Information transmission in delayed-coupled neural circuits

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Abstract

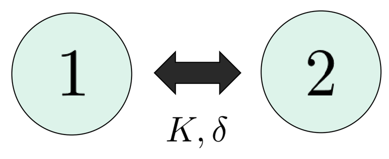
The information that we received through our sensory system (e.g. auditory, visual, tactile, etc), needs to be transmitted to different regions of the brain for its processing. These different regions may be directly connected together by axonal fibers. Due to the latency in the communication between different regions, it is possible that they synchronize in phase or out of phase, or even not synchronize [1]. These types of synchronization, when occur, may have important consequences in the information transmission and processing [2]. Multielctrical recordings have revealed zero-lag synchronization among remote cortical areas (feature binding [3]). This phenomenon has been observed across different species with different brain sizes and at different stages of the developmental growth of brain structures. Therefore, this requires a generic mechanism for generating zero time lag long-distance cortical synchrony maintaining the functionality independently of axonal lengths/delays. A V-motif circuit is proposed to represent two cortical areas bidirectionally connected with a third one that might represents the thalamus. In addition, a third connection can be considered to represent a cortico-cortical connection generating a circular motif. It is well known the presence of that kind of connections in the brain. Therefore, we study here the information transmission in a V and a circular motif.

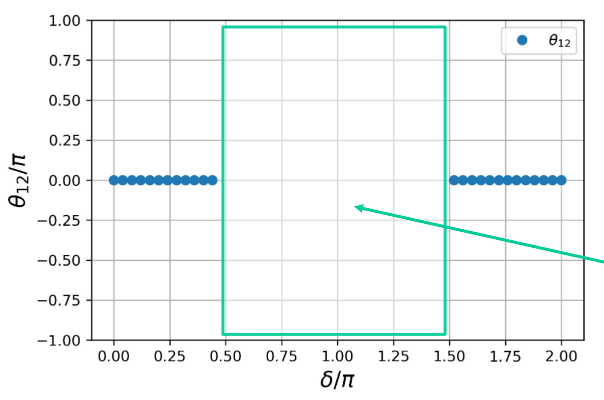
Neural circuits

We consider each node of the circuit as a **Kuramoto** phase oscillator.

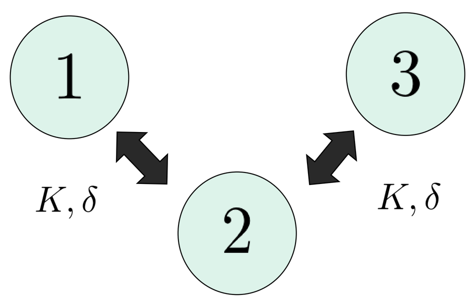
$$\dot{\theta}_i = \omega_i + \sum_{i=1}^{N} K_{ij} \sin(\theta_j - \theta_i - \delta_{ij}) \qquad i = 1, \ldots, N$$

Two mutually coupled oscillators: it represents the simplest connection between population. For simplicity we consider $K_{21} = K_{12},\ \delta_{12} = \delta_{21},\ \omega_1 = \omega_2$.

