Suppression of Synchronization due to Delayed Feedback Signals in Neural Networks

Conference on Perspectives in Nonlinear Dynamics, 2019

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July 17, 2019

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Acknowledgements

Antonio M. Batista (UEPG)
José D. Seszech Jr. (UEPG)
Ricardo L. Viana (UFPR)
Adriane S. Reis (UFPR)

Iberê L. Caldas (USP)
Kelly C. Iarosz (USP)
José C. P. Coninck (UTFPR)
Alexander Pisarchik (UPM)

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Structural Connections of the Human Brain

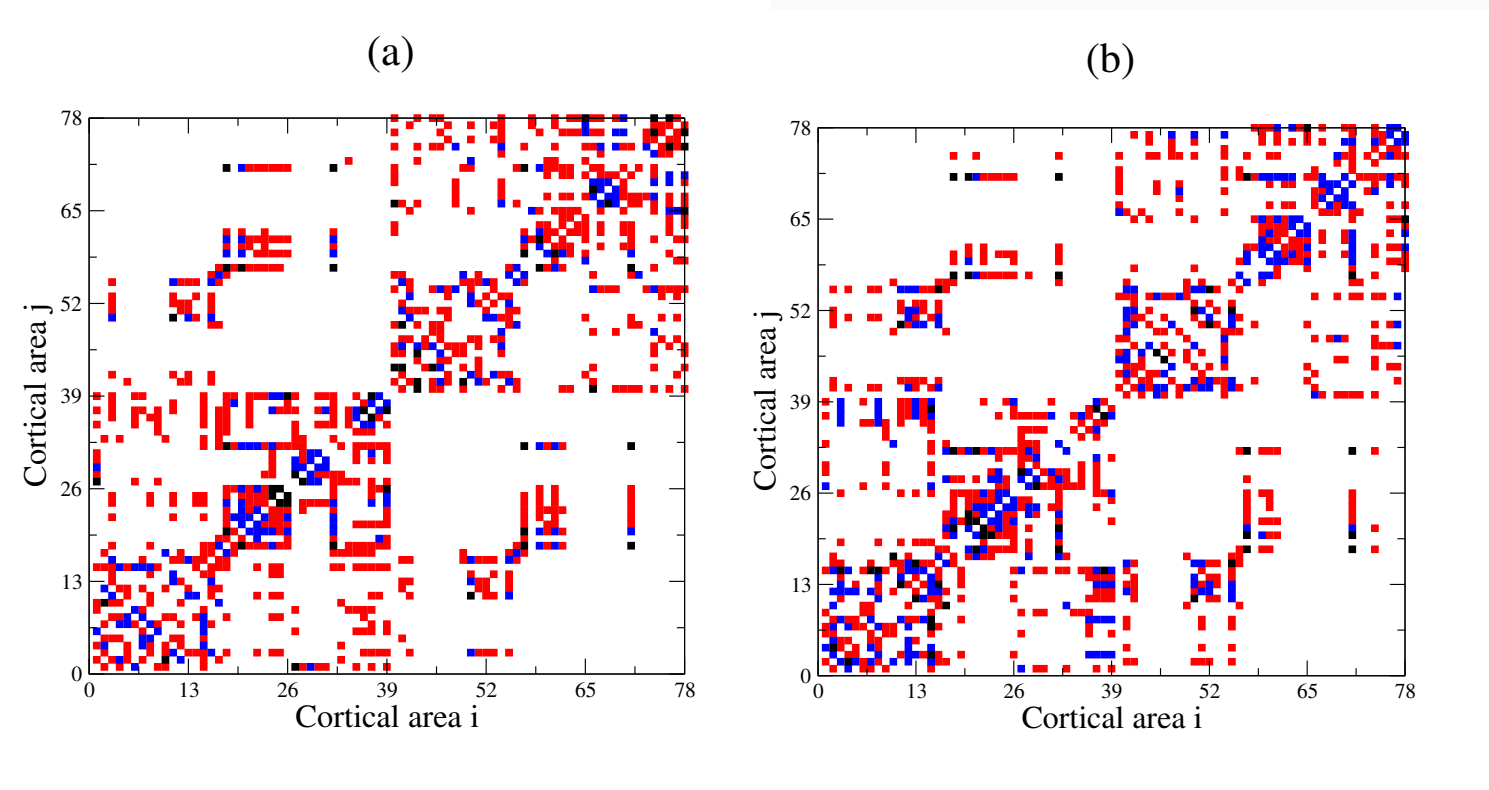

Figure 1: Samples of strucutral connections matrix of the Human brain. (a) Subject with Alzheimer's disease, and (b) healthy subject. Intensity of connections: red (weak), blue (medium) and black (strong).

