SYLLABUS

Academic year 2024-2025

Dean,
Prof. Vasile-Ion Manta

1. Program data

1.1 Higher education institution	"Gheorghe Asachi" Technical University of Iasi
1.2 Faculty	Automatic control and Computer Engineering
1.3 Department	Computers Engineering
1.4 Field of studies	Computers and information technology
1.5 The cycle of studies[1]	Masters
1.6 Study program	Artificial Intelligence

2. Discipline data

2.1 Name of the subject/Code	Brain inspired computing / IA.109						
2.2 Owner of course activities	Dr. Mircea Hulea						
2.3 Owner of Application Activities	Dr. Mircea Hulea						
2.4 Year of studies[2]	1	2.5 The semester[3]	1	2.6 Type of assessment[4]	E	2.7 Type of discipline[5]	DS

3. Estimated total time of daily activities (hours per semester)

3.1 Number of hours per week	1	of which 3.2 course	1	3.3rd sem.	-	3.3b laboratory	1	3.3c project	-
3.4 Total hours from the curriculum[6]	28	of which 3.5 course	14	3.6th sem.	-	3.6b laboratory	14	3.6c project	-

The distribution of the time allocated for the discipline[7]	No. hours
Study according to the textbook, course support, bibliography and notes	30
Additional documentation in the library, on specialized electronic platforms and in the field	12
Preparation of seminars/laboratories/projects, assignments, reports and portfolios	24
Tutorial[8]	-
Examination[9]	6
Other activities:	-

3.7 Total hours of individual study[10]	72
3.8 Total hours per semester[11]	100
3.9 Number of Credits	4

4. Prerequisites (where applicable)

4.1 Of the curriculum[12]	
4.2 Skills	

5. Terms (where applicable)

5.1 Course development[13]	Whiteboard and video projector or connection with students via an online platform
5.2 Laboratory[14]	Laboratory room with computers and Internet access or connection with students through an online platform

6. The specific skills which are got[15]

		Number of credits allocated to the discipline [16]:	4	Distribution of credits by skills[17]
Professional skills	CP1	Operating with scientific, engineering and foundations of artificial intelligence		0.5
	CP2	Design of bioinspired networks of neurons and components		0.5
	CP3	Implementation of neuromorphic systems dedicated to solve particular problems		0.5
	CP4	Design of biomimetic systems which mimic the behavior of the natural areas		0.5
	CP5	The use and programming of the neuromorphic systems		2
Cross competences	CT1	Honorable, responsible, ethical behavior in the spirit of the law to ensure the reputation of the profession		0.1
	CT2	Identifying, describing and running the processes of project management, taking over the different roles in the team and the clear and concise description, verbally and in writing of the results in the field of activity		0.1
	CT3	Demonstrating the spirit of initiative and action to update professional, economic and organizational culture knowledge		0.1

7. The objectives of the discipline (resulting from the grid of specific skills accumulated)

7.1 The general objective of the discipline	Creating programs that improve problem-solving performance based on previous data and results. The course presents the theory and practice of neuromorphic computing from several perspectives. After completing the course, students will know how the information is sensed, processed and learned by the brain and which are main characteristics and advantages of neuromorphic computing as well as the main applications for such biologically plausible systems.
7.2 Specific objectives	After listening to the course, performing the laboratory work and passing the exam, the student is expected to: - Know the main elements related to plasticity of biological synapses and information procession in the neural areas; - Model the behavior of individual neurons and neural areas, to design the structure of spiking neural networks (SNN) for specific applications, - Design intelligent systems based on spiking neural networks (SNN) starting from the structural characteristics of the neural areas in the brain. - Use dedicated neuromorphic hardware and software to develop intelligent systems.

8. Contents

8.1 Course[18]	teaching methods[19]	Remark
Lecture 1 Part 1: *Introduction to Brain-Inspired computing* - Overview of the Brain Computation - Computation at the level of neurons and synapses towards the biological neural circuits - Brain functions: processing the sensorial information, motion control, memory and cognition Part 2: *Physiology of biological neurons and synapses* - Neural cell: structure and information processing - Dendritic computation, neuron homeostasis, modularity and exploratory growth - Types of biological neurons and activation patterns Lecture 2 Part 1: *The main elements of learning in the brain* - Hebbian learning: Hebb's rule, formation and extinction of conditional reflex - Spike timing dependent plasticity (STDP): long-term potentiation and depression - Importance of firing rate, depolarization and postsynaptic response to learning - Influence of triplets of spikes on STDP (t – STDP) - Mathematical model for STDP Part 2: *Biophysically realistic neuron models* - Models for hardware implementation: *Integrate and fire*, *Conductance-based*, *Hodgkin-Huxley* - Implementation of artificial synapses - Technologies for storage of the synaptic weights - analogue and digital Lecture 3 Part 1: Neurons models for software simulation - *Izhikevich* and *Spike Response Model* - Polichronization - reproduction of time-locked spike patterns - Computational complexity of the neuron models Part 2: Spiking neural networks - Definition and concept of spiking neural networks - Advantages of spiking neural networks - Encoding of information, temporal coincidence detection - Temporal patterns and their significance in information processing Lecture 4 Part 1: Brain computation at the macroscale - The Brain as an optimization machine - Principles of efficient wiring - Formation of efficient neural structures - Evolving neuronal populations - Fundamentals of neuronal populations and perception Part 2: Types of neural structures - Hopfield networks, Hopfield search in the brain - Self-organizing maps	- the lecture: presentation and explanation of the subject matter; - presentation of some examples in the course; - the attempt to maintain a dialogue with the students during teaching, - repeating some explanations if there are any misunderstanding -recommendation, for individual study, of some paragraphs from the indicated bibliography, in order to deepen or expand the knowledge acquired during the course.	

