OPINION

on the dissertation


# NEURAL NETWORKS FOR FACILITY LOCATION PROBLEMS


submitted to the Faculty of Mathematics and Informatics of Sofia University

in partial fulfillment of the requirements for the degree of doctor of philosophy

by the doctoral candidate

**Vladislav Valeriev Haralampiev**

science area: 4. Natural Sciences, Mathematics and Informatics

subarea:  4.6. Informatics and Computer Science

doctoral programme: Computer Science – Algorithms and Complexity

Department of Mathematical Logic and Applications

Faculty of Mathematics and Informatics

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The author of the opinion is assoc. prof. Minko Marinov Markov, PhD, Department of Mathematical Logic and Applications, Faculty of Mathematics and Informatics, Sofia University "St. Kliment Ohridski", a member of the doctoral committee for the doctoral student Vladislav Valeriev Haralampiev according to decree № RD-38-292 / 02 July 2021 by the Chancellor of Sofia University "St. Kliment Ohridski"


1.  **A General Description of the Dissertation**

    The dissertation presented by Vladislav Haralampiev is in English. It comprises 180 pages: an introduction, chapters „Metaheuristics for combinatorial optimization", „Competition-Based Neural Networks (CBNNs)", „Analysis of CBNNs", and „Applications of CBNNs", a conclusion, two appendices, and bibliography.  The bibliography contains 107 items.

2. **About the Doctoral Candidate**

Vladislav Haralampiev has been committed to Mathematics and Computer Science since school. He has been a member of the Bulgarian Olympic team in Informatics.

I personally know his since the fall of 2011 when he took my Discrete Structures course at FMI. He was the top student by far in the class. Likewise, did a stellar performance in every course he took as a bachelor student. After graduating from our Computer Science programme he got a Master's degree at FMI in the Artificial Intelligence programme. Afterwards he got into the doctoral programme Algorithms and Complexity at FMI with myself as the doctoral advisor.

During those ten years Vladislav Haralampiev made an incredible progress. On several occasions we were co-workers in FNI science projects in SU. And he did several internships at Google Inc. in California, developing AI and ML applications in natural language recognition.

His main scientific interest is the application of Neural Networks for solving computational problems that the tradition, symbol-based Computer Science considers intractable.

Professionally, I know Vladislav Haralampiev very well.

3. **The Scientific Accomplishments of the Dissertation**

The most impressive result of Vladislav Haralampiev's dissertation is the design and implementation of a novel kind of neural networks called Competition-Based Neural Networks (CBNNs) and their successful use as a computational tool for solving instances of hard intractable Facility Location computational problems. By "successful use" I mean the doctoral candidate did obtain excellent, nontrivial solutions to relatively big instances of **NP-hard** problems; the question whether **P = NP** remains unanswered.

CBNNs are described in detail in Chapter 3 of the dissertation. Loosely speaking, a CBNN has a fixed number of computing agents, every one of which is in precisely one of two states. The set of all agents is partitioned into groups. Making analogy to the real world, those groups correspond to some sort of organisations and the agents within one organisation compete with each other but agents from different organisations do not do so. A certain nondeterminacy called "luck" is introduced and there is an aspect of the system called

"temperature" that controls luck. An instance of optimisation problem can be encoded with Boolean variables – that corresponds to the fact that any agent is in one of two states. Once initialised, a system of that kind evolves according to certain rules, and the Boolean vector of all agents traverses a trajectory in some phase space with the tendency to "find" good minima or maxima – whatever the problem requires.

The dissertation points out on page 24 that the idea to use neural networks to solve optimisation problems is far from new; in fact, it originates at least in the 80'ies. However, it is widely believed that neural networks are not suitable heuristic for **NP-hard** problems; rather, genetic algorithms or algorithms, based on the Simulates Annealing paradigm yield better results. The CBNNs, designed and implemented by Vladislav Haralampiev are a powerful counterexample to that. He makes a compelling argument in favour of using neural networks a heuristic for **NP-hard** optimisation problems.

The doctoral candidate has chosen the following problems from **NP-hard** to analyse the performance of CBNNs: P-MINISUM, also known as P-MEDIAN, P-HUB, P-DEFENSE-SUM, MAXIMUM COVERING LOCATION, and FLOW INTERCEPTING FACILITY LOCATION. The computational results are presented in Chapter 5 of the dissertation. It is worth mentioning that CBNNs are superior, in that aspect, to the previously known Hopfield networks and Boltzmann machines.


4.  **Approbation of the Results**

The main result of the dissertation—the design and implementation of a no vel kind of neural networks and their usage in facility location problems—has been published in the articles NEURAL NETWORK APPROACHES FOR A FACILITY LOCATION PROBLEM and THEORETICAL JUSTIFICATION OF A NEURAL NETWORK APPROACH TO COMBINATORIAL OPTIMIZATION", items [42] and [44] in the bibliography, respectively. The bibliography contains another article of Vladislav Haralampiev, namely SINGLE FACILITY LOCATION PROBLEMS IN K-TREES that predates the usage of neural networds and presents efficient solutions to facility location problems on a restricted graph class called k-trees.

These articles cover both the minimum national requirements stated in art. 2B, par. 2 and 3 of the Bulgarian law for the Higher Education and the additional requirements of Sofia University for acquiring the PhD degree. The results presented in the dissertation are original and have not been presented by Vladislav Haralampiev for the purpose of acquiring

any degree in the past. No plagiarism has been found in the dissertation or in any of the articles it is based on.

## 5. About the Abstract

The abstract of the dissertation presented by Vladislav Haralampiev is in two versions: in English and in Bulgarian. Both versions cover all requirements. They reflect accurately the content of the dissertation.

## 6. Critical Remarks and Suggestions

I am very impressed by the dissertation of Vladislav Haralampiev and my critical remarks are few and minor. I think the dissertation would benefit from a more extensive discussion on the similarities and dissimilarities between CBNNs, on the one hand, and the previously introduced Hopfield networks and Boltzmann machines, on the other hand. And I think that Chapter 2.3 would benefit from a deeper discussion on the neural networks computational model that is so radically different from the traditional symbolic computational models.

## 7. Conclusion

Having made myself familiar with the presented dissertation and the corresponding articles, having analysed their significance, I **confirm** that the presented dissertation and articles covers the requirements of the Bulgarian Law for the Higher Education and the requirements of Sofia University for getting a PhD degree in the area **4. Natural Sciences, Mathematics and Informatics**, the subarea **4.6. Informatics and Computer Science**. The doctoral candidate meets the minimum national requirements in the said subarea. No plagiarism whatsoever has been found: neither in the articles nor in the dissertation.

Having in mind the above, I **recommend** to the esteemed committee should confer the degree of Doctor of Philosophy to **Vladislav Valeriev Haralampiev** in area **4. Natural Sciences, Mathematics and Informatics**, the subarea **4.6. Informatics and Computer Science**.

30 August 2021            Signed:

                        Assoc. prof. Minko Marinov Markov, PhD