Master thesis topic (Masterproefonderwerp)	Demystifying convolutional neural networks using sparse coding
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Keywords (Trefwoorden)	Image processing, Convolutional neural networks, Dictionary learning, Sparse coding
Location – (Locatie)	Technicum, De Sterre, thuis

References (Referenties):

1. M. Elad, D. Simon, A. Aberdam, Another step toward demystifying deep neural networks, 2020.
2. P. Vardan, Y. Romano, M. Elad. Convolutional neural networks analyzed via convolutional sparse coding, 2017.
3. V. Papyan, Y. Romano, J. Sulam, M. Elad, Theoretical foundations of deep learning via sparse representations, 2018.

Description of the problem (Probleemstelling)	Recently, the rapid development of neural networks (NNs) in machine learning has led to many empirical successes in image and data processing, even outperforming humans in certain tasks. A substantial part of this success can be attributed to human machine learning experts. They are usually in charge of a wide variety of aspects of machine learning problems. From analysing the problem and data, towards constructing an experimental setup and tuning hyperparameters. This is often experienced as a sophisticated process driven by a considerable amount of intuition and trial-and-error strategies, where many open questions remain. For instance, how do we design an optimal NN architecture? What information in the data is exploited by the NN to make them arrive at a particular decision? Since this lack of transparency can be a major drawback, the development of methods for explaining and interpreting deep learning models has recently attracted increasing attention. Deep learning as an instance of general representation learning is naturally connected to sparse signal representations and dictionary learning. While the development of new variants of deep neural networks have been largely driven by a considerable amount of intuition, dictionary learning offers a sound theoretical formulation. Hence, there is a lot of interest in combining the two into a powerful, yet better interpretable framework. Many problems like image and video restoration benefit from the sparse representation model. The goal of such a sparse representation model is to approximate well a signal using only few elements from a (typically redundant) dictionary. Recently, the convolutional sparse coding (CSC) paradigm has been introduced [2]. CSC is a special case of the sparse representation model, built around a very structured dictionary being a union of banded and circulant matrices. An extension of the CSC model, known as multi-layer sparse model has raised insightful connections between sparse representations and convolutional neural networks (CNN) (see Fig. 1). The multi-layer CSC leads to a solid and systematic theoretical justification of the architectures used in deep learning for CNN networks. However, many aspects of this approach are yet to be explored, both theoretically and in terms of the practical design. Taking into account that this approach allows analysis of CNNs architectures and suggests how to build new ones in a systematic fashion, different sparse coding techniques should be analyzed and compared since different architectures are resulting from different solvers for the features. Student will be guided by the supervisors from the research group GAIM whose research expertise is on representation learning, deep learning and sparse coding.

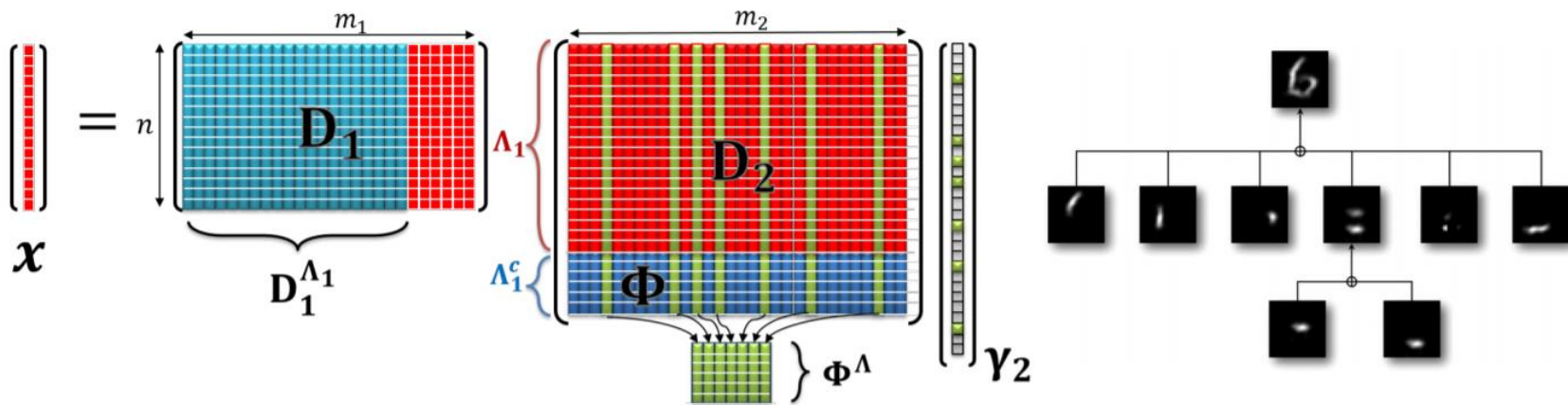|	
Goal of the thesis (Doelstelling)	The ability to interpret the learning process is receiving an increasing amount of attention and therefore there is a high need for extension of the interpretable framework that sparse representations offer. The goal of the thesis is to build on recent works in multi-scale convolutional sparse coding. Firstly, the student should study and understand the theory behind the representation learning, deep learning and dictionary learning in particular. In this regard a 3-day minicourse will be organized at the beginning in order to familarize student with the topic and to put him/her on the right track. Secondly, concrete solvers for the features should be chosen and the performance of the constructed architectures should be compared both among themselves and against some of the more conventional tools for image processing tasks. Practical applications will be chosen in the agreement with the student based on his/her affinities. Possible applications are in large-scale hyperspectral data processing in remote sensing and multimodal data analysis in art investigation or medical image processing (see Fig. 2 and 3). This implies that the existing convolutional sparse coding models should be adapted towards hyperspectral and multimodal data. The existing code and literature will also be made available to the student.