- Reservoir computing: *Liquid-state machine* and *Echo-state network* Lecture 5: Part 1: Synaptic plasticity and learning in SNN - Hebbian learning, Unsupervised learning, Reward based learning in SNN - Dynamics in plastic SNN - Self-tuning of neural circuits through short-term synaptic plasticity Part 2: Neuromorphic hardware for custom applications - The utility and advantages of neuromorphic hardware - Artificial neural platforms: i.e. SpiNNaker, BrainScaleS - Neuromorphic chips: Loihi (Intel), NorthPole(IBM) - Design considerations for artificial neural platforms and typical applications Lecture 6: Part 1: Simulators for networks of artificial neurons - Simulator for individual neurons: NEURON - Simulator for large biologically plausible neural networks: NEST - Advantages, necessary resources, accessibility of simulators Part 2: Applications of SNN in Robotics - Solving logical and non-linear problems using SNN - SNN for motion control and detection - SNN for audio and video processing - Comparison of SNN based methods with algorithms and computational neural networks Lecture 7: Part 1: Advanced applications of Brain inspired computing - Brain controlled prosthesis, Brain implants - Understanding the physiology of different neural areas in the brain Part 2: Future direction of brain-inspired computing - Overview of recent developments in Brain-inspired computing - The emerging challenges and the application fields. - The future and main R&D in the area for brain inspired computing.		

Bibliography

[1] M. Hulea, Applications of hardware implementation of spiking neural networks, Editura Performantica, 2023.

[1] Taherkhani A et al. "A Review of Learning in Biologically Plausible Spiking Neural Networks." Neural Netw. vol. 122 pp. 253-272, 2020

[2] López LJ, Del Ser J, Bifet A and Kasabov N, "Spiking Neural Networks and online learning: An overview and perspectives", Neural Netw. vol. 121 pp. 88-100, 2020.

[3] Wang X, Lin X and Dang X, "Supervised learning in spiking neural networks: A review of algorithms and evaluations", Neural Netw. vol. 125, pp. 258-280, 2020.

[4] Kim J, Kim K and Kim J, "Unifying Activation- and Timing-based Learning Rules for Spiking Neural Networks", arXiv e-prints, 2020.

[5] Hao Y, Huang X, Dong M and Xu Bo, "A biologically plausible supervised learning method for spiking neural networks using the symmetric STDP rule", Neural Netw. vol. 121, pp. 387-395, 2020.

[6] Lobov SA, Mikhaylov AN, Shamshin M, Makarov VA and Kazantsev VB, "Spatial Properties of STDP in a Self-Learning Spiking Neural Network Enable Controlling a Mobile Robot", Front. Neuroscience. Vol. 14, article 88, 2020.

[7] Demin V et al. "Necessary conditions for STDP-based pattern recognition learning in a memristive spiking neural network", Neural Netw. 134 pp. 64-75, 2020.

[8] Shi M, Zhang T and Zeng Y "Corrigendum: A Curiosity-Based Learning Method for Spiking Neural Networks" Front. Computer. Neuroscience. Vol. 14, article 7, 2020.

[9] Qu L, Zhao Z, Wang L and Wang Y, "Efficient and hardware-friendly methods to implement competitive learning for spiking neural networks", Neural Comput. & Appl. Vol. 32 pp. 13479-13490, 2020.

[10] RC O'Reylli and Y. Munakata, "Computational Explorations in Cognitive Neuroscience", The MIT Press, pp. 32-37, 2000.

[11] W. Swiercz and KJ Cios, "A New Synaptic Plasticity Rule for Networks of Spiking Neurons", IEEE Transaction on Neural Networks, vol. 17, no. 1, pp. 94-99, Jan. 2006.

