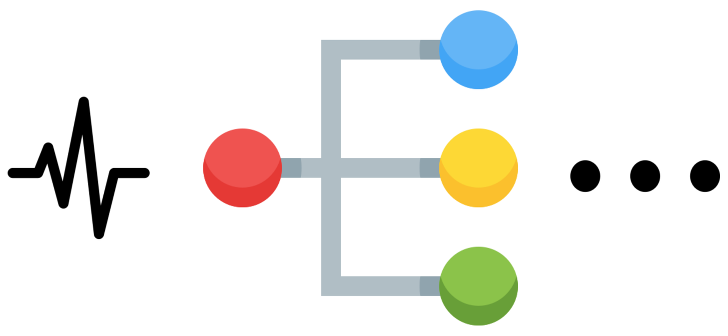
In a context of homogeneous frequencies, signals applied to a frequency-boosted neuron lead to a process of harmonics generation within the network. The **quality of their propagation is highly dependent on the response of the senders and the sender-receiver relative phases**.

Lastly, the **network structure seems to restrict information spreading in structural hubs in favor of nodes with lower out-degree**, when compared to degree-preserved randomizations. Furthermore, the effect of the topology qualitatively differs depending on the neuron type.

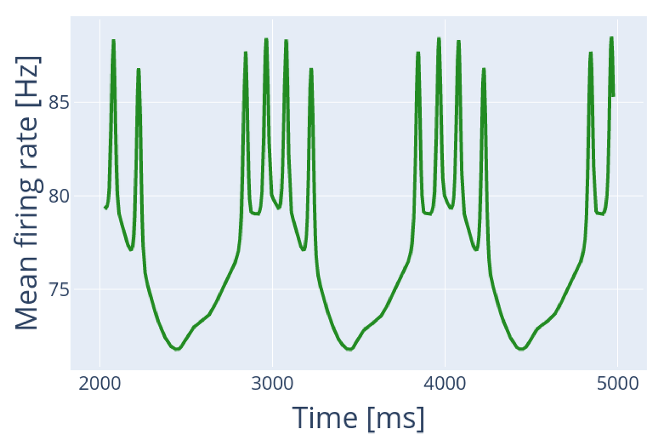


Methodology scheme

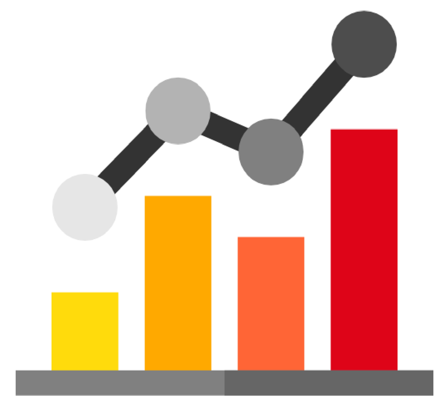
1. Apply signal to the high-frequency neuron



2. Firing rate becomes modulated

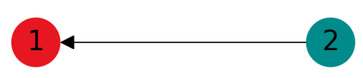


3. Analyze propagation of the modulation



Harmonics generation

Neuron pair

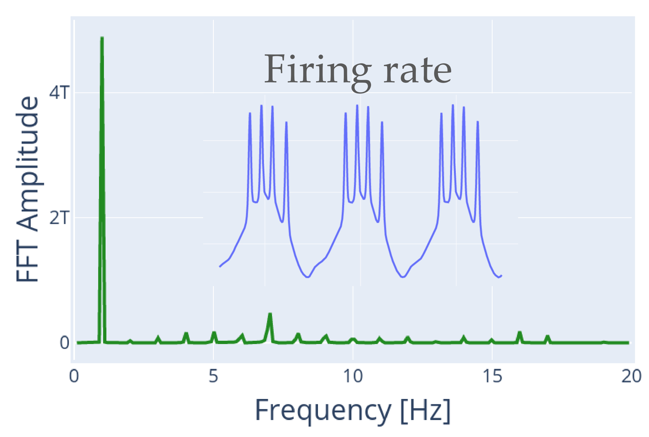


- Neuron pair with frequency difference Δv.
- Sinusoidal signal applied to the high frequency neuron (**HFN**).
- Unidirectionally coupling from LFN to HFN.

