Univerza v Mariboru

FRAMEWORK PROGRAMME OF EARLY STAGE RESEARCHER TRAINING[1]

1. BASIC DATA

Mentor's name and surname	**Eva Klemenčič**	Mentor's register number at ARRS:	37865
Mentor's e-mail:	eva.klemencic@um.si	Mentor's tel. no.:	040292414
Research programme (RP) leader's name and surname:	Matjaž Perc	RP leader's register number at ARRS:	**23428**
Title of research programme:	**Computationally intensive complex systems**	RP's Register number at ARRS:	P1-0403 (A)
Research organisation (RO) of University of Maribor, where training shall be conducted:	FNM UM	RO Register number at ARRS:	0552-2547
Research field according to ARRS classification:	1.02.02	Research field according to Ortelius classification (EURAXESS)	18.0

2. DEFINITION OF RESEARCH PROBLEM AND GOALS OF DOCTORAL RESEARCH[2]

Starting point of research task of the early stage researcher and its position in the research programme, where the mentor is included, work hypothesis, research goals and foreseen result with emphasis on an original contribution to science:

The phenomenon of oscillation within complex networks is ubiquitous across various scales and encompasses numerous scientific fields, including biology, physics, chemistry, social networks, and technological applications. Such networks, defined by a diverse population of often heterogeneous oscillators and a network delineating their interactions, exhibit a complex and captivating dynamic behavior. This interplay between heterogeneous oscillators and their interconnectedness continues to intrigue and captivate the scientific community, fostering further research endeavors. Over time, both mesoscopic and macroscopic models have been formulated

[1] *Term early stage researcher (ESR) is written in male form and used as neutral for women and men.*

[2] *Research and study programme of training have to harmonise with contents of the research programme, where the mentor is a member.*

to elucidate various forms of interaction among oscillatory systems. The comprehension of collective behavior within complex networks, and the emergence of novel phenomena due to interactions, remains a pressing concern at the forefront of scientific inquiry, and has in the last decade, received huge attention particularly in the fields of computational biology and computational medicine.
In investigations of dynamical processes within coupled systems, the interplay between structural and dynamical complexity presents a challenge in accurately characterizing the dynamical state of a network. Moreover, the factors like dynamic nature of a network's structure, or multi-layered interactions, add another layer of complexity. Even in scenarios where the network's topology remains static and unchanged, the dynamics within complex networks can be far from straightforward. From the perspective of nonlinear dynamics, the fundamental questions arise: How will a network composed of interconnected dynamical systems collectively behave, considering both the individual dynamics of each node and the structure of their interconnections? How are such network resilient to perturbations or malfunctions? And how do higher-order or multi-layered interactions between the oscillatory units affect the macroscopic dynamical behavior?

With such investigations, we have extensive experience in the P1-0403 program: Computationally Intensive Complex Systems. Therefore, the candidate would be involved in current research within the group, primarily focusing on the study of dynamic processes in complex networks. In the first phase of their training, their emphasis would be on fundamental theoretical and numerical research in the fields of dynamic systems, network science, numerical methods, and computational physics. Within this framework, they would address the following pressing questions:

- How does the collective activity of coupled oscillators depend on the coherent influence of the heterogeneity of individual units and the heterogeneous nature of interactions?
- How do the dynamic processes in networks of coupled oscillators depend on higher-order interactions?
- Which factors influence the stability of networks of coupled oscillators, and how are dynamic and static robustness of complex networks interconnected?

