
Deep Unrolling for Inverse Problems in Engineering and Science

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Abstract:

Inverse problems in science and engineering refer to estimating an internal representation (cause) from observed data (effects) of a physical system. These problems are generally solved by classical optimization methods, which are slow and unscalable. Motivated by these drawbacks and the substantial advancement in machine learning, the community has shown interest in applying deep learning to inverse problems. Consequently, complex scientific questions are raised. Among these, I have focused on addressing deep learning's data-hungry and low-interpretability properties, given that in inverse problems, a) acquiring supervised data is often expensive or infeasible, and b) goals extend beyond data fitting to yield scientific insights.

This talk introduces a novel unrolling method, which leverages statistical models to design sample-efficient and interpretable deep architectures. Focusing on sparse coding as a statistical model, the talk presents the theoretical properties of unrolling for model recovery. I highlight unrolling applications to a wide range of engineering and scientific domains, including computational neuroscience, medical imaging, radar sensing, and partial differential equations. Among these, I delve deeper into an example in computational neuroscience. Finally, the talk concludes with brief remarks on the method's socio-technical-economic implications.

Reading list: The talk mainly covers the following works of the speaker.

- [1]: The methodology and theoretical analysis.
- [2]: A computational neuroscience application.

Background and related works reading lists are

- [3]: An introduction to inverse problems (first chapter).
- [4]: A review paper on unrolling.

[1] B. Tolooshams and D. E. Ba, "Stable and interpretable unrolled dictionary learning," Transactions on Machine Learning Research, 2022. [Online]. Available:

<https://openreview.net/forum?id=e3S0Bl2RO8>

[2] B. Tolooshams, S. Matias, H. Wu, S. Temereanca, N. Uchida, V. N. Murthy, P. Masset, and D. Ba, "Interpretable deep learning for deconvolutional analysis of neural signals," bioRxiv, pp. 2024–01, 2024.

[3] G. Bal, "Introduction to inverse problems,"

<https://statistics.uchicago.edu/~guillaumbal/PAPERS/IntroductionInverseProblems.pdf>, 2019.

[4] V. Monga, Y. Li, and Y. C. Eldar, "Algorithm unrolling: Interpretable, efficient deep learning for signal and image processing," IEEE Signal Processing Magazine, vol. 38, no. 2, pp. 18–44, 2021.