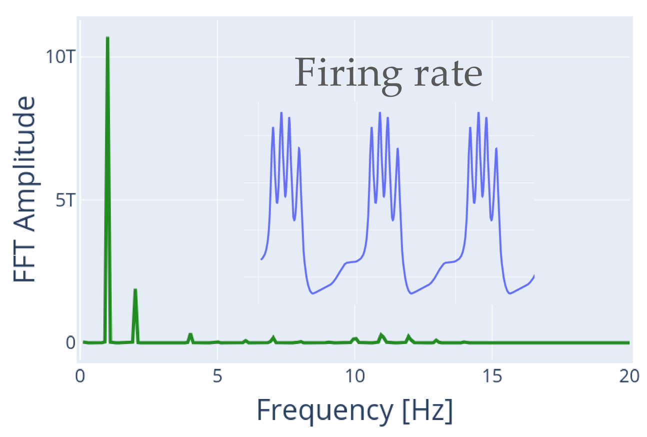
If the coupling can not overcome the frequency difference, the interaction produces **harmonics**:
- Centered in **Δv**
- With distribution dependent on the input signal.

Seems to be a more general property of oscillators exhibiting syncrhonization

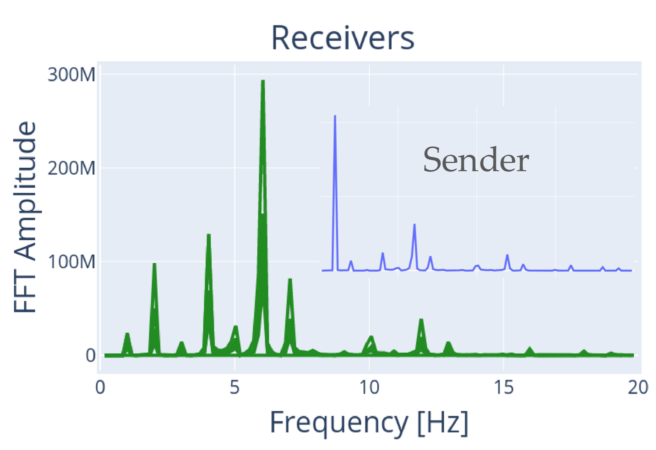
H.H. neuronal model [1]

