Review

of the procedure for defending the PhD Thesis

Neural networks for object placement tasks

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The review is prepared by **Assoc. Prof. Hristo Alexandrov Ganchev, from the Faculty of Mathematics and Informatics of Sofia University** as a member of the scientific committee appointed with Order № RD-38-292 / 02.07.2021 of the Rector of Sofia University.

1. General characteristics of the dissertation

The presented dissertation is in English. It consists of 180 pages divided into an abstract , five chapters, two appendices and a bibliography containing 107 titles. In addition to the dissertation, the procedure documentation also includes an abstract in Bulgarian and English, diplomas of higher education (Bachelor's and Master's degrees) , CV , an order for enrollment in the doctoral program, certificate of passed exams in the curriculum, report from the supervisor on readiness for defense of the dissertation, declaration of authorship of the dissertation, protocol and opinion of the supervisor on the verification of the originality of the dissertation, reference to the minimum national requirements (as well as documents proving the declared points), lists of the articles, atained conferences and research projects of the PhD student, scientific papers related to the dissertation.

2. Personal data about the candidate

Vladislav Haralampiev was born in 1992. He graduated with honors consecutively from the Sofia Mathematics High School (2011), Faculty and Mathematics and Informatics at Sofia University "St. Kliment Ohridski ": Bachelor's degree, Computer Science (2015) and Master's degree, Informatics, Master's program Artificial Intelligence (2017) . In 2017 he was enrolled as a full-time PhD student at FMI at Sofia University "St. Kliment Ohridski "in the doctoral program Computer Science - Algorithms and Complexity. He has finished his doctoral studies in 2020. He has participated in 7 scientific projects and has give talks at 11 national and international scientific conferences. He has written 9 articles , three of which are referenced in zbMath , and one is in the Conference Proceedings series having SJR.

Unfortunately, I do not have the pleasure to know Mr. Haralampiev personally, but I have heard extremely good reviews about him from colleagues at FMI. Their words are confirmed by the awards Mr. Haralmpiev has won as a pupil and student. It is enough to note that as a student he won all possible awards including: Student of the Year given by the Ministry of Education and Science (2014); Student of the Year of Sofia University (for the academic 2015-2016); a special scholarship from Huawei Technologies for achievements in computer science (2016-2017).

3. Content analysis of the scientific and scientific-applied achievements of the candidate, contained in the presented dissertation and the publications to it, included in the procedure

The dissertation is well written and in my opinion is a pleasant and fascinating read. All concepts, tasks and algorithms are described in an accessible way, and for many of them the author has helped the reader with appropriate intuition.

The main goal of the thesis is to introduce and analyze a new algorithm called Competition-Based Neural Networks (CBNN) designed to solve the following optimization problem: find the smallest value of the cost function

$$\boldsymbol{F}(\boldsymbol{x_1}, \dots, \boldsymbol{x_t}), \text{ subject to}$$

$$\sum_{x_i \in G_k} x_i = 1, \text{ за } k = 1, \dots, r,$$

where $x_1, \dots, x_t$ are variables taking values either 0 or 1, and $G_1, \dots, G_k$ is a partition of the set $\{x_1, \dots, x_t\}$.

A number of optimization allocation problems can be modeled with this formalism: the problem for positioning p warehouses so that the sum of the minimum distances between them and their customers is minimized (p-MiniSum); the problem of positioning p post offices, so as to minimize transport costs (p-Hub); the problem of positioning p objects so that they are furthest away from each other (p-Defence-Sum); the problem of positioning p mobile operator cells so that a maximum part of the territory is covered (p-MCLP); the problem of positioning p advertising billboards so as to maximize the number of people who see them (FIFL). These problems are known to be NP- hard and therefore the proposed formal problem is also NP-hard. The algorithm considered in the dissertation is not intended to give an accurate result, but a solution that is "close" to the optimal and is found for a "reasonable" number of steps.

The first chapter is introductory. In it, the reader is introduce in a very accessible lway to the problems of combinatorial optimization and in particular with location problems, as well as with some of the main methods for solving them. An intuitive idea of the class of NP-hard problems is given. The problems p-MiniSum , p-Hub, p-DefenseSum and p-MCLP are formulated.

The second chapter introduces the reader in more detail to some of the most commonly used methods for solving optimization combinatorial problems. Special attention is paid to a class of methods called neural networks, which includes the algorithm, which is the central object of study in the dissertation. The methods of Hopcroft Networks , Boltzmann Machines and Selforganized Approaches are presented and carefully analyzed , as it can be said that they serve as the inspirationof the CBNN algorithm . The strengths and weaknesses of these methods are studied, and an argument is give why they are not particularly suitable for solving location problems.

