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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: Prof. Ivan Oseledets

Name of the Reviewer:

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Signature:**  **Date: 05-10-2020**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

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

Review of PhD Thesis of Valentin Khrulkov

The main topic of the thesis is exploring how geometrical structure of underlying complex data can be investigated and analyzed for various challenging theoretical questions, which may have potential practical impacts.

Valentin Khrulkov investigated of wide but rather loosely connected theoretical problems related with representation learning, mathematical analysis of expressivity of deep neural networks and optimization, and generative modeling.

Particularly, the Author of thesis explored the following scientific questions and problems:

- Why are deep neural networks are so efficient in practice, especially Convolutive and Recurrent Neural Networks ?

- How to measure performance and reliability of Generative Adversarial Networks (GAN) ?

- How to avoid in some optimization methods based on the low-rank matrix and tensor manifolds, a difficult problem of singular points, where curvature tends to infinity. Is it possible to build robust second-order optimization methods avoiding problem of singular points, where curvature tends to infinity?

- Often Discrete data sets appearing in Natural Language Processing (NLP) and graph analysis have underlying hierarchical structure. Does the same hold for visual data, and can we utilize it using means of hyperbolic geometry?

All these problems are based on exploring new approaches to incorporate his wide knowledge of data geometry into algorithms. Each of the problems is quite challenging and interesting not only from theoretical point of view but can may practical impacts. The Author of the thesis significantly contributed to solve these problems. Theoretical analysis of neural networks is still not fully explored and it is far behind practical applications. For example, it is well known, that in practice, deep networks are typically much more efficient than shallow networks, but still we do not understand why? Moreover, evaluating performance of GANs is still an open question with no widely accepted solutions. The most common approaches (FID, Inception Score) are not always correlated with intuitive human judgment and require a pre-trained networks, which makes them applicable only to GANs dealing with images. The above challenging problems have been addressed by Valentin by designing new algorithms suitable for wide class of data sets. Proposed by him metric can be applied in many practical GANs, e.g., in particle physics.

Another problem considered by the Author of the thesis was low-rank matrix optimization using robust second-order optimization methods. He developed a new method using some known geometrical approaches to resolving singularities. He proposed original and new method, which can be in fact, applied to any kinds of matrix optimization problems.

Another important topic of research, in which Valentin make important contributions is Hyperbolic Geometry, which is quite promising and emerging approach in machine learning. In fact, many real-life data (word taxonomies, citations, movies, etc.) have a hierarchical structure that can be often quite well captured by hyperbolic spaces. If this is the case for visual data, then even simple baseline Euclidean algorithms can perform much better when adapted to hyperbolic geometry. In particular, this is especially true for representation of learning algorithms in such areas as few shot learning, metric learning, and in facial recognition problems. For hyperbolic image embedding, he compared his method with most popular few-shot learning algorithms (approximately 10 methods) for two popular datasets, and he demonstrated that it is possible to achieve competitive (i.e. , better results) than many existing algorithmically quite sophisticated and difficult methods. For GAN evaluations, he tested his method on four common datasets and compared it with the popular method called Inception Score. Moreover, he verified his theoretical findings by experiments on the popular CIFAR10 dataset.

For the low-rank matrix optimization algorithm, he tested it on two tasks: Matrix approximation and matrix completion. He used the common MovieLens dataset in his numerical experiments and compared it with two other optimization algorithms on manifolds. He wrote all the code in Python, which is available on Github for all his research projects https://github.com/KhrulkovV

In my opinion, the contributions of Valentin Khrulkov are not only very original and creative but also very interesting and potentially useful in practice. I think that the most original idea is applying sophisticated apparatus of topology to evaluate performance of GANs, which provides a new perspective from the theoretical and practical point of view.

In my opinion, the weakest point of this thesis is the lack of a "single" area of research. While all the results share the common underlying principle, they are quite diverse. Moreover, the thesis is just collection of his excellent publications. I would prefer that Valentin would write more detailed and extensive introduction to each topic and provided detailed discussion and interpretation of results, and he would indicate more explicitly still opened problems.

In summary, the main achievements of the Thesis are as follows:

- Development of a novel evaluation metric for GANs
- Development of a novel optimization algorithm on low-rank matrix manifolds
- Empirical demonstration of benefits of hyperbolic geometry for several visual tasks
- New Proof of expressivity of multiplicative Recurrent Neural Networks (RNNs) and RNNs with ReLU.
- Publications in top A/A* conferences devoted to AI and Machine Learning, especially ICML, CVPR, ICLR and one journal paper published in the prestigious SIAM Journal SIMAX.

I recommend that the candidate should proceed the Thesis Final Review

Andrzej Cichocki

Provisional Recommendation
☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*
☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*
☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*