Prof. Dr. Dr. h.c. Eckehard Schöll, PhD

Projekte zur Statistische Physik des Nichtgleichgewichts

Durchführung

Die Projekte beinhalten Aufgaben aus verschiedenen Bereichen der statistischen Physik des Nichtgleichgewichts und können nach eigenen Vorstellungen bearbeitet werden (Numerik, Analytik, Zusammenfassung der Literatur, Experimente . . .). Die in jeder Projektbeschreibung aufgeführten Punkte können als Leitfaden dienen, Sie können aber auch in Absprache mit den BetreuerInnen eigene Ideen verfolgen.
Die Projekte sind so konzipiert, dass die Bearbeitung mit der angegebenen Literatur und dem Wissen aus der Vorlesung möglich ist.
Zur vollständigen Bearbeitung gehören folgende Punkte:

1. Bearbeitung des Projekts in Dreiergruppen
2. Präsentation der Ergebnisse in einem 15 minütigen Kurzvortrag (+5 Minuten Diskussion) am 14.02.19. Wichtig ist hierbei in erster Linie die verständliche Darstellung. Beschränken Sie sich deshalb auf die zum Verständnis wesentlichen Punkte.
3. Abgabe einer schriftlichen Ausarbeitung mit vollständiger Dokumentation der Lösungswege und vollständigen Quellenangaben bis 28.02.19. Auch hier steht die Verständlichkeit und übersichtliche Darstellung im Vordergrund. Der Umfang der Ausarbeitung soll fünf bis zehn Seiten umfassen.

Während der gesamten Bearbeitungszeit stehen Ihnen die BetreuerInnen des jeweiligen Projektes für Fragen zur Verfügung. Bitte machen Sie individuell Termine mit den Betreuern aus.

Projekt 1: *Coherence-resonance chimeras in neural networks*

Betreuer: Anna Zakharova, Iryna Omelchenko

The counter-intuitive effect of coherence resonance describes a non-monotonic behavior of the regularity of noise-induced oscillations in the excitable regime, leading to an optimum response in terms of regularity of the excited oscillations for an intermediate noise strength [1]. Recently, a new type of coherence resonance, **coherence-resonance chimeras**, has been discovered [2]. It combines features of coherence resonance, i.e., the constructive role of noise, and properties of chimera states, i.e., coexistence of spatially coherent and incoherent domains in a network of identical elements. This phenomenon is distinct from classical chimeras, which occur in deterministic oscillatory systems. Chimera states are intriguing spatiotemporal patterns made up of spatially separated domains of synchronized (spatially coherent) and desynchronized (spatially incoherent) behavior. They arise surprisingly in networks of identical units and symmetric coupling topologies [3-5]. In the present project noise-induced chimeras are studied in networks of coupled neural elements.

- Perform a literature review about this topic based on the given literature and the material cited therein. Understand why the patterns reported in [2] were called coherence-resonance chimeras.
- Reproduce the results obtained in [2] for one-layer network.
- Recently, *multilayer networks* have been suggested to offer better representation of the topology and dynamics of real-world systems in comparison with isolated one-layer structures [6]. Consider a two-layer network. Do you observe coherence-resonance chimeras?
- Turn off noise in one of the layers. In isolation such a network will demonstrate a steady state. Slowly (with a smaller step) increase the inter-layer coupling strength. Can you induce coherence-resonance chimeras in the deterministic layer by multiplexing?

Literatur

[1] A. Pikovsky and J. Kurths: Coherence resonance in a noise-driven excitable system, Phys. Rev. Lett. 78, 775 (1997).
[2] N. Semenova, A. Zakharova, V. S. Anishchenko, and E. Schöll: Coherence-resonance chimeras in a network of excitable elements, Phys. Rev. Lett. 117, 014102 (2016).
[3] M. J. Panaggio and D. M. Abrams: Chimera states: Coexistence of coherence and incoherence in networks of coupled oscillators, Nonlinearity 28, R67 (2015).
[4] E. Schöll: Synchronization patterns and chimera states in complex networks: interplay of topology and dynamics, Eur. Phys. J. Spec. Top. 225, 891 (2016).
[5] S. Majhi, B. K. Bera, D. Ghosh, and M. Perc: Chimera states in neuronal networks: A review, Phys. Life Rev. 26 (2018).
[6] S. Boccaletti, G. Bianconi, R. Criado, C. I. del Genio, J. Gomez-Gardenes, M. Romance, I. Sendina Nadal, Z. Wang, and M. Zanin: The structure and dynamics of multilayer networks, Phys. Rep. 544, 1 (2014).

