Lecture series: **Featuring AI methods applied to cloud satellite observations**

Total number of hours: 8
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Description of the seminar series. This series of lectures focuses on the topic of computer vision since this research branch, already finding huge applications in very diverse fields, has an enormous potential also for advancing in the atmospheric field. We will go through the working principle of convolutional neural networks, exploring the different aspects of the so-called deep learning methods. We will also introduce recent works that exploit deep learning methods to analyze satellite cloud and precipitation observations. We will show how classification methods can be used to characterize cloud fields and how the Long Short Term Memory models can help in the predicting precipitation. The course is presenting very recent research results and it will create an occasion for everyone, students and lecturer as well, to learn more about these topics.

Resources: In preparation, contact the lecturer for additional info. Detailed material and references will be provided on the first lecture and made available online at this page https://www.claudiaacquistapace.it/activities/teaching.html and/or on the website https://expats-ideas4s.com/

Lecture 1, 30/11/2023 (2 h): Classification of images using a data driven approach: Convolutional neural networks (CNN) explained
In this first lecture, we will start by discussing how to perform the task of assigning a label (from a given ensemble of labels) to an image with a computer. We will introduce a linear classifier (fully connected) based on a score function that maps images to labels and a loss function that can quantify how good is the agreement between the assigned labels and the image truth. Then we will understand how the network is learning with a process called optimization, that includes various processes behind it: stochastic gradient descent, backpropagation etc. Finally, we will look at the neural network architecture and its different layers and how they are spatially arranged, together with an overview of the functions and parameters involved. We will conclude with some methods to visualize convolutional neural networks and corresponding examples.

Keywords: Data driven approach, k-nearest neighbor, classification and optimization tasks with stochastic gradient descent, backpropagation, neural network architecture, activation functions, spatial arrangement, layer sizing patterns, hyperparameters,

Lecture 2, 01/12/2023 (1h): Learning and evaluation of a CNN: babysitting the learning process
We will start with a small recap from the previous lecture and we will then dig into how to prepare the data, initialize weights and run the network. We will discuss the batch normalization and will present tips and tricks that reduce the risks of overfitting and improve

the network performance, like regularization, L2 dropout and data augmentation. We will then introduce one example, Resnet, which is often used in meteorological applications.

Keywords: Preprocessing, weight initialization, batch normalization, regularization and L2 dropout, loss functions, data augmentation. Overview of some checks to perform for monitoring the CNN algorithm, using one example. Resnet, fine-tuning, transfer learning.

Lecture 3, 07/12 (2 h): Applying CNN to improve our understanding about clouds and precipitation.

After the first three hours of theory on CNN, it is time to see how this powerful method can contribute to increase our understanding of cloud and precipitation processes. In this lecture we will give a detailed look at recent research works that exploited CNN to classify cloud mesoscale patterns. We will introduce supervised, unsupervised and self-supervised methods and we will describe how they are used in the different research works. Finally, we will also present current research work done by the EXPATS research group and present the main open research questions they are currently working on.

Keywords: supervised, unsupervised, self-supervised learning, human-label

Lecture 4, 08/12 (1 h): Recurrent neural networks (RNN): LSTM models and their application for nowcasting precipitation

In this lecture we will introduce the usage of recurrent neural networks to model sequences of data. We will talk about the architecture of the RNN, the problems associated with backpropagation and the Long Short Term Memory model, that tries to mitigate the issues that RNN can encounter. We will then conclude the lecture with an example of application of the LSTM model in the prediction of precipitation fields.

Keywords: LSTM, recurrent neural networks, ifog, exploding gradients, vanishing gradients, gradient clipping

Lecture 5, 14/12 (2 h): from CNN to attention model and vision transformers for image classification tasks

In this last lecture, we will introduce the vision transformers (ViT). ViTs are models that recently outperformed CNN in many computer vision tasks. For years and until 2017, the CNN models represented the most capable model in performing image classification tasks. ViTs are deep learning models that weight the input data in a differential way based on self-attention mechanisms. We will describe their architecture and explain in what they differ from RNNs, trying to understand the implication of such differences. Finally, we will show some of the main computer vision tasks they are able to achieve. If time allows, we will conclude our seminar series with a brief overview of the deep learning methods for video prediction.

Keywords: Vision transformers, self-attention, frame prediction, patches, linear embeddings