In the second part of their training, the candidate is expected to focus on more real-world examples of dynamic networks, particularly in the field of biomedicine. To this end, they would collaborate with experimental groups both within the UM and with international partners. Specifically, collaboration is anticipated with the Institute of Physiology at the Faculty of Medicine, University of Maribor, and the research program P3-3096: Cellular and Tissue Networks, with which we already have a fruitful interdisciplinary collaboration established. This institute conducts measurements of cellular activity in networks of coupled cells within intact tissues, representing a paradigmatic real system of coupled nonlinear oscillators. However, since experimental measurements alone provide only limited insight into the mechanisms of operation, we will strive to achieve a more in-depth mechanistic understanding of intracellular and intercellular activities through the integration of computational modeling. Within this framework, the candidate is expected to develop realistic models of networks of cellular oscillators and conduct intensive simulations of collective cellular activity under various conditions. The model results would be compared with experimental findings. Through these studies, numerous current questions in the field of multicellular dynamics in tissues would be addressed, such as:

- What mechanisms are crucial for regulating synchronous responses in a population of coupled cells? What factors ensure good agreement between the results of multicellular activity simulations and experimental data?
- Are higher-order interactions present in cell populations, and how do they affect their collective activity?
- How does the dynamics of coupled cells begin to change in diseases – which physiological determinants contribute most to the dynamic robustness of tissue networks?

All the mentioned questions from the first and second training modules of the young researcher represent pressing issues in the fields of nonlinear science, mathematical physics, network science, and computational physiology. In the second and interdisciplinary part of the candidate's training, advanced biophysical-computational approaches will be used for research on specific cases in the field of biomedicine, aligning with the latest guidelines. For these reasons, we expect the candidate's research to discover new fundamental principles of dynamic processes in networks, which will have significant practical value and will arouse broader scientific interest.

3. STUDY PROGRAMME

Foreseen study programme, to which early stage researcher shall be enrolled in academic year 2023/2024:

3rd degree study program Physics (doctoral school)

4. DESCRIPTION OF WORK AND TASKS

The candidate's work and tasks throughout the entire training can be summarized into 5 points:

1. Development and implementation of various network models to simulate interactions between oscillatory units.
2. Development and implementation of various models of oscillatory dynamics: from paradigmatic models of limit-cycle oscillators (e.g., Poincaré oscillator) and excitable oscillators (e.g., FitzHugh-Nagumo oscillator) to detailed models of cellular oscillators.
3. Construction of heterogeneous oscillator network models with the implementation of multilayer interactions and higher-order interactions.
4. Development of advanced algorithms for the analysis of experimental data on collective cellular dynamics.
5. Construction of a complex realistic model of a coupled cell network and comparison of simulation results with experimental data.

In addition to this, the candidate will be actively involved in writing research findings and scientific articles, attending scientific conferences and short training sessions abroad, and it is also envisaged that they will participate to a lesser extent in teaching activities at their home institution.

5. REQUESTED LEVEL OF EDUCATION

Completed 2nd Bologna level VII/2. rate group

6. REQUESTED FIELD OF EDUCATION

Natural sciences and Mathematics

7. KLASIUS SRV

Required education: 17003 (Second-level university education and similar education/second-level university education and similar education)

8. KLASIUS P

P: 44
P-16: 0533

9. REQUESTED KNOWLEDGE

Comprehension and understanding of physics concepts and their application in solving basic physics problems on a qualitative and quantitative level.
Computer skills (use of Microsoft Office, basics of programming)

10. REQUESTED SPECIAL REQUIREMENTS

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11. REQUESTED LANGUAGES

Slovene and English

12. REQUESTED WORK EXPERIENCE

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13. FORESEEN POSTDOCTORAL TRAINING

It is currently challenging to provide a concrete description, but the goal is to equip the candidate for a postdoctoral visit at a well-regarded institution abroad. Such institutions could be our external partners working on dynamic network processes, and nonlinear dynamic or biophysical modeling, particularly in connection with endocrine cellular models. The career path after the doctorate would largely depend on the candidate's preferences.

Mentor's signature:

EVA KLEMENČIČ

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Datum: 2024.02.26 20:42:05 +01'00'

Research programme leader's signature:

Matjaž Perc

Digitally signed by Matjaž Perc
Date: 2024.02.27 10:28:15 +01'00'

Name and surname of Dean or authorised person[3]:
Prof. Iztok Banič, actdean

Signature of dean or authorised person:

Marko Jakovac

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Place and date:

Maribor, 27. 02. 2024

Stamp:

[3] The training program is signed by the dean of the member where the ESR's employment and training will take place.