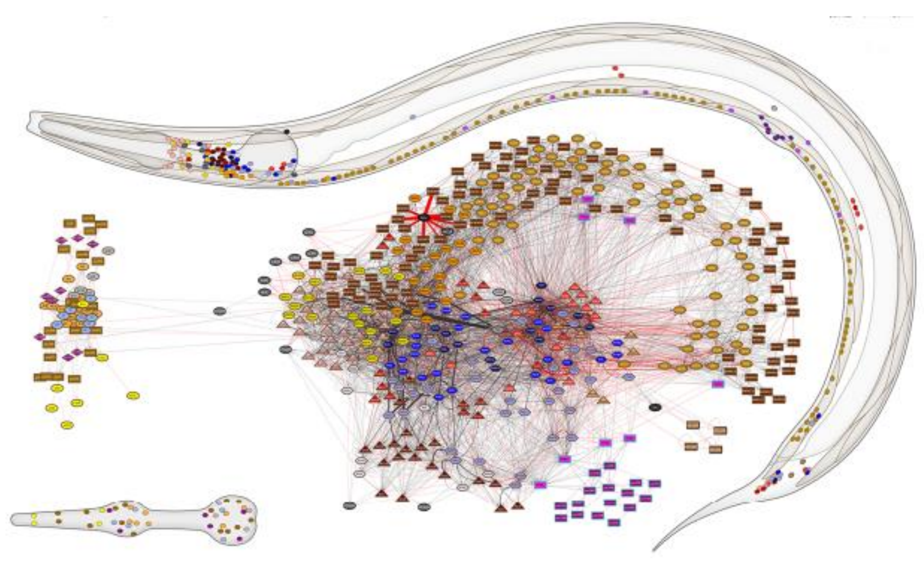


Kuramoto oscillators



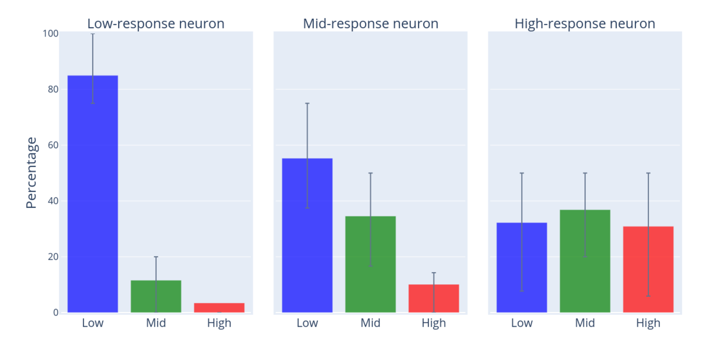
C. elegans





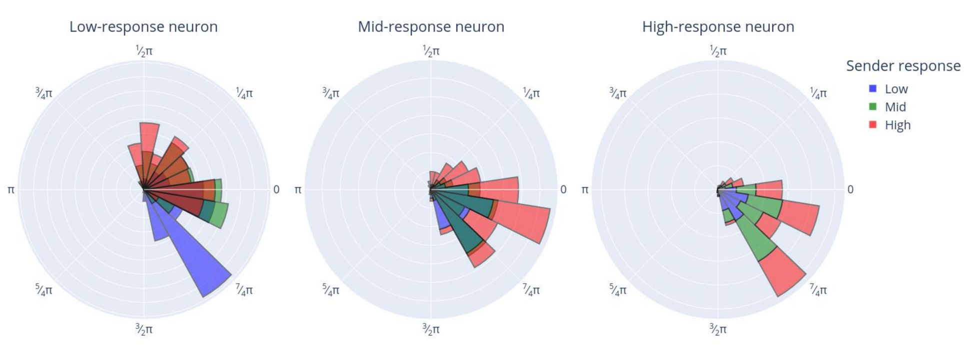
In *c.elegans* network [2] with a setting of **homogeneous frequencies** (with the exception of the HFN), most of the information is transmitted in the harmonics. Loops and incoming connections with nodes unreachable from the HFN have been found to be linked to harmonic generation.

Factors affecting quality of the propagation



Response of the presynaptic neurons

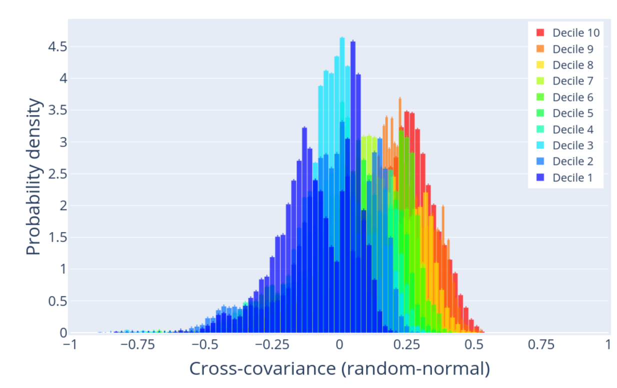
Postsynaptic neurons with high (low) response - the cross-covariance between the firing rates of sender and receiver - receive a greater proportion of their synaptic currents from neurons with high (low) response.



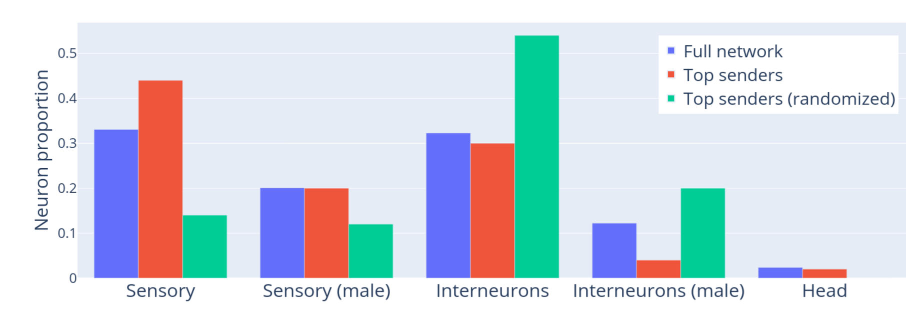
Sender – receiver relative phase

Postsynaptic neurons with high (low) response have a larger proportion of high-response presynaptic neurons spiking before (after) them, when they are more (less) excitable.

The role of the topology



Cross-covariance difference for each out-degree decile.



Proportion of neurons in the *c. elegans* network (blue) and the top 20% propagators in the usual (red) and randomized (green) networks.

Comparing the cross-covariances in the usual *c. elegans* network and degree-preserving randomizations, we find that the latter enhances (diminishes) the propagation for high (low) out-degree neurons. In other words, **the structure of *c. elegans* would prevent the structural hubs from controlling the network;** usually interneurons, in favor of the low-degree, sensory neurons.

Conclusions and outlook

The quality of the propagation of information is highly dependent on the response of the senders and the sender-receiver relative phases in *c. elegans,* provided the frequencies of the receivers are homogeneous.

The **network structure restricts the a priori advantage of structural hubs for controlling the network**, allowing lower-degree neurons to have greater impact on the collective dynamics.

Next step: Analyze information propagation in a context of heterogeneous detunings by measuring the **consistency**. In principle, it would highlight the ability of each neuron to repeatedly drive the others to a certain state, regardless of the initial conditions.

References

[1] **Hodgkin, A.L. and Huxley. A.F (1952).** "A quantitative description of membrane current and its application to conduction and excitation in nerve". In: J Physiol 117.4.

[2] **Cook, S. J. et. al. (2019).** Whole-animal connectomes of both Caenorhabditis elegans sexes. Nature 571,

Icons from www.flaticon.com. Authors: Smashicons, Kiril Kazachek, Becris, Pixelmeetup, Vectorsmarket, Freepik, Vaadin.