– PhD Course for Center for Interdisciplinary Mathematics (CIM) Graduate School, Uppsala University, 2026 –
Brain Inspired Learning: A Dynamical Systems Perspective

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1 Course Overview

Brain-inspired learning refers to a class of computational approaches that draw inspiration from the structure, dynamics, and learning mechanisms of biological neural systems. These methods emphasize recurrent connectivity, temporal processing, and local learning rules that closely resemble how the brain operates. In recent years, brain-inspired learning has achieved notable progress in several areas including energy-efficient data processing. This course considers brain-inspired learning from an algorithm development and a dynamical systems perspective. It provides a unique perspective for analysis of brain-inspired learning by emphasizing and integrating approaches from signal processing, machine learning, control theory, dynamical systems theory and neuromorphic computing.

Neural systems are naturally described as evolving processes in continuous or discrete state spaces. Hence, state-space modeling framework provides powerful tools for understanding both biological intelligence and artificial learning systems. The course will study how brain-inspired architecture and learning algorithms can be understood through the lens of nonlinear dynamics, stability theory, and state-space representations. Connections to modern deep state-space models will be drawn. Overall, the course will provide a foundational knowledge for brain-inspired artificial intelligence and neuromorphic computing which are becoming increasingly relevant in modern intelligent systems, particularly in applications requiring real-time energy efficient processing of time-series data.

2 Prerequisites

Background on linear algebra, differential equations, basic probability theory. Familiarity with machine learning at least on the level of an introductory course.

3 Course Credits

3hp

4 Learning Outcomes

On completion of the course, the course participants shall be able to

- Describe the basic mechanisms of brain-inspired learning
- Analyze brain-inspired learning systems using concepts from dynamical systems theory
- Explain the benefits and limitations of brain-inspired learning for future computing systems
- Explain and evaluate a selected sub-field of brain-inspired learning from a dynamical systems perspective

5 Course Scope

The following are of interest as they relate to the dynamical systems approach for brain-inspired learning. Other subjects related to brain-inspired learning may be also proposed by the course participants.

State-space models, continuous-time vs. discrete-time systems, fixed points, stability analysis,, phase portraits, limit cycles, bifurcations, integrate-and-fire neurons, Hodgkin–Huxley models, population models, recurrent neural networks, spiking neural networks, attractor dynamics, Hopfield networks, associative memory, energy-based models, Hebbian learning, spike-timing-dependent plasticity, neural ordinary differential equations, reservoir computing, liquid state machines, echo state networks, deep state space models.

6 Instruction

The course will start with an introduction to dynamical systems approach for brain-inspired learning. After the introduction, course participants will choose one of the topics from Section 5, self-study the topic in some depth and prepare a presentation that they present in a seminar series. The self-study is expected to be based on research articles. A list of suggested research articles will be provided by the course director. Course participants may also propose articles outside the list.

7 Organization and Schedule

5 lectures consisting of 3 lectures by the course staff and 2 by external guest lecturers. Seminars by the course participants. Lectures and seminars will take place in Fall 2026.

8 Assessment

The course participants will read research articles on a subject of their choice as described above and present them to the other course participants. In order to pass the course, one should both give a presentation and also attend the presentations of other course participants.