In the third chapter the CBNN algorithm is introduced . It is described in great detail and in an understandable way. An analogy is made with a simplified business system made up of competing companies in an imaginary region. Further, some modifications of the algorithm are suggested, which might speed up the performance of the algorithm in some specific cases.

The algorithm itself can be described as follows. The algorithm is executed in steps. At each step only one of the variables $x_1, \dots, x_t$, say x_i from the group G_j, is considered. In case that for every variable $x_s \in G_j, s \neq i$, having value 1, the inequality $F[x_i = 1](\vec{x}) < F[x_s = 1](\vec{x})$ (where $F[x_s = 1](\vec{x})$ is the value of F obtained by making zero all variables from the group G_j except the variable x_s), then the algorithm has the rational desire to make x_i equal to 1, and make x_i equal to 0, otherwise. In case, the algorithm starts from a bad configuration and follows only its rational desires, it might turn out that the algorithm finds a local but not global minimum of F, from which it cannot escape. In order to deal with this kind of problems, the algorithm is made non-deterministic in the following way: the algorithm takes exactly the opposite action of its rational desire with probability $\frac{1}{1+e^{\frac{\Delta}{T}}}$, where Δ is the absolute value of the largest of the considered differences $F[x_i = 1](\vec{x}) - F[x_s = 1](\vec{x})$, and T is a global parameter. It is clear that with larger values of Δ, as well as with smaller values of T, the probability of irrational behavior of the algorithm de-creases.

The steps of the algorithm are grouped into epochs. Each epoch consists of a fixed quantity of consecutive steps (this quantity is another parameter of the algorithm). For each step, the variable to be considered is chosen randomly. The number of steps in an epoch is cho-sen so that each variable is considered several times. The parameter T does not change its value during a fixed epoch. It decreases exponentially with each succeeding epoch. The number of epochs is the second fixed global parameter.

Chapter four gives an analysis of the algorithm and an argument for the convergency of the algorithm to an optimal solution. This is done by connecting each epoch of the execution to a Markov chain. The states of the chain are all 2^t configurations of the variables $x_1, \ldots, x_t$. The probability $P(v, v')$ of transitioning from state v to state v', differeing in the values of more then one variable is 0. The probability for transitioning from a state v to a state v', differing in the value of exactly one variable, is equal to $\frac{1}{t}\left(1 - \frac{1}{1+e^{\frac{\Delta}{T}}}\right)$, if this is the rational desire of the algorithm, and it is equal to $\frac{1}{t} . \frac{1}{1+e^{\frac{\Delta}{T}}}$ otherwise. The probability of remaining in the state v is $P(v, v) = 1 - \sum_{v' \neq v} P(v, v')$. The general theory tells us that the resulting Markov chain has a stationary distribution. The next step is to show that small values of T will give higher probability of the optimal solutions in the stationary distribution. For this purpose, the Markov chain is modified so that for states v and v', differing in the value of exactly one variable, the probability $P'(v, v')$ of a transition from v to v' is equal to $\frac{1}{t}\left(1 - \frac{1}{1+e^{\frac{|F(v)-F(v')|}{T}}}\right)$, when $F(v) > F(v')$ and it is equal to $\frac{1}{t} . \frac{1}{1+e^{\frac{|F(v)-F(v')|}{T}}}$, otherwise. For this modified chain, the stationary distribution is explicitly found. It clearly shows that the states optimizing the cost function are more probable then the others, and as T decreases this probability increases. In the proof of Theorem 4.4.1, it is stated that in the case of the p-MiniSum problem the two Markov chain are close and that when T is very small, they coincide. In my opinion, this statement is not true. The reason for this is that for the p-MiniSum problem the cost function is a sum of monomials of the form $d_{ij}x_i x_j$, where d_{ij} are fixed non-negative numbers, and the variables x_i and x_j belong to different groups. Thus in order the inequality $F(v) > F(v')$ to be satisfied for the states v and v', differing in the value of exactly one variable, say x_s, it must be the case that in v' x_s has value 0, and in v it has value 1. In this case, lowering T, the probability $P'(v, v')$ converges to $\frac{1}{t}$. However, it might be the case that the rational desire of the algorithm, is to make x_s equal to 1 and then by lowering T, the probability $P(v, v')$ from the original Markov chain will converge to 0.