[12] H.-X. Wang, R. Gerkin, D. Nauen and G.-Q. Bi, "Coactivation and timing-dependent integration of synaptic potentiation and depression", Nature Neuroscience, vol. 8, February 2005;

[13] J.-P. Pfister and W. Gerstner, “Triplets of Spikes in a Model of Spike Timing-Dependent Plasticity”, J. Neurosci., vol. 26, pp. 9673–9682. September 2006.

[14] R. Jolivet, TJ Lewis, and W. Gerstner, "The Spike Response Model: A Framework to Predict Neuronal Spike Trains", O. Kaynak et al. (Eds.): ICANN/ICONIP 2003, LNCS 2714, pp. 846–853, 2003.

[15] A. Herrmann and W. Gerstner, "Noise and the PSTH Response to Current Transients: II. Integrate-and-Fire Model with Slow Recovery and Application to Motoneuron Data", J. of Comput. Neuroscience. Vol. 12, pp. 83–95, 2002.

[16] AN Burkitt, "A review of the integrate-and-fire neuron model: I. Homogeneous synaptic input", Biol. Cybern., vol. 95, pp. 1–19, 2006.

[17] IH Witten, F. Eibe, MAHall, CJ Pal, Data Mining – Practical Machine Learning Tools and Techniques, Fourth Edition, Elsevier, 2016.

8.2b Laboratory	Teaching methods[20]	Remark
The first 4 laboratories are based on the implementation of the electric scheme of an artificial neuron in a hardware simulation environment. 1. Information processing by spiking neurons – input encoding into trains of spikes 2. The influence of weights on the energy generated by neurons 3. Control of the synaptic configuration of the neural network through STDP 4. Implementation of the encoding and decoding layers for a *Liquid State Machine* 5. Implementation of PID controller using spiking neural networks 6. Learning patterns of motions using spiking neurons based on sensors output 7. Image classification using spiking neurons and STDP.	The main purpose of the laboratory works is to implement intelligent systems based on the concepts presented in the course.	

9. Corroboration of the contents of the discipline with the expectations of representatives of the epistemic community, professional associations and representative employers in the field related to the program[21]

The curriculum aims to train students in the field of artificial intelligence, including the leading branches. The discipline, first the theoretical and the practical part, fits perfectly into this objective, given the increased interest in automatic learning techniques for hardware and software systems.

10. Evaluation

Type of activity	10.1 Evaluation criteria	10.2 Evaluation methods	10.3 Weight of the final grade
10.4 Course	• Acquired theoretical knowledge (quantity, correctness, accuracy)	Test from the topics presented in the course	50% (minimum 5)
10.5b Laboratory	• Knowledge of the presented methods, how to implement them, understanding the concepts and algorithms involved and their application to solve concrete problems	Assessment of progress during laboratory hours, through discussions with students, questions, checks of practical results obtained	50% (minimum 5)
10.6 Minimum Performance Standard[22]			
• Grade 5 in the exam and the laboratory activity			

Date of completion, — Signature of course and application holders,

04/01/2024 — Dr. Mircea Hulea

Date of approval in the department, — Department Director,

2024 — Dr. Andrei Stan

[1] *Bachelor / Master*
[2] *1-4 for a bachelor's degree, 1-2 for a master's degree*
[3] *1-8 for the bachelor's degree, 1-3 for the master's degree*
[4] *Exam, colloquium or VP A/R - from the curriculum*
[5] *DF - fundamental discipline, DID - discipline in the field, DS - specialized discipline or DC - complementary discipline - from the curriculum*
[6] *It is equal to 14 weeks x the number of hours from point 3.1 (similar for 3.5, 3.6abc)*
[7] *The lines below refer to the individual study; the total is completed at point 3.7.*

[8] *Between 7 and 14 hours*
[9] *Between 2 and 6 hours*
[10] *The sum of the values on the previous lines, which refer to the individual study.*
[11] *The sum of the number of hours of direct teaching activity (3.4) and the number of hours of individual study (3.7); must be equal to the number of credits allocated to the discipline (point 3.9)* x *25 hours per credit.*
[12] *The subjects that must be passed before or equivalent are mentioned*
[13] *Blackboard, video projector, flipchart, specific teaching materials, etc.*
[14] *Computing technique, software packages, experimental stands, etc.*
[15] *Competencies from Grids G1 and G1bis of the study program, adapted to the specifics of the discipline, for which credits are allocated (www.rncis.ro or the faculty website)*
[16] *From the curriculum*
[17] *The credits allocated to the discipline are distributed among professional and transversal skills depending on the specifics of the discipline*
[18] *Headings of chapters and paragraphs*
[19] *Presentation, lecture, blackboard presentation of the studied issue, use of video projector, discussions with students (for each chapter, if applicable)*
[20] *Practical demonstration, exercise, experiment*
[21] *The connection with other disciplines, the usefulness of the discipline on the labor market*
[22] *The minimum standard of performance from the competence grid of the study program is customized to the specifics of the discipline.*