PREDICTIVE CODING AND BIOLOGICAL PLAUSIBLE NEURAL NETWORKS

Bachelor Thesis overview

Aim:

The aim of this study is to gain insight into the fundamental learning rules underlying intelligence as we know it from our own brain and modern deep learning systems. By better understanding these underlying principles, we might discover alternative ways to build, train and deploy systems that learn from data in more efficient ways.

Background:

In the recent years, deep learning has shown impressive results due to the availability of massive parallel compute and huge amounts of data. From the biological inspiration of the neuron to the perceptron where data inputs are weighted, summed together and thresholded, several new modern architectures, like recurrent, residual and transformer neural networks have pushed the limits and achieved state of the art results in speech recognition, computer vision and natural language understanding. Despite of these networks being originally inspired by the brain, the backpropagation (backprop) algorithm for learning the weights and deep learning in general has been criticized for being biologically *implausible.*[1]. In their 2015 paper, Bengio et al. lists several reasons as to why that is. This project will primarily be dealing with on of them: *The weight transport problem* which arises from the way backprop uses the connection weights in both the forward pass (inference) and the backwards parse (calculating the gradients), requiring that both forward and backward connections have symmetric weights.

Content:

This bachelor thesis will discuss the biological plausibility of modern deep learning. It will compare backpropagation to biologically constrained learning algorithms from the literature such as Predictive Coding (and a derivative hereof called Z-IL)[2] and make connections to the learning process in the brain, variational bayesian methods and active inference[3]. At last it will include a discussion on what possible benefits deep learning can gain from studying the brain and how this might be used in practice.

Research questions:

The project will address the following three research questions:

- *According to the current literature, what are the biological constraints of biological learning?*
- *To what extent can predictive coding be used to approximate backpropagation under the above mentioned biological constraints?*
- *In what ways can modern deep learning benefit from biological plausible learning algorithms?*

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[1] Bengio, Y., Lee, D.-H., Bornschein, J., & Lin, Z. (2015). Towards Biologically Plausible Deep Learning. arXiv: arXiv:1502.04156

[2] Song, Y., Lukasiewicz, T., Xu, Z., & Bogacz, R. (2020). Can the Brain Do Backpropagation? -Exact Implementation of Backpropagation in Predictive Coding Networks. Advances in neural information processing systems, 33, 22566–22579.

[3] Friston, K., FritzGerald T., Rigoli, F., Schwartenbeck, P., O'Doherty, J. Pezzulo, G., Active inference and learning, Neuroscience & Biobehavioral Reviews, Volume 68, 2016, Pages 862-879, (https://www.sciencedirect.com/science/article/pii/S0149763416301336).

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Learning objectives:

This bachelor thesis will address DTU's learning objectives for BSc students as follows:

The BSc student can work independently and is able to structure a major project, including meeting deadlines and organizing and planning the project work,

> A high level roadmap and Gantt chart has been planned in order to structure the project work and ensure that the bachelor thesis is finished and handed in before the deadline.

can summarize and interpret technical information and is fully familiar with technical problem solving through project work,

> In the thesis, relevant technical information and results from research papers are interpreted and summarized for the reader in order to answer the presented research questions.

is able to work with all project phases, including the preparation of proposals, solutions, and documentation,

> This project description presents several proposals for research and will require data to be gathered in order to clarify the answers to these questions.

is able to independently acquire new knowledge and adopt a critical approach to the acquired knowledge and carry out relevant and critical information searches, and on this basis find the right methods to shed light on the problem in question,

> This bachelor thesis incorporates both knowledge acquired from courses taken at DTU as well as obtained knowledge from critically evaluated research papers.

is able to communicate technical information, theory, and results in written, visual/graphic, and oral form,

> The bachelor thesis will present theory and results obtain through the project work in both written and visual/graphical form as well as an oral presentation of the key results and discussion thereof in the bachelor defense.

Duration:

The project duration is set for 16 weeks starting from the October 11th 2021 with deadline for hand-in January 30th 2022.