2SC8210 – Optimization for neuro-inspired computing with physical architectures

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Department: CAMPUS DE METZ
Language of instruction: ANGLAIS
Campus: CAMPUS DE METZ
Workload (HEE): 60
On-site hours (HPE): 34,50

Description

The ever-increasing amount of data generated requires the development of novel processing/analyzing strategies. Automatic classification techniques originating from the field of Machine Learning are a promising candidate, however, their digital implementations remain relatively low and energy-intensive. An alternate solution consists of designing physical (hardware) neuro-inspired architecture that allows the alleviation of parts if not all of these technological challenges. This theme is the current focus of research laboratories worldwide and has caught the attention of large technological groups such as IBM or Google.

In this particular context and through the framework of *reservoir computing*, which consists of an artificial neural network trained only at its final output layer, This module proposes to the students to discover the principle of conception and design physical (hardware) neuronal networks. Toward this, the students will be familiarized with various optimization techniques such as ridge regression or gradient descent and their accelerated versions, or stochastic heuristics (ex. simulated annealing, genetic algorithms...).

Quarter number

ST7

Prerequisites (in terms of CS courses)

Basics of General Physics (Ordinary differential equations and partial derivative equations) (level L2)
Modeling (1CC3000)
Statistics and Machine Learning (1CC5000).
Digital Signal Processing (1CC4000)
Computing and programming skills in Matlab, Python, or C/C++.

Syllabus

Physical neuro-inspired architecture (7.5h L + 6h SC)

- Introduction to artificial neural networks (perceptron, feed-forward and reccurent networks)
- Physical implémentations in electronics, photonics and spintronics
- Review of essential notions in dynamical systems. Introduction to nonlinear systems.
- Notions on echo-state networks (ESN) and liquid state machines (LSM) – Reservoir computer and necessary conditions for information processing
- Memory Capacity (MC) and Computational Ability (CA)

Small Class / Labs #1 : Numerical simulation of an ESN for solving a regression task (3h)
Small Class / Labs #2 : Numerical simulation of a reservoir computer for solving a classification task (3h)

Emergent approaches (1.5h L)

- Integrated and nanoscopic physical systems for machine learning
- Perspective on deep physical architectures (deep neural networks)

Machine Learning and Optimization for physical neuro-inspired architectures (16.5h L + 1.5h SC)

- Basics in Machine-Learning and connection with optimization
- Supervised and unsupervised learning, loss function, learning curves, cross-validation
- Offline supervised learning (batch): linear (Moore-Penrose) and ridge regression - Online Learning : gradient descent (stochastics, mini-batch, averaged), recursive least square method.
- Acceleration of first order methods.
- Solving classficiation tasks (winner-takes-all, multi-logistic regression)
- Machine Learning and parametric optimisation for physical architecture (reservoir computing architectures).

Small Class #3 : Implementation of online optimization techniques (1.5h)

Class components (lecture, labs, etc.)
Lectures with emphasized interactions with numerical and experimental demonstration in the lab. The presentation of mathematical tools is limited to essential notions necessary for the understanding of concepts seen in class.
Two Small classes will be organized for the assimilation of key notions

Hourly volume:
Lectures + interactive demonstrations : 25.5h
Small class: 7.5h
Final Exam: 1.5h

Grading
Final Exam : Duration : 1.5h - 50% of the final grade

- In case of unjustified absence, the grade is 0 for this part of the grade

- Homework (similar to.a mini project)with numerical simulation to solve a particular task or Analysis of a scientific article with a short report (5 pages max) - 50% of the final grade
    - If the report is not sent prior to the deadline, the grade is 0 for this part of the grade.
- Second Session Exam : In case of failure at the final exam, an oral exam of 20 min will be scheduled.

Course support, bibliography

D. Brunner, M. C. Soriano and G. Van der Sande, "Photonic Reservoir Computing: Optical Recurrent Neural Networks" Ed. De Gruyter (2019)

Resources
Teaching Staff / Faculty : Damien Rontani & Piotr Antonik
Computing ressources for numerical simulation and remote access to an experimental setup located in CentraleSupélec Laboratories

Learning outcomes covered on the course
This specific lecture will be divided in three sections with the following learning objectives :

- Simulate and experiment with physical implementation of artificial neural networks

- Apply various optimization techniques as learning strategies and apply them in the specific context of physical architectures
- Synthetize/summarize recent advances and state-of-the-art results on the implemenation of neuro-inspired physical systems on electronic/photonic chips for application in ultrafast information processing

Description of the skills acquired at the end of the course

C2 Develop in-depth skills in an engineering field and a family of professions

C6 Be operational, responsible, and innovative in the digital world