AAP Contrats doctoraux en Intelligence artificielle

Cofinancé par l'ANR

OPTIMIZATION AND LEARNING FOR INVERSE PROBLEMS

1. DESCRIPTION OF THE PHD THESIS PROJECT

1.1 OBJECTIVES OF THE PROJECT BASED ON THE CURRENT STATE OF THE ART

Inverse problems consist in recovering an object of interest from indirect observations. They appear in various applications such as, for example, in analytical chemistry, astrophysics, biology, medical imaging, … As an insight, one can think of source separation which appears in Nuclear Magnetic Resonance (NMR) spectroscopy where one aims to recover the constituting molecules of a mixture [Cherni et al., 2019] or of image reconstruction where one aims to estimate an artefact free version of a cell image or of audio signal processing where one aims to recover missing samples.

Usually, one way to deal with an inverse problem is to formulate it under as a variational problem which means that the object we are seeking for is the solution of an optimization problem [Chaux et al., 2007]. Solving such a minimization problem requires to specify a priori information on the object to be estimated such as nonnegativity, smoothness, sparsity, …

Lately, when enough data are available, machine learning approaches have also been designed to solve inverse problems and have proved to be powerful [Arridge et al., 2019]. However, in some cases/applications, one may not have enough data to learn the model. In some cases, people resorted to simulated data which requires a perfect knowledge of the model [Adler, Ozan, 2017]. Unfortunately, this is not always the case and learning machine on simulated data may not be adapted nor efficient on real data. Another problem is that such approaches still involve a large amount of data, and also, large computational resources.

It thus appears necessary to better understand the learning algorithm and in particular neural networks operation and behavior in order to reduce the requested amount of data that is needed to train them. Indeed, recent works [Combettes, Pesquet, 2019][Gribonval et al., 2019] showed some relations between iterative optimization algorithms and neural networks. Understanding learning algorithms with such mathematical tools, may help to reduce the neural network complexity by compressing them [Han et al., 2016]. One can also think of exploiting specific structure of the data such as sparsity either by tuning the neural network for sparse data or by representing data in a transform domain [Cotter, Kingsbury, 2018] or by learning the best data representation.

1.2 METHODOLOGY

In the doctoral thesis, the objective is twofold: firstly, we aim at formalizing some properties of neural networks; secondly, new approaches will be proposed for the resolution of inverse problems. To this end, we propose two research directions: one is to study how the knowledge a priori of the forward model can be injected in the learning algorithm, the latter one being able to learn the calibration parameters itself. The other is to exploit the capacity of learning algorithms to learn data representations (dictionary/regularization learning) in order to build new sparse representations [Gribonval et al., 2017]. All these methods will be applied to inverse problems dealing with real data. A key will be to provide efficient algorithms and to do so one may rely on approaches such as studied in [Cherfaoui et al., 2019]. We are particularly interested in dictionary learning approaches for source separation in NMR spectroscopy and in calibration purposes for spectral tomography [Tairi et al., 2016].

In the meantime, this PhD may lead to the constitution of a signal database (without thinking in a big data database). We will work carefully on that point in order to be able to share these data publicly.

References

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F. Cherfaoui, V. Emiya, L. Ralaivola and S. Anthoine, (2019) Recovery and convergence rate of the Frank-Wolfe Algorithm for the m-EXACT-SPARSE Problem, in IEEE Trans. on Information Theory, Vol. 65, Issue 11.

A. Cherni, E. Piersanti, S. Anthoine, C. Chaux, L. Shintu, M. Yemloul, B. Torrésani (2019) A new penalized nonnegative third order tensor decomposition using a block coordinate proximal gradient approach: application to 3D fluorescence spectroscopy, Faraday Discussions, vol. 218, pp. 459 - 480.

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R. Gribonval, G. Kutyniok, M. Nielsen, F. Voigtlaender, (2019) Approximation spaces of deep neural networks, preprint arXiv:1905.01208

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S. Han, H. Mao and W. J. Dally (2016) Deep Compression: Compressing Deep Neural Network with Pruning, Trained Quantization and Huffman Coding,4th International Conference on Learning Representations (ICLR), arXiv:1510.00149

S. Tairi, S. Anthoine, C. Morel, and Y. Boursier (2016). Simultaneous reconstruction and separation in a spectral CT framework. In IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC).