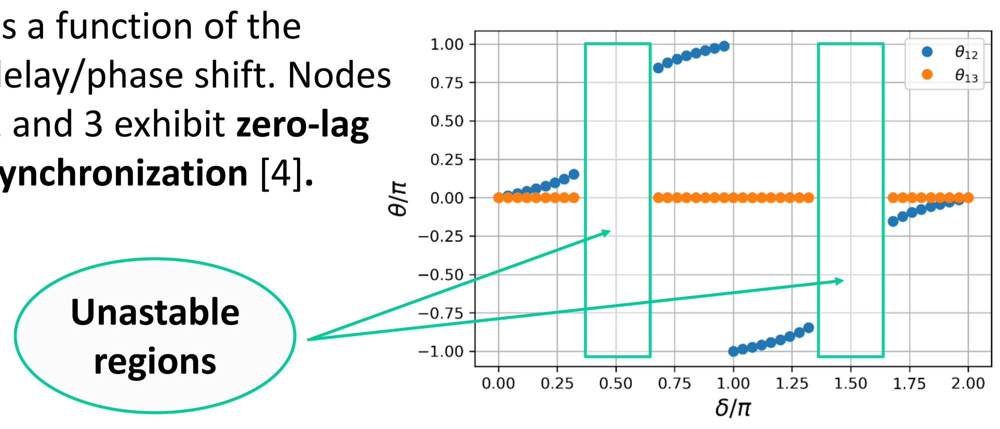




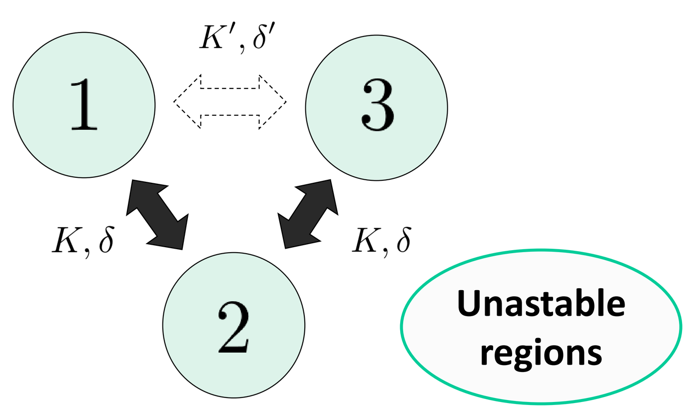
V-motif: nodes 1 and 3 can represent two cortical areas, and node 2 can be the thalamus acting as a mediator.



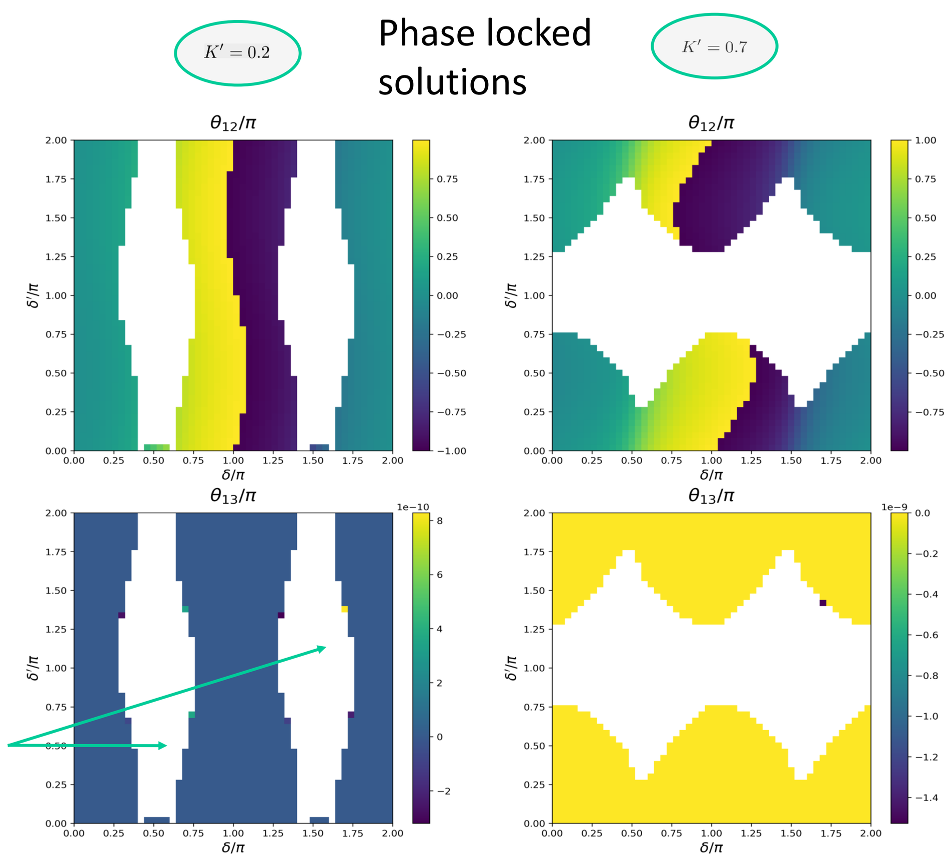
Phase locked solutions as a function of the delay/phase shift. Nodes 1 and 3 exhibit **zero-lag synchronization** [4].



Circular motif: the cortico-cortical connection is added with a synaptic strength K' and delay δ'. We study the phase locked solutions depending of both delays for different values of K'. The system still exhibits zero-lag synchronization.



