Mathematics and Machine Learning Internship

Third Draft (English)

Description (for Module Handbook)

- **Module title**: Mathematics and Machine Learning Internship
- **Responsible**: Professor of Geometry, Groups, and Dynamics
- **Teaching methods**:
    - "Mathematics and Machine Learning" Internship (2 SWS) = 30 hours of attendance and 120 hours of self-study = 150 hours
- **Workload**: 5 LP = 150 working hours
- **Duration**: One semester
- **Offering**: Each semester
- **Usability**: Elective module in the
    - M.Sc. Data Science
    - B.Sc. and M.Sc. Computer Science
    - B.Sc. and M.Sc. Mathematics
- **Planned number of participants**: 20
- **Goals**: After actively participating in this module, students will be able to
    - Critically read, interpret, and discuss research work on the theoretical foundations of AI and mathematical methods in AI. Suggest possible new research directions.
    - Contextualize mathematical methods in AI, including identifying core assumptions and limitations of machine learning models.
    - Develop or implement algorithms, numerical experiments, or symbolic computations for investigating and validating mathematical models and methods in AI. Analyze synthetic or real-world data. Test and falsify hypotheses, and evaluate model behavior. Suggest possible new mathematical methods or models.
    - Carry out a hands-on project. Undertake independent research. Lead and manage collaborations with peers and mentors. Use digital version control and collaboration tools. Apply critical thinking skills. Demonstrate planning and time management skills. Document experimental and theoretical work. Synthesize research findings.
    - Use computer packages for implementing models, analyzing data, and creating visualizations.
    - Report research findings in written and verbal forms.
- **Description/Contents**:
    - In this module, participants implement a mentored research project, allowing them to undertake a semester-long study of a problem in the theoretical foundations or mathematical methods of AI. At the start of the semester, the mentor(s) will provide a

curated list of research papers, reading materials, datasets, or computer packages for participants to explore and analyze. Participants, potentially working in groups, will investigate the assigned topics using theoretical, experimental, and computational methods. Group members can contribute to complementary aspects of the projects (e.g., theoretical analysis, algorithm development, or implementation).
    - Participants receive ongoing supervision from research mentors throughout the semester. Mentors will guide participants in refining their research questions, understanding the provided materials, and ensuring progress in their projects through regular feedback and meeting sessions.
    - The project culminates with participants synthesizing their project results in a written form such as a report or a blog post. They are also expected to report their results with presentations.
    - The projects (with the expectations of the mentors) will be advertised on <the courses website> in advance.
    - All written deliverables, code documentation, and presentations must be in English.
- **Participation requirements**:
    - B.Sc. students are required to have passed at least one of the following: Linear Algebra I, Probability I. Programming experience is an advantage.
    - No requirements for M.Sc students.
- **Literature**: To be provided by the mentor(s) at the beginning of the semester.
- **Awarding of credit points**: Credit points will be awarded based on the successful completion of a project as demonstrated by the following components:
        - A written report detailing the research work.
        - A complete, working, and well-documented code repository (or equivalent artifact) that demonstrates the hands-on work performed during the project.
        - Two 10-minute group presentations: one mid-semester to provide an update on progress and outline next steps, and one at the end of the semester to present final results.
- **Examination forms and performance**: Projektarbeit mit schriftlicher Ausarbeitung und Code-Repository (Bearbeitungszeit: 10 Wochen) und zwei 10-minütigen Gruppenpräsentationen.
- **Changes to the examination (preliminary) performance in the event of a crisis**: In case of unforeseen circumstances (e.g., illness or personal emergencies) affecting participation in research, self-study, or group work, students should promptly inform their mentor(s). Together, they will create a plan to address missed contributions and ensure the learning objectives are met.
- **Starting semester**: Summer 2025
- **Evaluation cycle**: <entered by quality control>

Project Example (for the Catalog)

Note: The list of projects will be collected and announced in advance through the semester offering catalog.

- **Title**: Bayesian Deep Learning with Variational Autoencoders
- **Mentor(s)**: Diaaeldin Taha & Parvaneh Joharinad

- **Number of participants**: 4
- **Description**: This project aims to explore the fundamentals of Bayesian inference and deep learning by designing, implementing, and analyzing variational autoencoders (VAEs). Participants will:
    - Learn the Bayesian foundations of VAEs, including variational inference, the Evidence Lower Bound (ELBO), and latent variable models.
    - Learn encoder/decoder architectures.
    - Implement VAEs and apply them to real-world and synthetic datasets.
    - Visualize latent embeddings and explore disentanglement.

  If time permits, participants will investigate extensions such as conditional VAEs or links to reinforcement learning.
- **Extra prerequisites**: Prior exposure to neural networks (e.g., CNNs/autoencoders) or Bayesian statistics is a plus.
- **References**:
    - Kingma, D. P., & Welling, M. (2013). Auto-Encoding Variational Bayes. arXiv.
    - Doersch, C. (2016). Tutorial on Variational Autoencoders. arXiv.