Lo CY, Wang PN, Chou KH, He Y, Lin CP. Diffusion tensor tractography reveals abnormal topological organization in structural cortical networks in Alzheimer's disease. J Neurosci 2010; 50: 16876-16885.

Network Properties

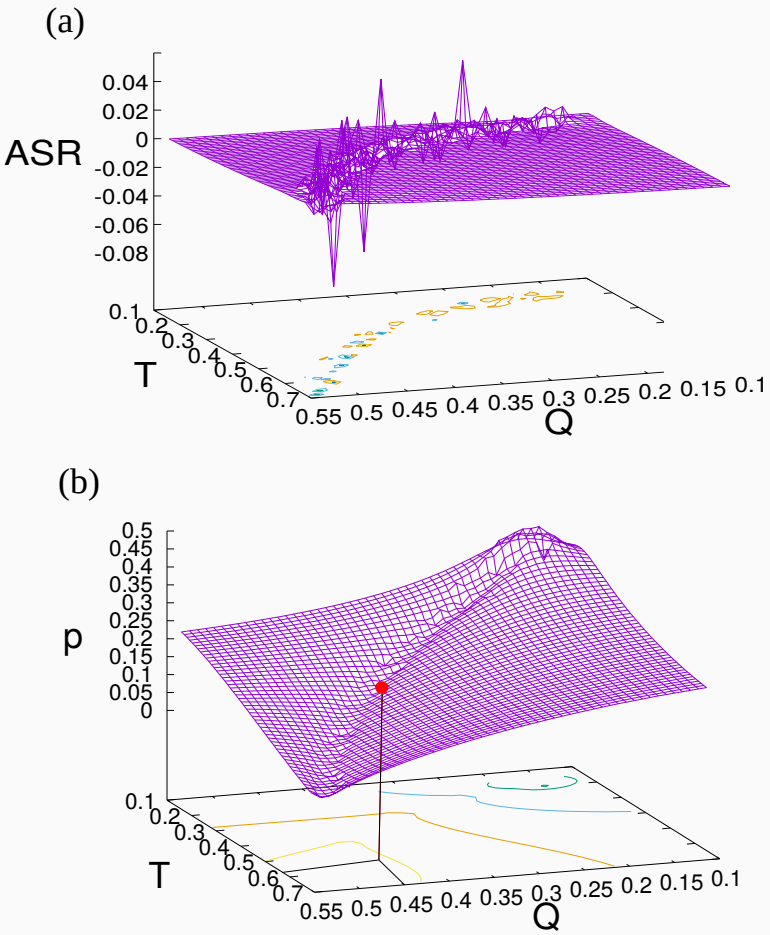

Figure 2: Probabilistic valley as functions of modularity and transitivity for: (a) Assortativity and (b) probability of non-local connections.

	Health human (real)	Small-world (Simulated)	error (ε)
Average path length	2.2487	2.1964	+2.32%
Density of links	13.333	14.000	-5.00%
Transitivity	0.5781	0.5386	+6.79%
Assortativity	0.0815	0.0882	-8.32%
Eccentricity	3.6667	3.5128	+4.20%
Modularity	0.4515	0.4889	-8.27%

	Alzheimer's brain (real)	Small-world (Simulated)	error (ε)
Average path length	2.28172	2.1964	+3.74%
Density of links	13.3846	14.000	-4.59%
Transitivity	0.55989	0.5386	+3.80%
Assortativity	0.21846	0.0882	+59.62%
Eccentricity	3.76923	3.5128	+6.80%
Modularity	0.49083	0.4889	+0.39%

JCP Coninck, FAS Ferrari, AS Reis, KC Iarosz, AM Batista and RL Viana. *Network properties of healthy and Alzheimer's brains*, submitted to Cognitive Neurodynamics.

