# A COURSE SYLLABUS – DOCTORAL SCHOOL

## REGARDING THE QUALIFICATION CYCLE FROM 2024/2025 TO 2027/2028

| GENERAL INFORMATION ABOUT COURSE | |
|---|---|
| Course title | **DOCTORAL LABORATORY** |
| Name of the unit running the course | Doctoral School at the University of Rzeszów |
| Type of course *(obligatory, optional)* | obligatory subject |
| Year and semester of studies | year I -IV, semester: I - VIII |
| Discipline | **Physical Sciences** |
| Language of Course | English language |
| Name of Course coordinator | Dr. Andrzej Wal, Prof. UR<br>Dr. Levan Chotorlishvili, Prof. PRz |
| Name of Course lecturer | Dr. Andrzej Wal, Prof. UR<br>Dr. Levan Chotorlishvili, Prof. PRz |
| Prerequisites | In-depth knowledge of mathematical analysis and physics. |

**BRIEF DESCRIPTION OF COURSE**
**(100-200 words)**

Non-linear phenomena and chaos are a characteristic feature of dynamic systems, initially studied by theoretical physicists and mathematicians. However, the models developed to describe such systems are so universal and attractive that they have also found application in biological models, in particular for the description of nervous tissue. These models are characterised by non-linear differential equations that determine the dynamics of the system. The main objective to be pursued during the course will be the analysis of these equations, in particular: determination of fixed points, analysis of bifurcations, determination of Lyapunov coefficients, analysis of overlapping non-linear resonances. Carrying out such an analysis will allow us to determine the parameters of the equations that may lead to instability of the model, which in biological systems manifests itself in the form of so-called dynamic diseases - disturbances in the system described by bifurcations, 'explosion' of non-linear resonances or uncontrolled oscillations.

**COURSE LEARNING OUTCOMES AND METHODS OF EVALUATING LEARNING OUTCOMES**

| Learning outcome | The description of the learning outcome defined for the course | Relation to the degree programme outcomes (symbol) | Learning Format (Lectures, classes,...) | Method of assessment of learning outcomes (e.g. test, oral exam, written exam, project,...) |
|---|---|---|---|---|
| **Knowledge (no.)** | knows and understands, has knowledge | | | |
| **P8S_WG1** | has a broad theoretical knowledge of the model of recurrent networks, their application in the description of nonlinear dynamic systems and methods of description using nonlinear differential equations; | **P8S_WG** | conversation | report |
| **P8S_WG2** | has up-to-date knowledge on the directions of research conducted in the field of dynamic systems described by non-linear differential equations; | **P8S_WG** | conversation | report |

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| **P8S_WG3** | is familiar with specialist terminology used in the model of recurrent neural networks describing dynamic systems; | **P8S_WG** | conversation | report |
| **P8S_WG4** | has knowledge on methods of solving non-linear differential equations with the use of both analytical and numerical methods; | **P8S_WG** | conversation | report |
| **Skills (no.)** | can | | | |
| **P8S_UW1** | based on his/her knowledge of physics and mathematics, is able to solve non-linear differential equations describing dynamic systems, including neuronal systems, and thus determine parameter ranges leading to unstable model behaviour; | **P8S_UW** | conversation | report |
| **P8S_UW2** | is able to select and use scientific literature to properly diagnose and solve problems related to the analysis of recurrent neural networks, as well as apply such computational techniques to diagnose states of systems leading to behaviours characteristic of dynamic diseases; | **P8S_UW** | conversation | report |
| **P8S_UW3** | is able to independently acquire knowledge, enhance analytical skills and stimulate critical sensitivity to recognise dilemmas when conducting research and fulfilling the role of a university teacher at the interface of two disciplines; | **P8S_UW** | conversation | report |
| **Social competence (no.)** | is ready to | | | |
| **P8S_KK1** | critically evaluate the body of work related to the use of recurrent neural networks for the description of dynamical systems, and to critically evaluate his/her own achievements in this field; | **P8S_KK** | conversation | report |

**LEARNING FORMAT – NUMBER OF HOURS**

| Semester (no.) | Lectures | Seminars | Lab classes | Internships | others | ECTS |
|---|---|---|---|---|---|---|
| **I - VIII** | **-** | **-** | **8 x 30 hrs. – 240 hrs.** | **-** | **-** | **24** |

## METHODS OF INSTRUCTION

CONVERSATIONS IN TRADITIONAL FORM; DISCUSSION; CONDUCTING RESEARCH;

## COURSE CONTENT

**conversion seminar**

**semester I**

1) Review of literature related to the topic of the thesis.
2) Formulation of a system of differential equations for a recurrent network model.
3) Definition of the equilibrium point (or trajectory) around which stability is to be studied.
4) Determination of Lyapunov coefficients from the solutions of the system, analysing the behaviour of differences between trajectories over time.

**Semester II**

1) Study of the superposition of nonlinear resonances.
2) Analysis of long-term instabilities in recurrent networks.
3) Analysis of emergent large gradients in recurrent networks.

**semester III**

1) Mathematical aspects of equations: Fixed points and bifurcations.
2) Searching for the values of the system parameters at which the fixed point loses stability and oscillations appear.
3) Bifurcation analysis for non-linear gain functions.

**semester IV**

1) Linearisation of the system around fixed points using Taylor series expansion (retaining linear expressions).
2) Consideration of non-linear expressions of second and higher orders in the Taylor expansion to investigate the effects of weak non-linearity.