Projekt 2: *Control of coherence resonance in multiplex neural networks*

Betreuer: Anna Zakharova, Rico Berner

The counter-intuitive effect of coherence resonance describes a non-monotonic behavior of the regularity of noise-induced oscillations in the excitable regime, leading to an optimum response in terms of regularity of the excited oscillations for an intermediate noise strength [1]. Recently, *multilayer networks* have been suggested to offer better representation of the topology and dynamics of real-world systems in comparison with isolated one-layer structures [2]. The phenomenon of coherence resonance for a two-layer multiplex network has been studied in [3]. It has been shown that multiplexing can be used to control coherence resonance.

- Perform a literature review about this topic based on the given literature and the material cited therein. Understand the control scheme reported in [3].
- Reproduce the results obtained in [3].
- How does the efficiency of the control scheme depend on the number of links between the layers? What is the minimum number of inter-layer links required for the proper functionality of the control scheme?

Literatur

[1] A. Pikovsky and J. Kurths: Coherence resonance in a noise-driven excitable system, Phys. Rev. Lett. 78, 775 (1997).
[2] S. Boccaletti, G. Bianconi, R. Criado, C. I. del Genio, J. Gomez-Gardenes, M. Romance, I. Sendina Nadal, Z. Wang, and M. Zanin: The structure and dynamics of multilayer networks, Phys. Rep. 544, 1 (2014).
[3] N. Semenova and A. Zakharova: Weak multiplexing induces coherence resonance, Chaos 28, 051104 (2018).

Projekt 3: *Control of coherence resonance in multiplex neural networks with unidirectional inter-layer coupling*

Betreuer: Iryna Omelchenko, Anna Zakharova

The counter-intuitive effect of coherence resonance describes a non-monotonic behavior of the regularity of noise-induced oscillations in the excitable regime, leading to an optimum response in terms of regularity of the excited oscillations for an intermediate noise strength [1]. Recently, *multilayer networks* have been suggested to offer better representation of the topology and dynamics of real-world systems in comparison with isolated one-layer structures [2]. The phenomenon of coherence resonance for a two-layer multiplex network has been studied in [3]. It has been shown that multiplexing can be used to control coherence resonance.

- Perform a literature review about this topic based on the given literature and the material cited therein. Understand the control scheme reported in [3].
- Reproduce the results obtained in [3].
- Study the case of unidirectional coupling and the role of topology. What is the impact of the layer topology on the control of coherence resonance? Instead of local coupling considered in the paper, take nonlocal and global coupling.

Literatur

[1] A. Pikovsky and J. Kurths: Coherence resonance in a noise-driven excitable system, Phys. Rev. Lett. 78, 775 (1997).
[2] S. Boccaletti, G. Bianconi, R. Criado, C. I. del Genio, J. Gomez-Gardenes, M. Romance, I. Sendina Nadal, Z. Wang, and M. Zanin: The structure and dynamics of multilayer networks, Phys. Rep. 544, 1 (2014).
[3] N. Semenova and A. Zakharova: Weak multiplexing induces coherence resonance, Chaos 28, 051104 (2018).

Projekt 4: *Time-delayed feedback control of coherence resonance in a system of two coupled Stuart-Landau oscillators*

Betreuer: Jakub Sawicki, Rico Berner

The counter-intuitive effect of coherence resonance describes a non-monotonic behavior of the regularity of noise-induced oscillations in the excitable regime, leading to an optimum response in terms of regularity of the excited oscillations for an intermediate noise strength [1]. In the present project coherence resonance is studied for two delay-coupled generalized Stuart-Landau oscillators below a subcritical Hopf bifurcation.

- Perform a literature review about this topic based on the given literature and the material cited therein. Understand why the phenomenon reported in [1] was called coherence resonance.
- Reproduce the results obtained in [2] for one oscillator with time-delayed self-coupling.
- Replace the self-coupling in [2] by a second, identical oscillator. What difference can you observe regarding the coherence resonance in comparison to the results obtained in [2]? Compare also to coherence resonance in two coupled excitable sytems (FitzHugh-Nagumo) with time-delayed feedback [3].
- Turn off noise in one oscillator. Can you induce coherence resonance in the other oscillator by tuning the delay time?

Literatur

[1] A. Pikovsky and J. Kurths: Coherence resonance in a noise-driven excitable system, Phys. Rev. Lett. 78, 775 (1997).
[2] Geffert, P.M., Zakharova, A., Vüllings, A., Just, W. and Schöll, E., Modulating coherence resonance in non-excitable systems by time-delayed feedback, Eur. Phys. J. B 87, 291 (2014).
[3] Hauschildt, B., Janson, N. B., Balanov, A. G. and Schöll, E., Noise-induced cooperative dynamics and its control in coupled neuron models, Phys. Rev. E 74, 051906 (2006).