Network of Networks in the Human Brain

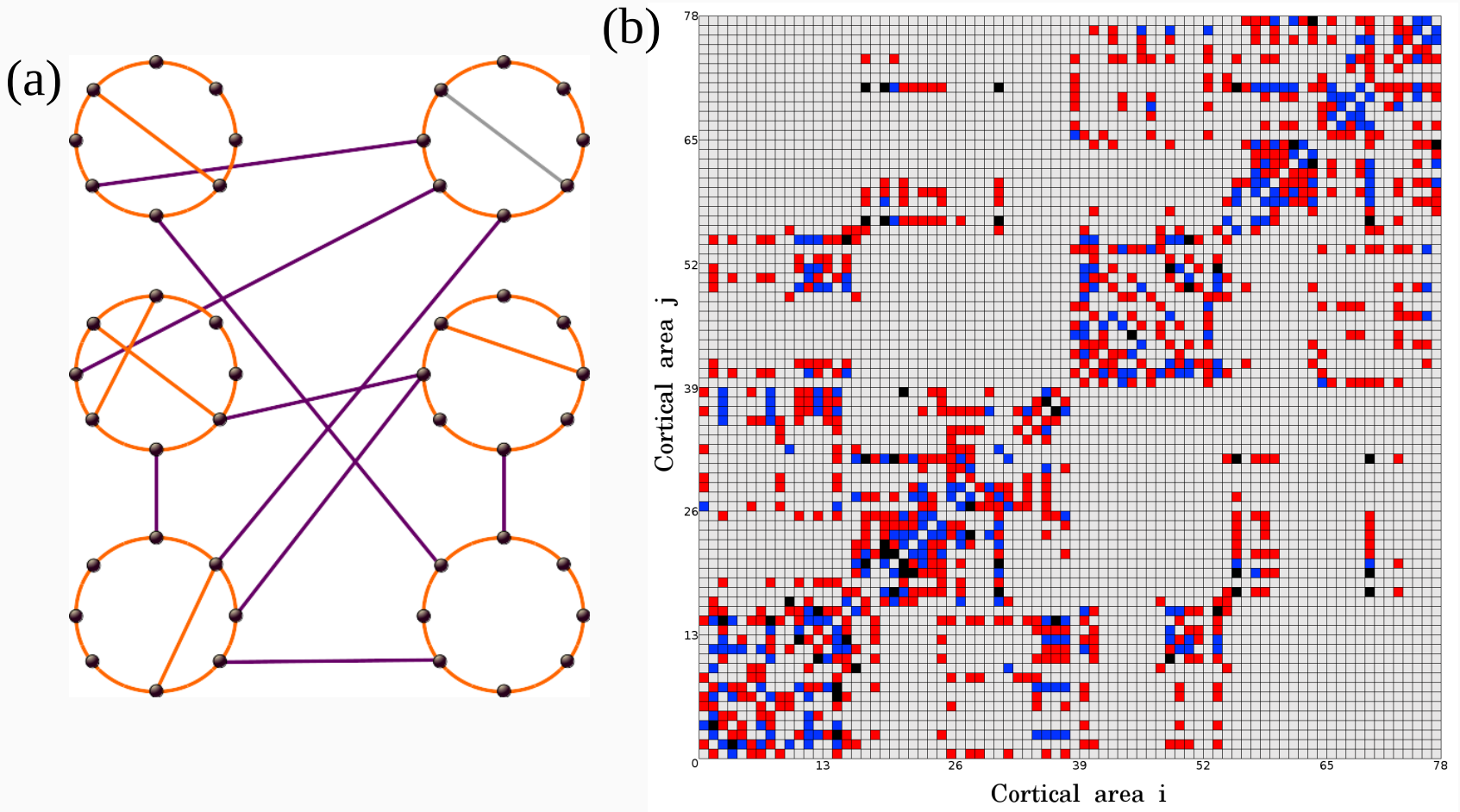

Figure 3: (a) Network of networks representation of the cerebral cortex with intra (orange lines) and inter (magenta lines) connections. (b) Adjacency matrix of the cortical areas with absent of connection (white), sparse (red), intermediate (blue), and dense (black).

FAS Ferrari, RL Viana, AS Reis, et. al. *A network of networks model to study phase synchronization using structural connection matrix of human brain*, Physica A, **v. 493**, 162-170, 2018.

