Summary of activities

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Research activity

Computed tomography (CT) ranks amongst the most popular, non-invasive medical imaging techniques. It makes use of computer-processed combinations of X-ray measurements, taken from different angles, in order to provide a detailed reconstruction of the inner structure of the body. The focus of my Ph.D. research is a particular setup of CT, called *limited-angle* CT (LA-CT), where the X-ray measurements are restricted to a small angular range. This task, that arises naturally in a number of important, practical applications such as breast tomosynthesis or dental X-ray scanning, presents the advantage of lowering the X-ray radiation dose and reducing the scanning time, and has thus become one of the predominant research topics in CT.

The main challenge inherent to LA-CT comes from the fact that the incompleteness of the collected data makes the reconstruction problem extremely ill-posed. As a consequence, classical methods, such as the *filtered-backprojection* (FBP), show poor performance and result most frequently in undesirable artefacts. Iterative algorithms as well as machine learning approaches have also been proposed in the literature to address this problem, but they still present drawbacks and limitations.

The purpose of my doctoral research is to propose a novel algorithm, that combines both the trustworthiness of traditional, variational methods, and the powerful technology of deep learning strategies, in order to provide stable and reliable LA-CT reconstructions. More generally, the convolutional neural network (CNN) developed, called ΨDONet, is designed to learn pseudodifferential operators (ΨDOs) in the broad context of linear inverse problems. Thus, although so far ΨDONet has been concretely investigated in the special case of LA-CT, the theoretical results presented here can be extended to the broader case of convolutional Fourier integral operators (FIOs) and ΨDOs.

We formulate the LA-CT reconstruction problem as a regularised optimisation problem, in which the objective function to be minimised is the sum of a data-fidelity measure and a regularisation term that promotes sparsity in the wavelet basis. A well-known iterative technique for the solution of such a problem is the Iterative Soft-Thresholding Algorithm (ISTA) which, in the case of LA-CT, involves a ΨDO at each of its iterations. The convolutional nature of this very operator makes it possible to implement the unfolded iterations of ISTA as the successive layers of a CNN. We show, furthermore, that it is possible to compute the exact values of the parameters of the CNN in such a way that it reproduces the behaviour of standard ISTA, or a perturbation thereof. The strength of ΨDONet thus rests upon the fact that its parameters can be initialised with such values, and then trained through a learning process made particularly efficient thanks to the CNN technology.

Two implementations of ΨDONet have been investigated: Filter- Based ΨDONet (ΨDONet-F), where the pseudodifferential operator is approximated by means of a set of filters, whose central part is trainable; and Operator-Based ΨDONet (ΨDONet-O), where the pseudodifferential operator is not approximated but explicitly computed, and the learnable parameters are implemented as an additional operator. Numerical tests have been conducted on different datasets of simulated data from limited angle geometry. Both implementations provide similarly good and noteworthy results that clearly outperform the quality of standard ISTA reconstructions, the main difference being a greater computational efficiency for ΨDONet-O.

The presented approach offers promising perspectives and paves the way to applying the same idea to other convolutional FIOs or ΨDOs.

The codes are available at: `https://github.com/megalinier/PsiDONet`.

In parallel of this research topic, I also worked on a project linked to the so-called Hyperparameter Optimisation (HO). This emerging area of the deep learning universe aims to find the best hyperparameters (learning rate, optimiser, number of layers, number of hidden units, etc.) of a neural network (NN) in order to maximise its accuracy. The new method for HO that we developed uses Support Vector Machines in order to predict the final accuracy of a NN with chosen hyperparameters, based only on its accuracy over the very first epochs of its learning. Thanks to this low-cost strategy, the program is able to find the setting of best hyperparameters in a reinforcement learning fashion. We tested our programs on binary classifications problems, and they were able to find the setting of hyperparameters leading to the best accuracies known in the literature. The codes are available at: `https://git.hipert.unimore.it/mverucchi/optics`.

Furthermore, I also contributed to a project aimed at addressing the problem of deconvolution of an image corrupted with Poisson noise. To do so, the restoration process is reformulated as a constrained minimisation of a suitable regularised data fidelity function. The minimisation step is performed by means of an interior-point approach, in which the constraints are incorporated within the objective function through a barrier penalty and a forward–backward algorithm is exploited to build a minimising sequence. The key point of the proposed scheme is that the choice of the regularisation, barrier and step-size parameters defining the interior point approach is automatically performed by a deep learning strategy. Numerical tests on Poisson corrupted benchmark datasets show that the proposed method can obtain very good performance when compared to a state-of-the-art variational deblurring strategy.

Publications and accepted proceedings

[1] T. A. Bubba, M. Galinier, M. Lassas, M. Prato, L. Ratti, and S. Siltanen. Deep neural networks for inverse problems with pseudodifferential operators: an application to limited-angle tomography, 2020. *[to appear in SIAM Journal on Imaging Sciences (SIIMS)]*.

[2] B. Corradini, M. Alù, E. Magnanini, M. Galinier, and E. Silingardi. The importance of forensic storage support: DNA quality from 11-year-old salivaon FTA cards. 133(6):1743–1750, 2019.

[3] G. Franchini, M. Galinier, and M. Verucchi. Mise en abyme with artificial intelligence: How to predict the accuracy of NN, applied to hyper-parameter tuning. In *Recent Advances in Big Data and Deep Learning. INNSBDDL 2019. Proceedings of the International Neural Networks Society*, volume 1. Springer, Cham., 2020.

[4] M. Galinier, M. Prato, E. Chouzenoux, and J. . C. Pesquet. A hybrid interior point - deep learning approach for poisson image deblurring. In *2020 IEEE 30th International Workshop on Machine Learning for Signal Processing (MLSP)*, pages 1–6, 2020.

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