**Semester V**

1) Analysis of the superposition of internal resonances causing Arnold diffusion.
2) Study of how the lattice under Arnold diffusion "drifts" in phase space.
3) Work on the dissertation.

**semester VI**

1) Numerical solutions of systems of nonlinear equations modelling recurrent networks.
2) Analysis of solutions of systems of differential equations as a function of model parameters.
3) Work on the dissertation

**semester VII**

1) Attempts to find analytical solutions to the systems of equations under study.
2) Analysis of dynamic stochasticity caused by the non-linear gain function.
3) Work on the dissertation.

**semester VIII**

1) Dynamic diseases - conditions for the appearance of pathological physiological states.
2) Analysis of different perturbation cases in models describing biological systems, in particular neuronal activity.
3) Investigation of whether dynamic stochasticity occurring in such non-linear systems can lead to dynamic diseases.
4) Work on a dissertation.

## COURSE ASSESSMENT CRITERIA

The continuous work of the doctoral student in each semester and academic year is assessed in terms of: the implementation of research, the expansion of knowledge, the study of literature, commitment and progress in the preparation of the dissertation. Possible semester grades are: 2.0, 3.0, 3.5, 4.0, 4.5, 5.0.

In order to obtain a pass grade, a conversion factor is applied for the corresponding percentage of points obtained:

- **up to 50% - insufficient**, (the doctoral student does not make progress in scientific research, does not extend knowledge, does not study the literature, does not participate in substantive discussion, does not fulfil scientific duties);

**- 51% - 60% - satisfactory**, (the doctoral student makes negligible progress in scientific research, expands the knowledge, studies the basic literature, the discussion is limited to a narrow range of substantive knowledge, meets basic scientific obligations);
**- 61% - 70% - satisfactory plus**, (the doctoral student makes progress in scientific research, broadens knowledge, studies basic literature, participates in the discussion in a substantive manner, fulfils basic scientific duties);
**- 71% - 80% - good**, (the doctoral student makes significant progress in scientific research, expands knowledge, studies primary and secondary literature, substantively participates in discussion, meets all scientific obligations);
- **81% - 90% - good plus**, (the doctoral student makes significant progress in scientific research, systematically extends knowledge, studies primary and supplementary literature, substantively participates in discussions, meets all scientific obligations);
**- 91% - 100% - very good** (doctoral student makes significant progress in scientific research, systematically extends knowledge, studies basic, complementary and beyond obligatory literature, substantively participates in discussion, meets all scientific obligations);

**TOTAL PhD STUDENT WORKLOAD REQUIRED TO ACHIEVE THE INTENDED LEARNING OUTCOMES – NUMBER OF HOURS AND ECTS CREDITS**

| Activity | Number of hours |
|---|---|
| Scheduled course contact hours | **8 x 30 hrs. – 240 hrs.** |
| Other contact hours involving the teacher (consultation hours, examinations) | **10** |
| Non-contact hours – student`s own work (preparation for classes or examinations, project, etc.) | **470** |
| **Total number of hours** | **720** |
| **Total number of ECTS credits*** | **24** |

**INSTRUCTIONAL MATERIALS**

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|---|---|
| Compulsory literature: | [1] P. Dayan and L. F. Abbott, Theoretical neuroscience: computational and mathematical modelling of neural systems. in Computational neuroscience. Cambridge, Mass: Massachusetts Institute of Technology Press, 2001.<br>[2] W. Gerstner, W. M. Kistler, R. Naud, and L. Paninski, Neuronal dynamics: from single neurons to networks and models of cognition. Cambridge, United Kingdom: Cambridge University Press, 2014.<br>[3] J. Bélair, L. Glass, U. An Der Heiden, and J. Milton, 'Dynamical disease: Identification, temporal aspects and treatment strategies of human illness', Chaos: An Interdisciplinary Journal of Nonlinear Science, vol. 5, no. 1, pp. 1–7, Mar. 1995, doi: 10.1063/1.166069.<br>[4] S. Strogatz, Nonlinear dynamics and chaos: with applications to physics, biology, chemistry, and engineering, Repr. in Studies in nonlinearity. Cambridge, Mass: Westview Press, 2007. |
| Complementary literature: | [1] H. Zabel, Physical Aspects of the Human Body, 2nd ed. in De Gruyter STEM Series. Berlin/Boston: Walter de Gruyter GmbH, 2023.<br>[2] A. N. Pisarchik and A. E. Hramov, 'Coherence resonance in neural networks: Theory and experiments', Physics Reports, vol. 1000, pp. 1–57, Feb. 2023, doi: 10.1016/j.physrep.2022.11.004. |

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| | [3] A. L. Hodgkin and A. F. Huxley, 'A quantitative description of membrane current and its application to conduction and excitation in nerve', The Journal of Physiology, vol. 117, no. 4, pp. 500–544, Aug. 1952, doi: 10.1113/jphysiol.1952.sp004764. |

*(1 ECTS CREDIT CORRESPONDS TO 25 - 30 HOURS OF THE TOTAL WORKLOAD OF A DOCTORAL STUDENT, NEEDED TO ACHIEVE THE ESTABLISHED EFFECTS).

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Date and signature of the Course lecturer

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Approved by the Head of the Department or an authorised person