Network of Networks in the Human Brain

The model:

$$x_{n+1}^{(l,p)} =$$

$$\frac{\alpha(l,p)}{(1+(x_n^{(l,p)})^2)} + y_n^{(l,p)}$$

$$+\frac{\varepsilon_e}{2}(x_n^{(l-1,p)} + x_n^{(l+1,p)} - (2x_n^{(l,p)}))$$

$$-\varepsilon_c \sum_{d=1}^{Q}\sum_{f=1}^{P}[T_{(d,f),(l,p)}H(x_n^{(d,f)} - \theta)(x_n^{(l,p)} - V_s)]$$

$$y_{n+1}^{(l,p)} = y_n^{(l,p)} - \sigma(x_n^{(l,p)} - \rho)$$

FAS Ferrari, RL Viana, AS Reis, et. al. *A network of networks model to study phase synchronization using structural connection matrix of human brain*, Physica A, **v. 493**, 162-170, 2018.

Phase Synchronization

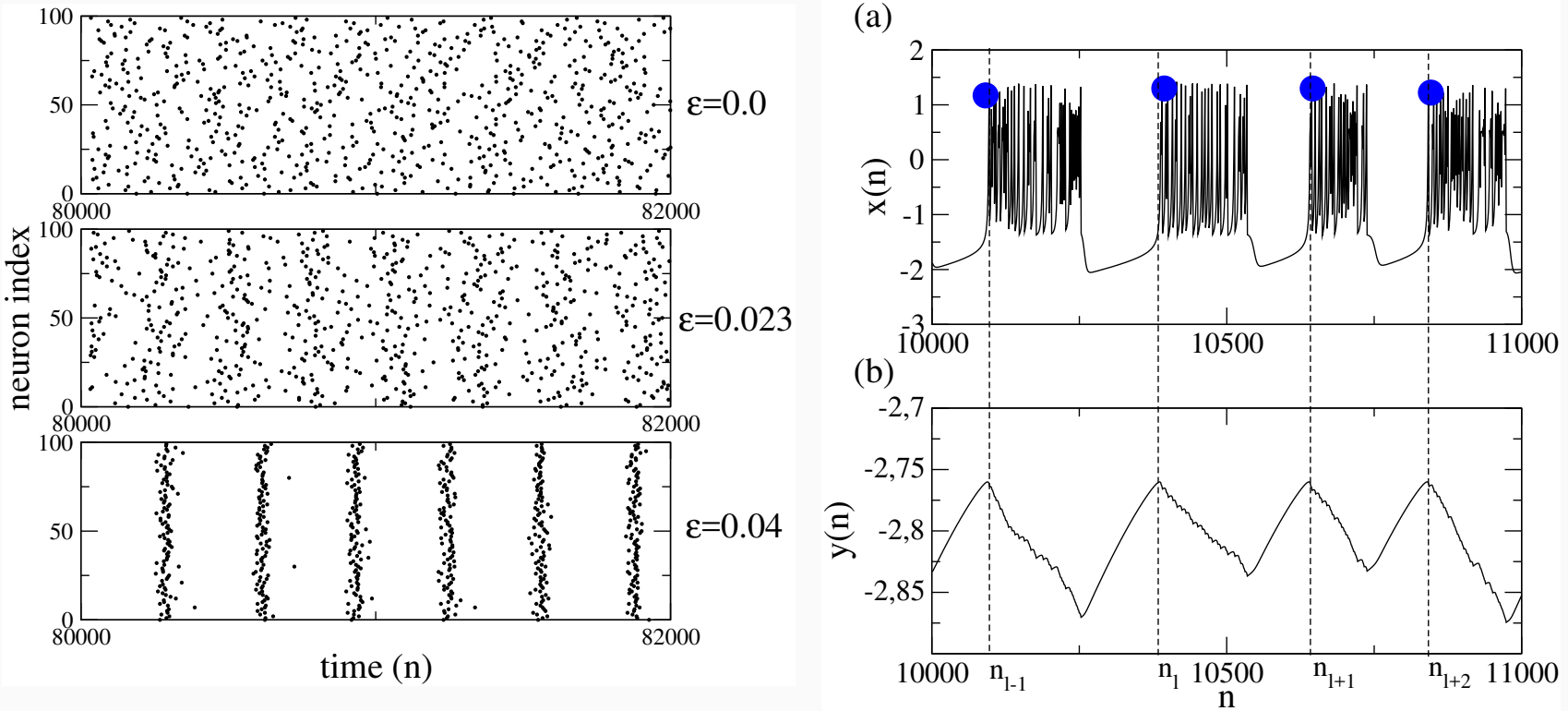

Figure 4: Phase synchronization in the Rulkov model.

