Skoltech

Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Valentin Khrulkov

PhD Program: Computational and Data Science and Engineering

Title of Thesis: Geometrical methods in machine learning and tensor analysis

Supervisor: Professor Ivan Oseledets, Skoltech

Name of the Reviewer: Associate professor Evgeny Burnaev

I confirm the absence of any conflict of interest	**Signature:** **Date: 28-09-2020**

Reviewer's Report
Reviewers report should contain the following items: • Brief evaluation of the thesis quality and overall structure of the dissertation. • The relevance of the topic of dissertation work to its actual content • The relevance of the methods used in the dissertation • The scientific significance of the results obtained and their compliance with the international level and current state of the art • The relevance of the obtained results to applications (if applicable) • The quality of publications The summary of issues to be addressed before/during the thesis defense

The thesis addresses several important problems in modern machine learning research. Namely, such problems are surprising efficiency of deep neural network in practical tasks, evaluation of generative models without an explicit loss function, utilization of specific geometric inductive biases for building efficient data representations, and robust optimization algorithms on matrix manifolds.

The first problem deals with the well-known practical phenomenon that deep neural networks are much more efficient in practice than shallow networks. E.g., much of the recent success in deep learning may be attributed to the increased depth of DNNs. The author considers the case of recurrent neural networks and builds on the connection of such networks and tensor decompositions. The geometrical properties of the space of tensors can then be used to analyze RNNs. The scientific significance of the obtained results is confirmed by the level of venues where they were presented (a well-known ICLR conference). In order to improve the presentation of the results I would recommend to provide a clear discussion on whether we can write out the classical RNNs as a tensor decomposition.

The second problem deals with the evaluation of the quality of GANs, which is known to be a challenging problem since they are trained via a minimax optimization process and do not have a single loss function. Several commonly utilized metrics (Inception score, FID) not necessarily correlate with human judgment. The author proposes a new approach that analyzes the geometrical properties of generated manifolds via topological data analysis. The authors construct a new metric by comparing such properties between the real and generated manifolds. The research was published in a respectable A* level conference ICML. It could be interesting to comment on how noise in data can influence the used relative living times and the performance of the proposed approach.

Next, the author deal with the problem of incorporating non-trivial inductive biases in visual tasks. Specifically, they utilize a hyperbolic data model, where the underlying data is assumed to have an underlying hierarchical structure. In this case, the data can be naturally embedded in Hyperbolic Spaces. The author demonstrates that many visual tasks in fact benefit from hyperbolic embeddings, and analyze whether such data is, in fact, hyperbolic (providing a positive answer). The problems that authors consider are very natural in practical applications, more concretely they study the few-shot learning tasks where the data is limited. The work was published at a premiere computer vision conference CVPR (A*). In their research the author considers the Poincare ball as a hyperbolic space. It could be an interesting question to comment on whether the made conclusions are the same if Lorentz model is used.

Finally, the author studies the geometry of matrix manifolds, and how it can be utilized to construct an optimization algorithm. Specifically, the set of low-rank matrices is known to be singular (i.e., it has singular points), and standard optimization algorithms struggle in the vicinity of such points. The author suggests to utilize the idea of desingularization and to move the optimization problem to the smooth "version" of the original set. Importantly, the resulting algorithm has the same computational complexity and helps to alleviate the problem of singular points. The paper was published in a top-ranked journal SIMAX.

The thesis starts with an introduction briefly describing the aforementioned topics and current research trends, followed by a summary of each paper. Then, it is followed by a series of chapters with each chapter being one of the five aforementioned papers. Such a structure is logical and follows one of the Skoltech accepted formats. The presented methods are original, competitive with SOTA at the time and all the codes are openly released at GitHub. The number of citations of these papers, as well as the activity surrounding these GitHub repositories supports compliance with the international level of research and its importance to the community.

The quality of the dissertation is high, and publications in reputable journals and conferences support it. The topic and the content of the PhD thesis coincide. The only drawback is that there is not enough glue between chapters. I would prefer if the author comments more on those common techniques, results, etc. that unite different chapters other than just mentioning geometric methods.

Provisional Recommendation

☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*