Control of Synchronization on Complex Neural Networks

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We apply a sinusoidal external signal to a small-world map-modeled neural network seeking minimization of its synchronization. We find the signal to be capable of partialy supressing the synchronization provided its amplitude is big enough and its frequency doesn't match the natural mean frequency of the network. It the latter case application of the external forcing can increase syncronization.

Introduction

Synchronization on neural networks is related to several neurological phenomena, eg. memory and learning [1], but it is also the cause of diseases such as Parkinson's disease and convulsions [2], making its control an object of interest.

Here we study the extent to which the addition of an external cosinosoidal signal on a simulated neural network suppresses its synchronization.

Methods

We simulate a network of 10000 Rulkov Map [3] neurons on a Small-World network. Then for varying degrees of synchronization, an external signal was added on some of the neurons and its effects on the synchronization were observed.

The evolution equations of the *i-th* Rulkov neuron, with coupling and the external signal already added are

$$x_{n+1}^{i}=\frac{\alpha}{1+x_{n}^{i\,2}}+y_{n}^{i}+\epsilon\frac{1}{C_{max}}\sum_{j=1}^{N}A_{ji}x_{n}^{j}+d\cos(\omega n)$$

$$y_{n+1}^{i}=y_{n}^{i}-\sigma x_{n}^{i}-\beta$$

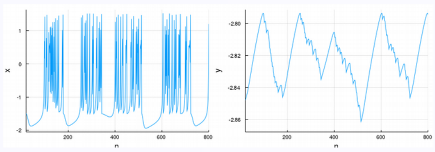


Figure 1: Time series of the x and y variables of the model

To measure the effects of the external signal on synchronization we use the Suppression Coefficient, given by

$$S=\sqrt{\frac{Var(X_0)}{Var(X_s)}}$$

where X_s and X_0 are the mean fields of the network with and without the external signal, respectively.

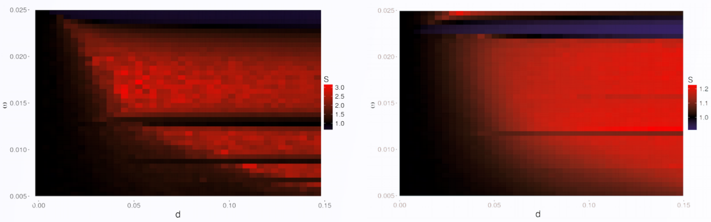
If the coefficient is greater (less) than 1 there is suppression (increase) of synchronization.

Results

We calculated the network's suppression coefficient *S* as a function of *d* and ω with ϵ and the fraction of neurons affected fixed. (Figure 2)

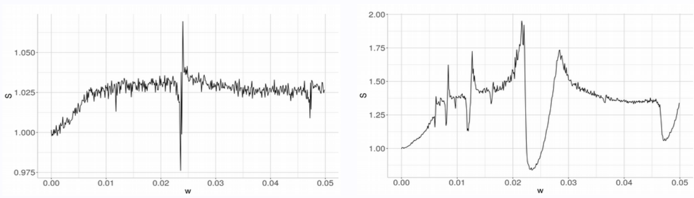
We see that the suppression coefficient is greater than 1 on most of the parameter space, with the exception of low amplitudes, when the signal isn't strong enough to cause change on the neurons, and for a couple selected frequencies.

Fixing *d* and focusing only on the dependency with ω, we have a clearer picture. (Figure 3)



ϵ = 0.06 ϵ = 0.085

Figure 2: Supression coefficient as a function of *d* and ω for a network with 10000 neurons, 10% of which were affected by the external signal. Low amplitude signals don't cause significant supression and, if the signal's frequency is close to the network's natural frequency (and to a lesser degree, its multiples), the supression is unsucessful and increase of synchronization is possible. Otherwise, supression of syncronization is achieved.



1% of the neurons affected 10% of the neurons affected

Figure 3: Supression coefficient as a functions of the signal's frequency for a network of N=10000 neurons, ϵ=0.07 and *d*=0.15. The supression is less effective if the signal's frequency matches the networks's natural frequency Ω=0.024, even reaching values less than 1. The frequency width of this interval increases with the fraction of affected neurons.

The network used here has a natural frequency – i.e. the average of the frequency of all neurons, which on a synchronized state is the frequency most of the neurons have – of Ω = 0.024.

We see that for ω ~ Ω the suppression coefficient drops heavily, even reaching values less than 1.

Also for frequencies of *n*Ω and Ω/*n* (n=1,2,3…) this effect is seen to a lesser degree.

Conclusions

- The application of a harmonic external signal to some neurons of a small-world Rulkov neuron network is capable of suppressing its synchronization.
- A signal with frequency matching the network's natural frequency doesn't suppress synchronization, and can even increase it.

References

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