Parameter Space for Synchronization

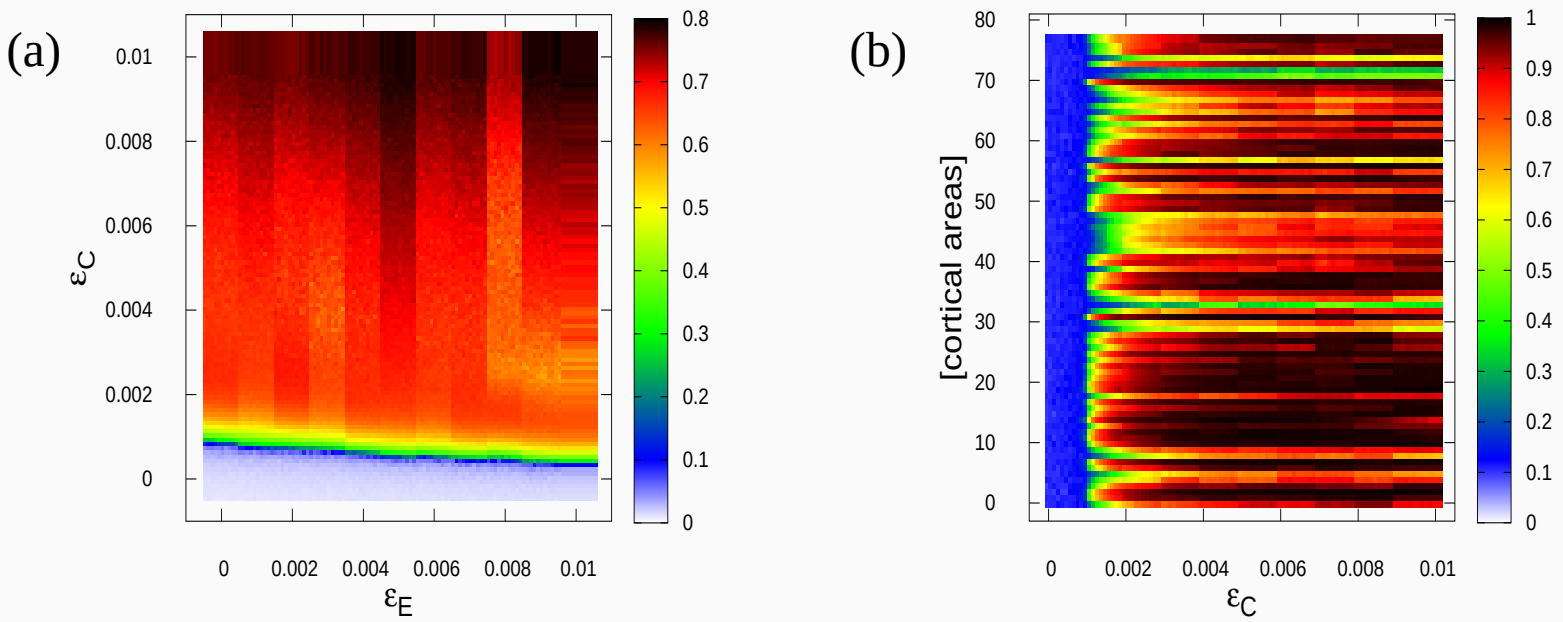

Figure 5: (a) Average Kuramoto order parameter (color bar) as function of ε_E and ε_C. (b) Average Kuramoto order parameter (color bar) for the cortical areas as a function of ε_C.

