

Jury Member Report - Doctor of Philosophy thesis.

Name of Candidate: Polovnikov Kirill

PhD Program: Physics

Title of Thesis: On connection between sparse graphs and hyperbolic geometry

Supervisor: Professor Mikhail Gelfand, Skoltech

Professor Sergey Nechaev, Interdisciplinary Scientific Center Poncelet

Name of the Reviewer: Vladimir V. Palyulin

I confirm the absence of any conflict of interest	Signature: Date: 31-07-2020
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Reviewer's Report
<p>The work "ON CONNECTION BETWEEN SPARSE GRAPHS AND HYPERBOLIC GEOMETRY" submitted as a PhD thesis by Kirill Polovnikov is mostly devoted to manifestations of hyperbolic geometry in systems where the description can be reduced to sparse matrices. This Thesis is submitted in a form of a coherent academic treatise and accumulates 5 papers published in WOS/Scopus indexed journals and 1 paper submitted to journal "Nature Communications". The papers are published in well-known and respected journals and as such fulfil the corresponding requirement of the Skoltech PhD policy. The manuscript consists of an introductory chapter and the following 6 chapters, the latter consisting of a short description of the defendant's contribution to the corresponding paper.</p> <p>The thesis expands the frontiers of modern statistical physics mostly contributing to the network science as well as random walk (RW) theory in complex geometries. In particular the Chapter 2 considers the spectral properties of exponentially ensemble of linear polymer chains. The defendant establishes the connection of the spectrum in a sparse regime with a Thomae function and finds the that the tails are Lifshitz tails. The Chapter 3 describes buckling of biological tissues, i.e. the model assumes an exponential growth of the periphery cells. The section presents a beautiful geometric-based solution and shows that the problem can be tackled with a 2D</p>

eikonal equation. The following Chapter 4 shows very exciting results about the properties of geometrically constrained random walks. The constraints change the statistics of the underlying stochastic process and effect in an atypical regime with anomalous statistics producing Kardar-Parisi-Zhang fluctuations in some of the cases. Chapter 5 then goes into consideration of a cryptocurrency market features which were described with a spectral modularity approach. This allows detection of hidden communities which cannot be found with conventional methods. Then the sparse matrix analysis and non-backtracking RWs are used in Chapter 6 which analyses topologically associating domains in Mammalian and Drosophila genomes. The defendant has verified that experimental sparse Hi-C matrices are not equivalent to random realisations of the configuration model graphs with conserved contact probability and used non-backtracking RWs to annotate TADs in sparse Hi-C matrices. The last Chapter with results (Chapter 7) explores the properties of non-backtracking walks on sparse chromatin interaction networks.

All papers which form the thesis use modern edge-cutting techniques of statistical physics. These range from classic differential equation approaches to highly popular random walk approaches and spectral analysis of adjacency matrices of graphs. As a whole the thesis presents a substantial advancement to the field and the author demonstrates a wide knowledge of pertinent literature, state-of-the-art methods and, most importantly, an ability to use them for producing solid and sound results.

Nevertheless, I would like to point out a few points which could be implemented in order to further improve the coherency and the quality of the manuscript.

1. The Introduction chapter contains a rather nice description of sparse matrices and their properties as well as community detection in networks. Unfortunately it seems to have a rather limited coverage of material relevant for Chapters 3 and 4 of the thesis. I believe that this could be cured by an addition into the Introduction of a section or two devoted to the concepts from the chapters 3&4 as well as their connection to other parts of the work which is important.

2. It seems that there is a substantial degree of similarity between the brief "Introduction" paragraphs of main chapters and the abstracts of the corresponding papers. I would recommend to rephrase it carefully to have an opportunity to use available space for a better summary and avoid repetitions.

Apart from these general remarks I have a list of minor points.

The surnames of Erdos and Renyi contain special characters not typical for any standard English. However, the characters can be found in modern typesetting programs and I strongly encourage author to use them.

Some of the notions, definitions and acronyms in the Introductory chapter are not defined prior to the first usage or even not at all. In particular I mean "cavity

equations" (page 19), "cavity distributions" (page 20), "Dedekind eta-function" (page 24), abbreviation SBM is not defined before the first usage.

The author omits the usage of punctuation marks at the end of equations. I would recommend to treat the equations as parts of sentences, i.e. add commas and full stops where necessary.

Page 21 has an expression "the last axiom" which sounds ambiguous in my opinion and better be avoided here.

Page 18 has a typo in Stratonovich surname (spelled as "Stratanovich" in the text)

On pages 15, 24 and 33 the noun analysis is used in a plural form "analyses" while retaining the singular meaning and producing the singular conjugation. Thus, the conversion to the singular form is a necessity.

Some of the expressions I would not use in a written scientific language. These include "to change smartly" on page 10, "at the end of the day" on page 11, "some of the kinds" on page 13, "Myriad methods" on page 26.

The references 59-62 in the list of references for the introduction chapter have blank entries and have to be filled with actual references

The phrase "I have realized" used on pages 83, 97, 164 is obviously used in the meaning "I have implemented". Unfortunately, the verb to realise does not have this meaning in any form of standard English, hence, it should be substituted with a more appropriate word.

There are also a few typos here and there across the manuscript to be corrected.

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*~~