1.3 WORK PLAN

The ideal work plan would be the following:

- The six first months of the PhD will be dedicated to make an overview of the state-of-the-art dealing with inverse problems and learning algorithm strategies. Pluridisciplinarity will be part of this PhD project and discussions with local actors of other labs (chemistry, bio-medical imaging) will be initiated. Some research directions will thus be privileged and new challenges in the resolution of some inverse problems will be identified.
- The next twelve months of PhD will be dedicated to the conception of new approaches enabling the knowledge a priori of the forward model to be injected in the learning algorithm and to study/quantify the gain one can have in using such strategies in specific inverse problems. In parallel, as data may be processed more efficiently through adapted data representations, dictionary learning approaches will be investigated. This could also lead to the reduction of the network complexity (by e.g. taking advantage of data sparsity) and is of particular interest when learning datasets are of limited size.
    - One or two publications are planned on these methodological studies.
- The second half of PhD will consist in combining the methodological works with concrete applications. Algorithms will be designed, adapted and tuned with respect to various inverse problems that we will have identified.
    - Additional publications are planed here based on interdisciplinary works.
    - The signal database acquired during the PhD will be shared with the community.
- The last six months will be devoted to finalizing research papers and writing the thesis manuscript.

Of course, this chronogram will be real time adjusted.

1.4 SUPERVISOR AND RESEARCH GROUP DESCRIPTION

The candidate will join the Equipe Signal et Image (SI) of the Institut de Mathématiques de Marseille (I2M). The team specializes in the mathematical aspects of image and signal processing and has several themes of research from statistical descriptions of signals to multiscale representations. The team has also developed a long-standing collaboration with the learning team (Qarma) of the neighboring computer laboratory (LIS). The supervisor and co-supervisor specialize in sparse representations, including time-frequency analysis, convex optimization and inverse problems and work jointly with the Qarma team on projects involving learning and signal processing tasks.

2. RECENT PUBLICATIONS

[Vu, 2017] X. T. Vu, **C. Chaux**, N. D. Thirion-Moreau, S. Maire, and E. M. Carstea (2017) A new penalized nonnegative third order tensor decomposition using a block coordinate proximal gradient approach: application to 3D fluorescence spectroscopy, Journal of Chemometrics, vol. 31, No. 4.

[Cherni, 2019] A. Cherni, E. Piersanti, **S. Anthoine, C. Chaux**, L. Shintu, M. Yemloul, B. Torrésani (2019) Challenges in the decomposition of 2D NMR spectra of mixtures of small molecules, Faraday Discussions, vol. 218, pp. 459 - 480.

[Cherfaoui , 2019] F. Cherfaoui, V. Emiya, L. Ralaivola and **S. Anthoine**, (2019) Recovery and convergence rate of the Frank-Wolfe Algorithm for the m-EXACT-SPARSE Problem, in IEEE Trans. on Information Theory, Vol. 65(11).

3. EXPECTED PROFILE OF THE CANDIDATE

The candidate will be interested in understanding the mathematical aspects of learning procedures, as well as in signal and image processing. The project will contain both a mathematical side and an implementation side. A solid theoretical background in mathematics and/or computer science is needed. Skills in signal/image processing are also required. In particular, some background on inverse problems and/or statistics, would be a plus. Good programming skills in Python/Matlab are necessary.

4. SUPERVISORS' PROFILE

Main supervisor: Caroline Chaux, I2M, Aix-Marseille University.

- Caroline Chaux has developed an expertise in **convex optimization, sparse representations and signal processing**. She is a member of the *Équipe Signal et Image* (SI) at *Institut de Mathématiques de Marseille* (I2M) since 2012. In the last five years, Caroline Chaux has been the supervisor of **1 postdoc, 3 PhD candidates and 4 interns**. She defended her Habilitation à Diriger des Recherches (HdR) in January 2019. She is the **principal investigator of the Amidex project Bifrost**. For three years, she has been a member of the ANR scientific evaluation committee on signal processing.
- *Caroline Chaux is currently co-supervising one PhD project: Marina Kreme's PhD on time-frequency inpainting (2017-2020).*

Co-supervisor: Sandrine Anthoine, I2M, Aix-Marseille University.

- Sandrine Anthoine has developed an expertise **sparse representations in signal processing and machine learning, convex optimization and inverse problems in image and signal processing**. She is a member of the *Équipe Signal et Image* (SI) at *Institut de Mathématiques de Marseille* (I2M) since 2009. She has co-supervised 3 Ph.D candidates, 1 postdoc and numerous master interns.
- *Sandrine Anthoine is currently co-supervising one PhD project: Farah Cherfaoui's PhD on active learning for the detection of rare events (2018-2021).*

VISA DU RESPONSABLE DE L'INSTITUT ET DU DIRECTEUR DE LABORATOIRE CONCERNÉS

Visa du responsable de l'institut, NOM Prénom	Visa du directeur du laboratoire, NOM Prénom
Emmanuel GODARD	
Fait à Marseille, le 15/05/2020	Fait à Marseille, le
Signature	Signature