Network of Networks in the Human Brain

The model:

$$x_{n+1}^{(l,p)} =$$

$$\frac{\alpha(l,p)}{(1+(x_n^{(l,p)})^2)} + y_n^{(l,p)}$$

$$+\frac{\varepsilon_e}{2}(x_n^{(l-1,p)} + x_n^{(l+1,p)} - (2x_n^{(l,p)}))$$

$$-\varepsilon_c \sum_{d=1}^{Q}\sum_{f=1}^{P}[T_{(d,f),(l,p)}H(x_n^{(d,f)} - \theta)(x_n^{(l,p)} - V_s)]$$

$$+\varepsilon_F M_n(\tau,p),$$

$$y_{n+1}^{(l,p)} = y_n^{(l,p)} - \sigma(x_n^{(l,p)} - \rho)$$

FAS Ferrari, RL Viana, AS Reis, et. al. *A network of networks model to study phase synchronization using structural connection matrix of human brain*, Physica A, **v. 493**, 162-170, 2018.

Supression of Synchronization - Order Parameter

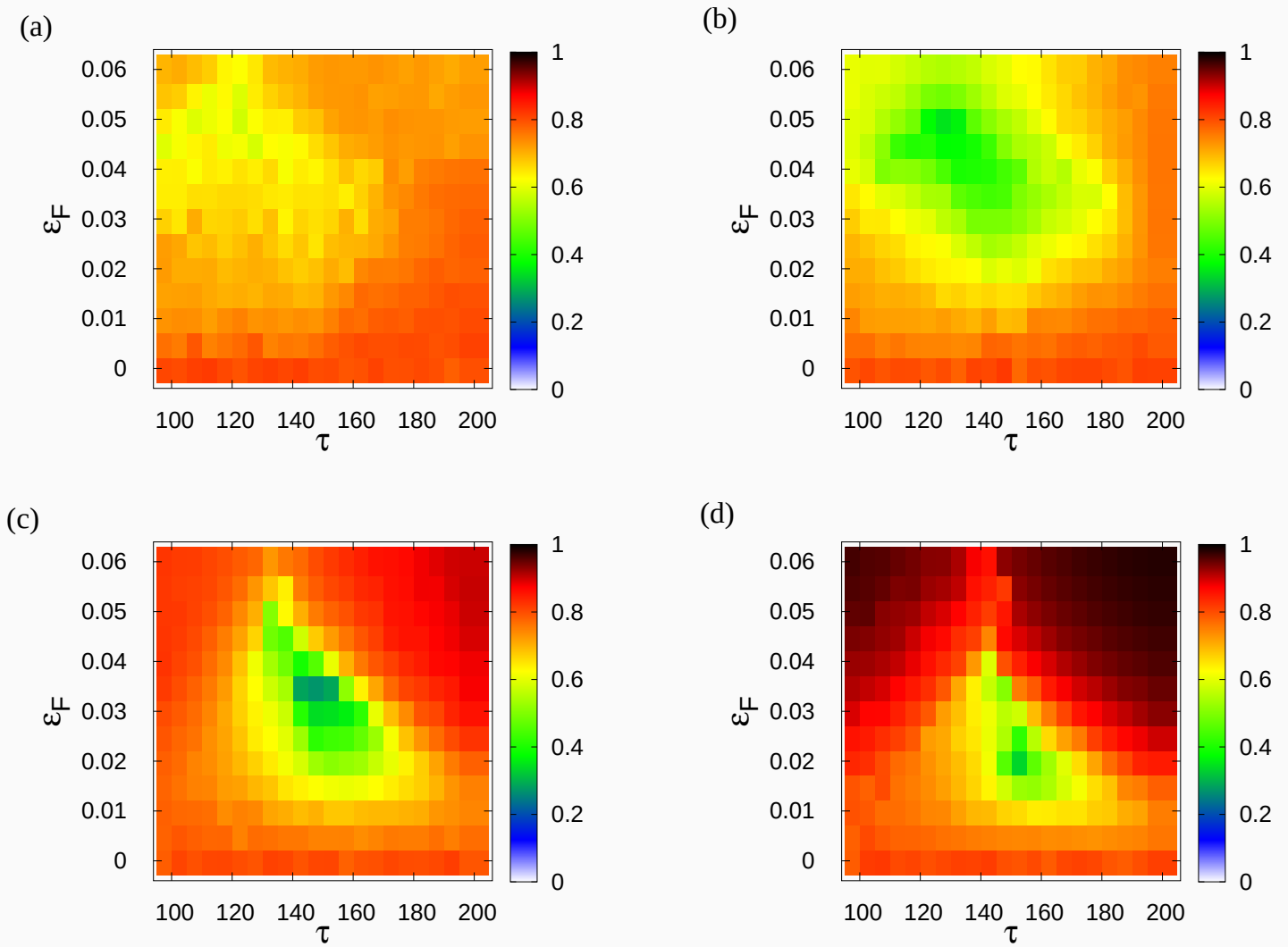

Figure 6: Average Kuramoto order parameter (color bar) as function of ε_F and τ for $\varepsilon_E = 0.005$ and $\varepsilon_C = 0.003$. Percentage of cortical networks where the delayed mean field is applied: (a) 25%, (b) 50%, (c) 75% and (d) 100%.