Phase locked solutions



Information transmission

To determine the dominant direction of the shared information between two nodes, we quantify asymmetries in the delayed mutual information using the difference [5]:

$$\delta MI_{i,j} = MI_{i\to j} - MI_{j\to i}$$

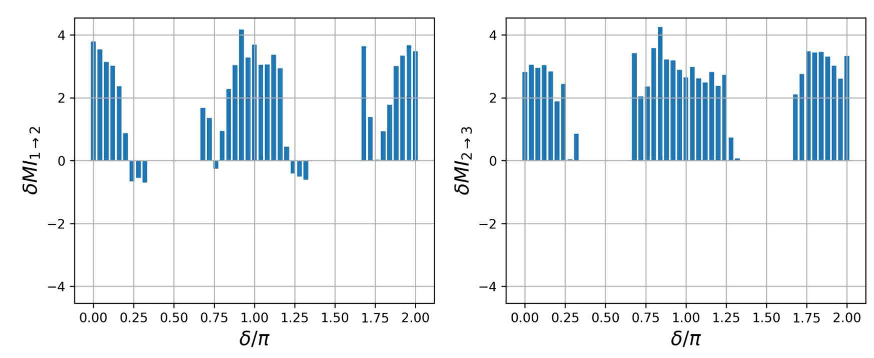
where

$$MI_{i\to j} = \int_0^\infty dMI_{i,j}(\tau)d\tau$$

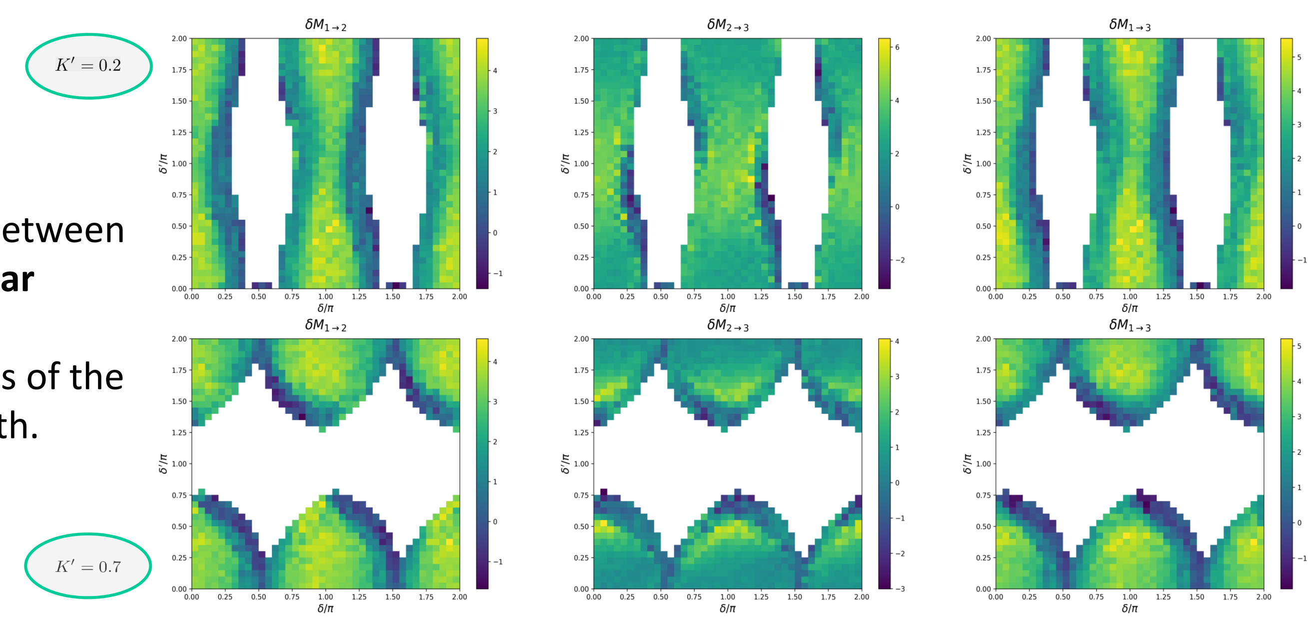
To compute information transmission, we modulate one of the nodes of the circuit by a **slow-frequency** sinusoidal signal.

By modulating node 1

Information transmission between nodes in **V-motif.** These results shows how the information goes from 1 to 2 and from 2 to 3, as exected.

