# A COURSE SYLLABUS – DOCTORAL SCHOOL

## REGARDING THE QUALIFICATION CYCLE FROM2024/2025 TO 2027/2028

| GENERAL INFORMATION ABOUT COURSE | |
|---|---|
| Course title | DOCTORAL SEMINAR |
| 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 - VII |
| 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)**

The aim of the research is to analyse the dynamics of neurons modelled by recurrent neural networks using mathematical and physical methods, with a particular focus on stochastic processes. The work focuses on the modelling of neuronal action potentials and the study of Hodgkin-Huxley (H-H) equations, key to the description of neuronal activity. Using nonequilibrium statistical physics methods, the stochastic properties of neural networks are analysed, allowing a better understanding of their dynamics and potential perturbations. The application of the Itô-Stratonovich integration method and the Fokker-Planck equations to describe the system is envisaged. The ultimate goal is to develop theoretical models to elucidate the influence of neural network parameters on pathological phenomena, which may contribute to a better understanding of the unstable behaviour of the system.

**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** | an extensive theoretical knowledge and current scientific achievements, including worldwide achievements in the field of modelling of recurrent neural networks, as well as knowledge of general issues in the field of structure of neurons of the nervous system and their properties; | **P8S_WG** | seminar | oral statement, discussion |
| **P8S_WG2** | directions of scientific research development and the latest discoveries, including of worldwide range in the field of description of recurrent networks by means of non-linear ordinary differential equations; | **P8S_WG** | seminar | oral statement, discussion |

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|---|---|---|---|---|
| **P8S_WG3** | he/she knows, understands and is able to apply professional concepts used in the description of a dynamic system with the use of recurrent neural networks; | **P8S_WG** | seminar | oral statement, discussion |
| **Skills (no.)** | can | | | |
| **P8S_UW1** | based on his/her knowledge from various fields of science, is able to solve systems of nonlinear differential equations describing dynamic systems, also using approximate methods; | **P8S_UW** | seminar | oral statement, discussion |
| **P8S_UW2** | select and use scientific literature to diagnose and solve research problems concerning the behaviour of recurrent neural networks depending on the model parameters, also to obtain new results in this area; | **P8S_UW** | seminar | oral statement, discussion |
| **P8S_UW3** | use their knowledge to analyse and evaluate the results of scientific research, including their critical evaluation; | **P8S_UW** | seminar | oral statement, discussion |
| **P8S_UK6** | speak in public to present the results of scientific research and participate in discussions on scientific and professional topics in an international environment, using a foreign language at the B2 level of the Common European Framework of Reference for Languages; | **P8S_UK** | seminar | oral statement, discussion |
| **Social competence (no.)** | is ready to | | | |
| **P8S_KK1** | critically evaluate the output related to the analysis of recurrent neural networks and critically assess the contribution of his/her own research activity to the development of this area of research; | **P8S_KK** | seminar | oral statement, discussion |
| **P8S_KK3** | thanks to his/her knowledge, solves cognitive and practical problems in the area of non-linear phenomena in recurrent neural networks; | **P8S_KK** | seminar | oral statement, discussion |

**LEARNING FORMAT – NUMBER OF HOURS**

| Semester (no.) | Lectures | Seminars | Lab classes | Internships | others | ECTS |
|---|---|---|---|---|---|---|
| **I - VII** | **-** | **-** | **-** | **-** | **7 x 15 hrs. – 105 hrs.** | **14** |

## METHODS OF INSTRUCTION

*SCIENTIFIC DISCUSSION, STUDY OF SCIENTIFIC LITERATURE, PREPARATION AND PRESENTATION OF RESEARCH METHODS, RESEARCH RESULTS.*

## COURSE CONTENT

**semester I**

1) Review of literature related to the topic of study.
2) Qualitative methods for solving non-linear ordinary differential equations.

**semester II**

1) Modelling of neuronal action potentials.
2) Hodgkin-Huxley equations, equation parameters related to the model describing the neuron.

**semester III**

1) Methods of nonequilibrium statistical physics.
2) Preparation of a speech presenting the results obtained.

**semester IV**

1) Linearisation of the Hodgkin-Huxley (H-H) equations around a fixed point.
2) Expansion of the H-H equations using the Kramers-Moyal method.

**semester V**

1) Analysis of the Fokker-Planck equations.
2) Ito-Stratonovich integration method as a tool in the theory of stochastic processes.

**semester VI**

1) Numerical solution of a set of differential equations describing recurrent neural networks.
2) Analysis of parameters describing neural networks with respect to their stochasticity.

**semester VII**

1) Nonlinear gain function and other parameters of a recurrent neural network and their influence on dynamic diseases.
2) Preparation of a speech presenting the results obtained.

## COURSE ASSESSMENT CRITERIA

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

Percentage requirements for the grading scale:
In order to obtain a pass grade, a conversion factor for the corresponding percentage of points obtained is applied:
**- up to 50% - inadequate**, (the doctoral student does not make progress in scientific research, does not extend knowledge, does not study scientific literature, does not participate in substantive discussion, does not fulfil scientific duties);
**- 51% - 60% - satisfactory**, (the doctoral student makes negligible progress in scientific research, broadens knowledge, studies 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 substantial way, 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 discussion, 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 | **7 x 15 hrs. – 105 hrs.** |
| Other contact hours involving the teacher (consultation hours, examinations) | **6** |
| Non-contact hours – student`s own work (preparation for classes or examinations, project, etc.) | **309** |
| **Total number of hours** | **420** |
| **Total number of ECTS credits*** | **14** |

| INSTRUCTIONAL MATERIALS | |
|---|---|
| Compulsory literature: | [1] D. W. Jordan and P. Smith, Nonlinear ordinary differential equations: problems and solutions: a sourcebook for scientists and engineers. Oxford: Oxford University Press, 2007.<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] P. Dayan and L. F. Abbott, Theoretical neuroscience: computational and mathematical modeling of neural systems. in Computational neuroscience. Cambridge, Mass: Massachusetts Institute of Technology Press, 2001. |
| Complementary literature: | [1] J. Cronin, Mathematical aspects of Hodgkin-Huxley neural theory. in Cambridge studies in mathematical biology, no. 7. Cambridge: Cambridge University press, 1987.<br>[2] V. Balakrishnan, Elements of nonequilibrium statistical mechanics. Cham, Switzerland: Springer, 2021.<br>[3] B. K. Øksendal, Stochastic differential equations: an introduction with applications, Sixth edition, Sixth corrected printing. in Universitext. Berlin Heidelberg New York Dordrecht London: Springer, 2013.<br>[2] F. M. Salem, Recurrent neural networks: from simple to gated architectures. Cham: Springer, 2022. |

*(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