Parameter Effect of Delayed Feedback Mean Field

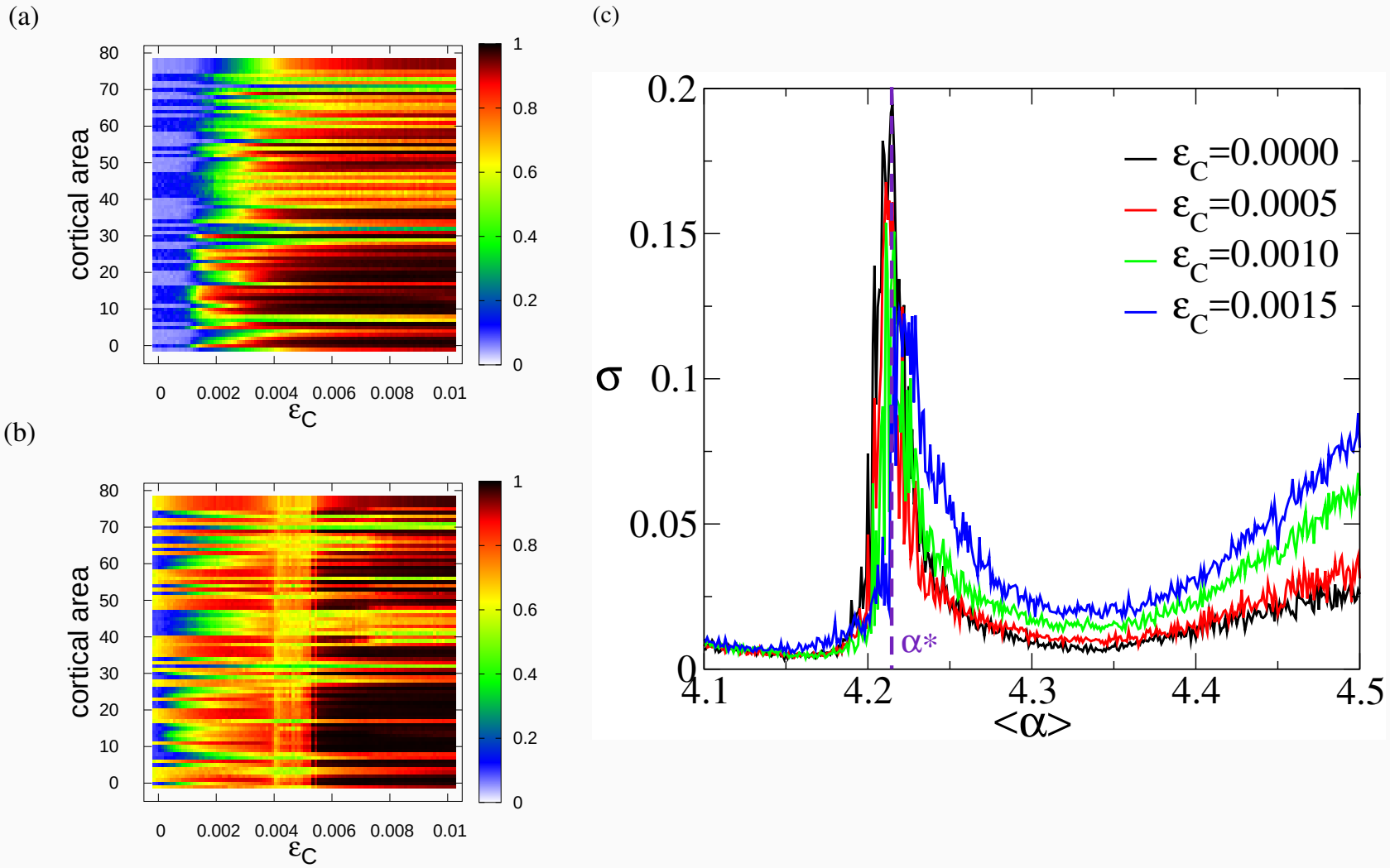

Figure 7: perturbation: (a) $\alpha < \alpha^*$, (b) $\alpha > \alpha^*$, (c) fluctuations in the order parameter.

What is behind α parameter?

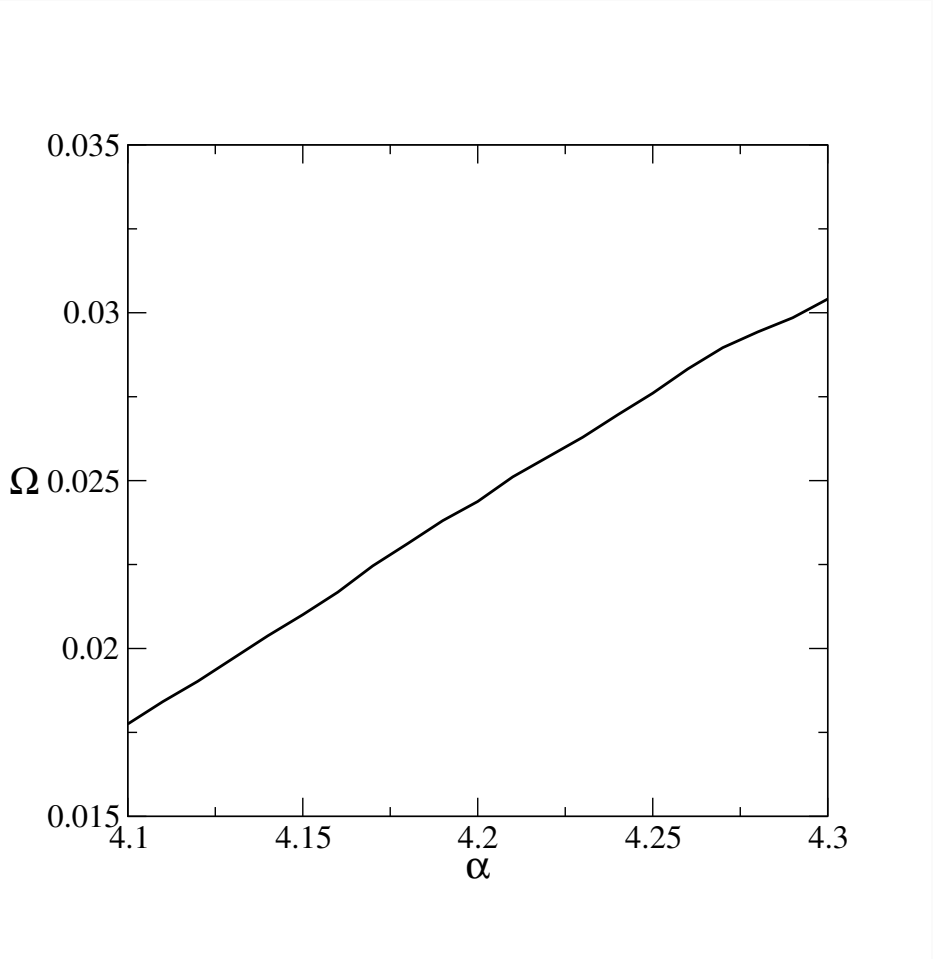

Figure 8: Variation of mean burst frequency Ω as function of α for the Rulkov model.

Final Remarks

- Fluctuations in the order parameter can provide information about the system structure.
- For Rulkov neurons, the fluctuations depend on the parameters of local dynamics.
- In our network of networks model there is a critical parameter that defines when synchronization will be induced by the feedback and when it will not.

Open Questions

- What is the dynamical mechanism behind it?
- Is the mentioned phenomenon observed in other neuronal models?

THANK YOU FOR ATTENTION

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