Having in mind this, I consider the proof of Theorem 4.4.1 as an intuitive argument and as a proper proof.

The fifth chapter is the most extensive (51 pages). It is dedicated to some applications and experimental results about the CBNN algorithm. The problems considered are p-MiniSum, p-Hub, p-SumDefence , p-MCLP, FIFL and the assignment problem. Each of the problemss is discussed in detail and it is supplied with an intuition and a detailed description. Further, it is described how it can be formalized so that it is suitable for solving with CBNN. Experiments were performed for each problem. The data for these experiments (except for the assignment problem) were taken from real geographical data , using mainly data for the road network in Bulgaria, except for the p-Hub task for which the data is taken from the Australia Post database . The solutions obtained by the CBNN algorithm are compared with the corresponding optimal solutions. In all experiments, the CBNN algorithm manages to find the optimal solution in most cases, and when it fails, the error is within 5% (usually around 2-3%). These results seem very good, we should have in mind that in order to be able to calculate the optimal solution, too small values of the parameter p indicating how many objects should be located have been used (the maximum value used is 20, but in almost all experiments it does not exceed 5-6). Usually the problems become more complex with larger values of p and it is not certain that the good performance of the algorithm will remain.

The assignment problem has been chosen because there is a polynomial algorithm finding an optimal solution. This allows experiments with larger input data. The experiment compares CBNN to three other algorithm (one based on a greedy strategy, one based on local search and one , combining both approaches). In all instances of the experiment CBNN produced the best solution.

4. Approbation of the results

The results of the dissertation are presented in 5 publications. Mr. All publications are not co-authored. One of the publications is in a conference proceedings, part of the ACM International Conference Proceeding Series , which has an SJR. Another publication is in the Annual of Sofia University and is referenced in zbMath . This fully satisfies the minimum national requirements (under Art. 2b, para. 2 and 3 of ZRASRB) and respectively the additional requirements of Sofia University “St. Kliment Ohridski ”for obtaining a PhD degree in the scientific field and professional direction of the procedure . There is no legally proven plagiarism in the submitted dissertation and the scientific papers on this procedure.

5. Quality of the Abstract

The abstract is less detailed than usual (for example, I would expect it to contain at least an intuitive description of the CBNN algorithm, as this is the central object of study of the dissertation). However, the abstract correctly reflects the results and the contributions of the dissertation.

6. Critical remarks and recommendations

I have two more significant remarks. The first one is related to the CBNN algorithm . Since the number of steps that the algorithm will run is fixed prior to its execution, there is no guarantee that the algorithm will stop in an acceptable configuration of the variables (i.e. exactly one of the variables will have a value of 1 in each group). I am aware that there is hardly a common strategy for this issue, but it should at least have been noted as a problem, and a solution should have been proposed in the specific applications under consideration. For example, for the p-MiniSum problem with non-negative coefficients (distances) there is a very simple strategy: for each of the groups choose randomly one of the variables that has a value of 1 in the solution, and assign all the others value 0 (this will not worsen the solution found by the algorithm).

The second remark is related to the experiments performed. Comparing the solution given by CBNN with the optimal solution is important and interesting. On the other hand, due to the complexity of finding the optimal solution, these comparisons can only be made at very low (unrealistic) values of the number of objects p (usually 5-6 in the experiments performed) that need to be allocated. Another important comparison that is missing in the dissertation is that between the presented algorithm and other algorithms that are known to give good results for the given problem. It seems to me that this comparison is even more important, because a priori it is clear that in realistic examples the algorithm will not give an optimal solution. Since all the considered problems are well known, there are certainly more than one algorithms, which are used in practice. Moreover, for specific optimization problems the comparison of two algorithms on a specific instance is elementary and does not require finding an optimal solution.

7. Conclusion

After getting acquainted with the dissertation presented in the procedure and the accompanying scientific papers and based on the analysis of their significance and the scientific contributions contained in them, I **confirm** that the presented dissertation meet the requirements of the Bulgarian legislation and the respective Regulations of Sofia University "St. Kliment Ohridski " for obtaining a PhD degree in the scientific field 4. Natural sciences, mathematics and informatics and professional field 4.6. Informatics and computer science. In particular, the candidate satisfies the minimum national requirements in the professional field and no plagiarism has been established in the scientific papers submitted at the competition.

Based on the above, **I recommended** Mr. Vladislav Valeriev Haralampiev to be given a doctoral degree in the scientific field 4. Natural Sciences, Mathematics and Informatics , professional field 4.6. Informatics and computer science .

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