CCNM17-114: Intelligent Systems Course Description

Aim of the course

Aim of the course: This is an introductory course to computational neuroscience. The main question is how to use mathematics in order to describe the structure, dynamics and function of the neural system. We will learn examples of neural implementation of cognitive functions. A science major is a great advantage for this course but it will provide interesting insight to our up to date understanding of the brain potentially for anyone. This is an introductory course to computational neuroscience. The main question is how to use mathematics in order to describe the structure, dynamics and function of the neural system. We will learn examples of neural implementation of cognitive functions. A science major is a great advantage for this course but it will provide interesting insight to our up to date understanding of the brain potentially for anyone.
Some chapters of Peter Dayan and LF Abbott: Theoretical Neuroscience (Computational and Mathematical Modeling of Neural Systems) are useful.
Background info: The Encyclopeida of Computational Neuroscience is under development: http://www.scholarpedia.org/article/Encyclopedia_of_Computational_Neuroscience

Learning outcome, competences
knowledge:
-
-

attitude:
-
-

skills:
-
-

Content of the course

Topics of the course
- We will discuss, how the mathematics can be applied to describe the neural dynamics underlying of its functions, action potentials and synaptic interactions. We will discuss the properties of voltage-gated and ligand gated ion-channels and the notion of membrane potential. The equilibrium of ionic concentrations, thus the generation of resting potential will be described by the Nerst-equation. The Nobel-prize awarded Hodgkin-Huxley equations will be introduced in order to describe the action potential generation in terms of differential equations.
- Theory of learning and its neural implementations: supervised, unsupervised and reinforcement learning in neural networks. Classical examples for learning neural networks: Perceptron, Hopfield-network, self-organizing maps, actor¬critic learning, Biological implementation of learning: from Hebb's-rule to spike¬time dependent plasticity.
- Technological detour: windows to the brain. What information is provided by intracellular and extracellular recordings of electric activity, evoked responses, EEG (electroencephalography), MEG (magnetoencephalography), PET (positron emission tomography), fMRI (functional magnetic resonance imaging), optical imaging and light sensitive ion-channels.
- The learned phenomena will be applied for an attempt to solve a puzzle of an ancient cortical area: the hippocampus. The specific anatomy and electro-physiology will be learned with

special attention to the hippocampal oscillations. The basic requirements of navigational strategies and the functional correlates of the cellular activity, the possible role of place cells and grid-cells in the spatial representation and the episodic memory will be reviewed.
- The question of the neural code will be raised and functional models of the hippocampus will be built up by using the concept of attractor networks for the possible role of the hippocampus in navigation and episodic memory.
- The description of the discussed models: Arleo and Gerster:
- Spatial cognition and neuro-mimetic navigation: a model of hippocampal place cell activity.
-

Learning activities, learning methods
Lectures and interactive discussions

Evaluation of outcomes

Learning requirements, mode of evaluation, criteria of evaluation:
requirements
- Reliable basic knowledge in the domain of informatics

mode of evaluation: examination and practical course mark

criteria of evaluation:
- Knowledge on basic concepts
-
-

Reading list

Compulsory reading list
- Llinas, R. (2008). Neuron. In Scholarpedia. Retrieved from http://www.scholarpedia.org/article/Neuron
- Lights, Camera, Action Potential (n.d.). In Neuroscience For Kids. Retrieved from http://staff.washington.edu/chudler/ap.html
- The Sounds of Neuroscience (n.d.). In Neuroscience For Kids. Retrieved from https://faculty.washington.edu/chudler/son.html
- Gerstner, W., & Kistler, W. M. (2002) Detailed Neuron Models. In: W. Gerstner, & W. M. Kistler. Spiking Neuron Models (pp. 31-68). Cambridge: Cambridge University Press. http://icwww.epfl.ch/~gerstner/SPNM/node12.html
- Schultz, W. (2007). Reward. In Scholarpedia. Retrieved from http://www.scholarpedia.org/article/Reward
- Barto, A. G. (2007).Temporal difference learning. In Scholarpedia. Retrieved from http://www.scholarpedia.org/article/Temporal_difference_learning
- Shouval, H. Z. (2007). Models of synaptic plasticity. In Scholarpedia. Retrieved from http://www.scholarpedia.org/article/Models_of_synaptic_plasticity
- Gerstner, W., & Kistler, W. M. (2002) Models of Synaptic Plasticity. In: W. Gerstner, & W. M. Kistler. Spiking Neuron Models (pp. 349-454). Cambridge: Cambridge University Press. http://icwww.epfl.ch/~gerstner/SPNM/node69.html
- Érdi, P., & Somogyvári, Z (1995). Post¬Hebbian learning algorithms In: M. A. Arbib (Ed.), Handbook of Brain Theory and Neural Networks (pp. 898-900). Cambridge, MA: The MIT Press. http://www.rmki.kfki.hu/~erdi/erdi_p2.pdf
- Kipke, D. R., Shain, W., Buzsáki, G., Fetz, E., Henderson, J. M., Hetke, J. F., & Schalk, G. (2008). Advanced neurotechnologies for chronic neural interfaces: New horizons and clinical

opportunities. The Journal of Neuroscience, 28(46), 11830–11838. http://www.kfki.hu/~soma/BSCS/Kipke08.pdf

- Costandi, M. (2007).Controlling animal behaviour with an optical on/off switch for neurons. Retrieved from http://neurophilosophy.wordpress.com/2007/04/05/controlling-animal-behaviour-with-an-optical-onoff-switch-for-neurons/
- Érdi, P. (n.d.). Computational approach to the functioning of the hippocampus. Retrieved from http://www.rmki.kfki.hu/biofiz/cneuro/tutorials/ICANN/icannall/index.html
- Place cell. (2014). In Wikipedia. Retrieved from http://en.wikipedia.org/wiki/Place_cell
- Moser, E., & Moser, M.-B. (2007). Grid cells. In Scholarpedia. Retrieved from http://www.scholarpedia.org/article/Grid_cells
- Arleo, A., & Gerstner, W. (2000). Spatial cognition and neuro¬mimetic navigation: a model of hippocampal place cell activity. Biological Cybernetics 83, 287-299. http://www.kfki.hu/~soma/BSCS/Arleo00.pdf
- Foster, D.J., Morris, R.G.M., & Dayan, P. (2000). A model of hippocampally dependent navigation using temporal difference learning rule. Hippocampus 10, 1-16. http://www.kfki.hu/~soma/BSCS/Foster00.pdf
- Trullier, O., & Meyer, J. A (2000). Animat navigation using a cognitive graph. Biological Cybernetics 83, 271-285. http://www.kfki.hu/~soma/BSCS/trullier00.pdf
-

Recommended reading list

-
-