Figure 1: Decomposition of an image from MNIST in terms of two multilayer convolutional dictionaries.
Two local convolutional atoms (bottom row) are combined to create molecules – at the second level, which are then combined to create the global atom (number 6) (see [2]).
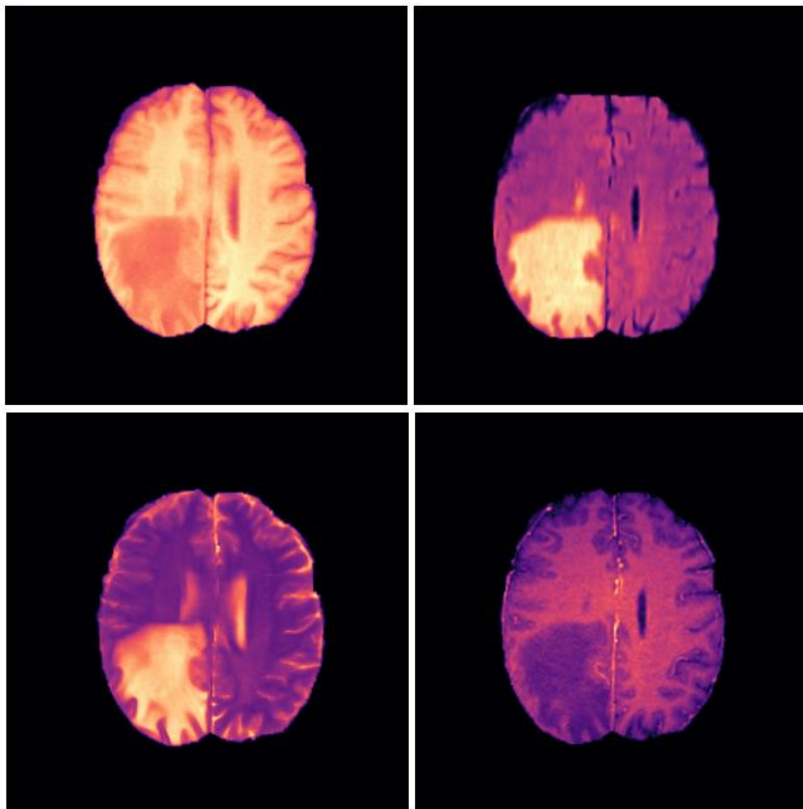
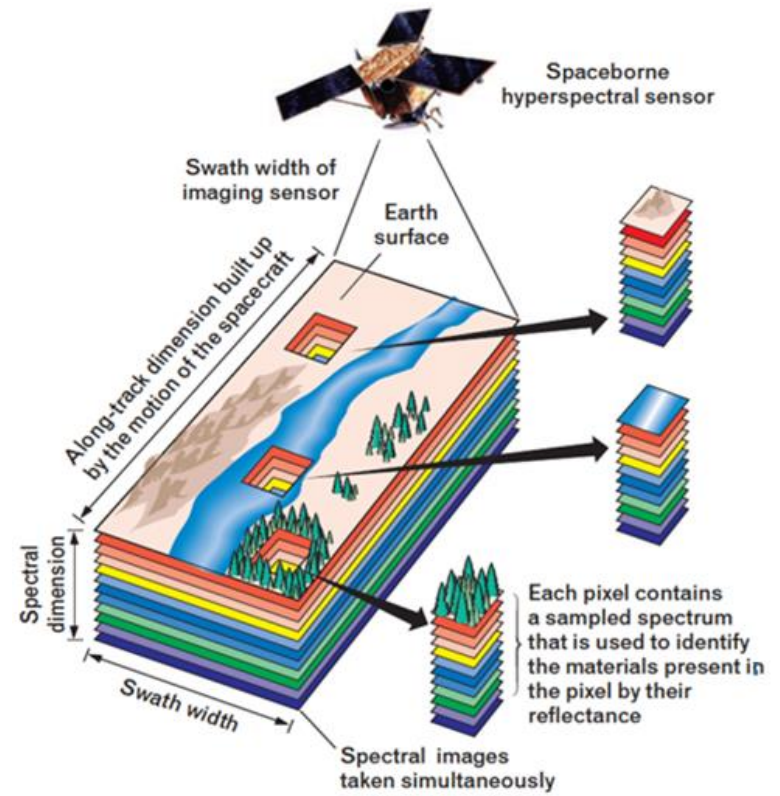**Figure 2:** Multimodal medical data (BraTS 2020 Challenge).

Figure 3: Hyperspectral image collection.