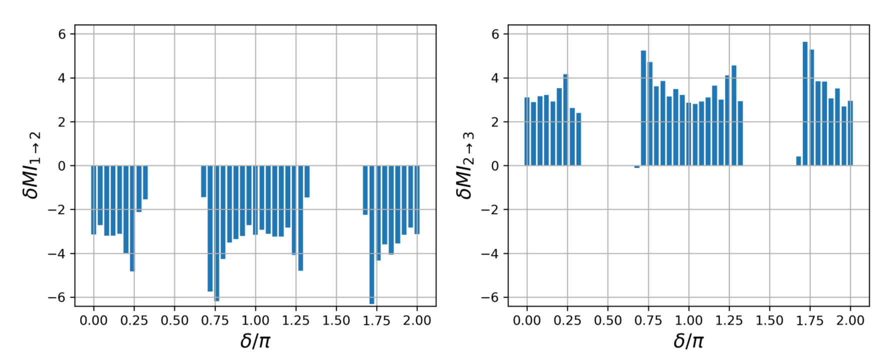


Information transmission between nodes in **circular motif** for two different values of the synaptic stength.

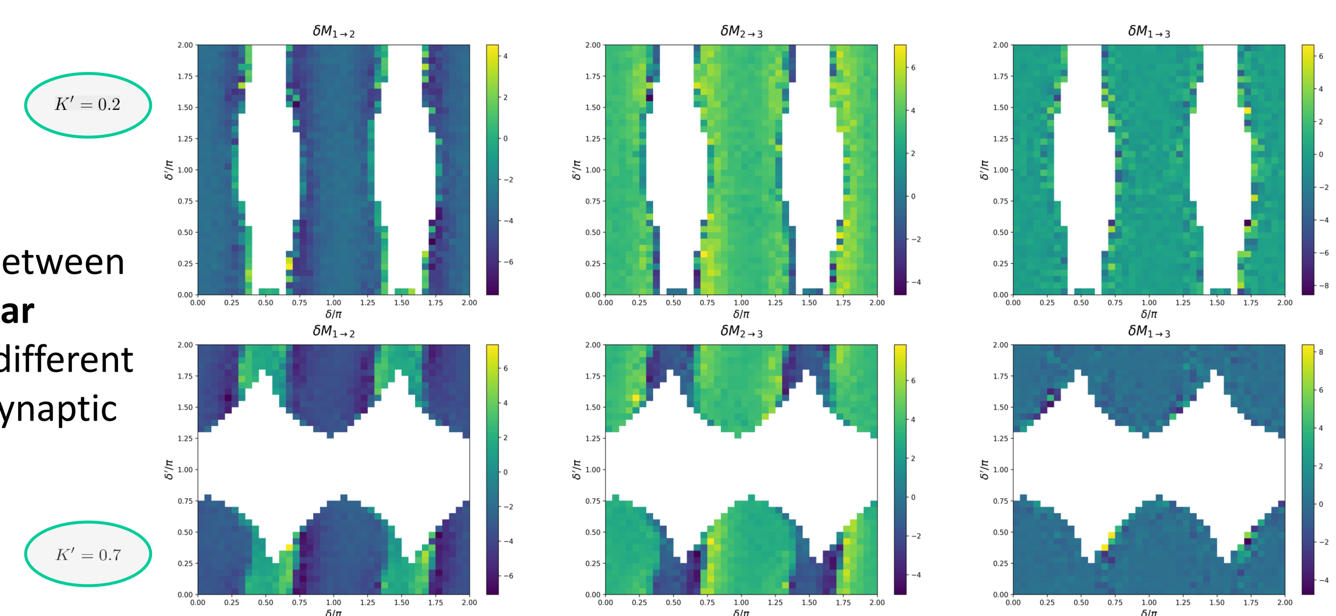


By modulating node 2

Information transmission between nodes in **V-motif.** Here, it can be seen how the information clearly travels from 2 to 1 and 3.



Information transmission between nodes in **circular motif** for two different values of the synaptic stength.



Discussion

- The question we addressed was how a the information can be processed in delayed-coupled oscillators in the presence of zero-lag synchronization.
- First, the stable solutions of both V and circular motifs have been obtained. Depending on the synaptic strength of the cortico-cortical connection, the system can became unstable for a certain delays which affects the information processing.
- The information transmission between a pair of nodes reveals the expected results in the V-motif. However, the situation is different with the addition of the third connection where its synaptic strength plays an important role enabling/desabling information routing.
- We are currently studying these circuits considering populations of neurons with more realistic neural models, like Izhikevich or Hodgkin-Huxley model. In contrast to Kuramoto model, their dynamic exhibit a refractory time that will not always allow the tranmission of information.
- Zero-lag synchronization has been recently observed in the sensory thalamo-cortical circuit [6],
- and so, we will consider it in further studies.

References

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