Postdoctoral Research Proposal

Large-scale Blackbox Bilevel Optimization

Supervisor: Samuel Vaiter
samuel.vaiter@cnrs.fr
Laboratoire J. A. Dieudonné, CNRS, Université Côte d'Azur

Context and Motivation

Bilevel optimization problems, in which one optimization problem is nested within another, arise in a wide range of machine learning settings. Typical examples include hyperparameter optimization, meta-learning, and adversarial training. The general bilevel problem can be written as:

$$\min_{x \in \mathbb{R}^d} F(x, y^*(x)) \quad \text{where} \quad y^*(x) = \arg\min_{y \in \mathbb{R}^p} f(x, y),$$

where F is the outer objective and f is the inner objective. Solving such problems is challenging due to the need to compute gradients through the solution of the inner problem.

In recent years, efficient techniques for bilevel optimization have emerged, leveraging automatic differentiation and stochastic approximations. However, these methods often require access to gradients of both F and f, and assume differentiability and tractability of the inner problem.

Blackbox Optimization for Bilevel Problems

In many realistic scenarios, such as simulation-based learning or reinforcement learning, gradients are either unavailable or unreliable. In such contexts, zeroth-order (blackbox) optimization becomes essential. Blackbox methods, such as finite differences or random direction stochastic approximations, offer general-purpose strategies that only rely on function evaluations.

While conceptually simple, zeroth-order methods tend to scale poorly with dimension, especially in the bilevel setting where each outer evaluation requires solving an inner optimization problem. This motivates the need for new approaches that can bridge blackbox optimization techniques and the structure of bilevel problems in large-scale settings.

Objectives

The goal of this postdoctoral project is to develop scalable blackbox optimization algorithms tailored to bilevel problems. This includes:

- Investigating and adapting zeroth-order strategies (e.g., random directions, coordinate-wise estimates) for bilevel structures.
- Studying variance reduction techniques in the blackbox setting.
- Designing algorithms that leverage problem structure (e.g., sparsity, low-dimensional embeddings) to improve scalability.
- Implementing and benchmarking these methods on realistic machine learning tasks (e.g., hyperparameter tuning, meta-learning).

This project builds upon recent work on stochastic bilevel optimization and variance reduction strategies, such as:

- M. Dagréou, P. Ablin, S. Vaiter, T. Moreau. *A framework for bilevel optimization that enables stochastic and global variance reduction algorithms.* NeurIPS 2022.
- D. Kozak, C. Molinari, L. Rosasco, L. Tenorio, S. Villa. *Zeroth-order optimization with orthogonal random directions.* Mathematical Programming, 199(1):1179–1219, 2023.
- J. Bolte, E. Pauwels, S. Vaiter. *Automatic differentiation of nonsmooth iterative algorithms.* NeurIPS 2022.

Candidate Profile

We are seeking a highly motivated postdoctoral researcher with the following qualifications:

- PhD in Mathematics, Computer Science, or a related field.
- Solid background in optimization and/or machine learning.
- Experience with blackbox/zeroth-order methods and bilevel optimization is a plus.
- Strong programming skills and a track record of research publications.

Practical Information

- **Duration:** 24 months
- **Location:** Laboratoire J. A. Dieudonné, Nice, France
- **Supervisor:** Samuel Vaiter (CNRS Research Scientist)
- **Start date:** Flexible (to be discussed)