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Review of the doctoral dissertation by M.Sc. Eng. Karol Struniawski:

Optimization and Applications of Extreme Learning Machine Method

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The review was prepared at the request of the Scientific Council of the discipline: Technical Informatics and Telecommunications at the Polish-Japanese Academy of Information Technology.

Structure and content of the doctoral dissertation

The thesis submitted for evaluation is 165 pages long and takes the form of a collection of monothematic publications in which the doctoral student was the main co-author.

The first section is the abstract, which contains the objective of the dissertation and the research hypothesis. Next, there is an introduction, which reviews the literature related to the topic under study, briefly discusses the structure, operation and learning of ELM, and presents four research problems that are solved in the dissertation. The introduction concludes with a summary detailing the main thesis contributions and a bibliography. The bibliography contains 85 items, which is not a large number for a doctoral thesis, although the literature review has been conducted quite thoroughly, and the cited literature is up to date and well selected.

The most important part of the dissertation is a collection of nine publications: five articles published in international conference proceedings, three articles in journals, and one chapter in a book. The dissertation is accompanied by statements from all co-

authors of the publications, specifying their percentage contribution to the publications and the scope of work performed by each person. In each case, the doctoral student's contribution to the publications was the most significant, i.e. it was more than 50% (from 60% to 90%). Only on this basis, I can conclude that the candidate's contribution to the work was the most important, and there can be no objections to this aspect. In computer science, as in other fields of science, work and publications are currently usually done in teams, which is why publications with only one author are rare today.

I consider the article "Extreme learning machines framework with Python and TensorFlow" published in SoftwareX journal to be the most important. It has a very high score of 200 ministerial points and 90% own contribution stated. The doctoral student developed a library that facilitates the use of ELM, which should significantly contribute to the popularization of this technique. Although a doctoral degree is not granted for software development, I consider the developed library to be one of the candidate's most important achievements. This is exactly what has the greatest impact on the development of machine learning as a field of science and enables its effective use in practice.

Other publications show research on the impact of various ELM parameters on learning efficiency and network performance. A significant part of the collection of publications are also articles in which the candidate applied ELM in practice to the task of identification in microbiology. The dissertation ends with conclusions and a brief description of planned future works and extensions.

I evaluate the presented publications positively. They are published in reputable journals and conference proceedings that are important for machine learning.

Objective of the study and research hypothesis

The objective of the work can be found in the abstract and has been formulated as follows: *to make a significant contribution to the development of ELM by developing modern programming tools such as the TfELM library, algorithmic optimization and practical applications in biological image analysis.*

The research hypothesis of the dissertation: *ELM can be significantly improved by developing its algorithmic techniques – in particular by applying the extensions described in the thesis. These changes not only improve the performance of ELM, but also expand its range of applications in solving real-world, data-driven problems.*

In my opinion, the objective of the work was correctly formulated and fully achieved. The candidate developed the TfELM library and performed research on ELM algorithmic optimization. The possibilities of using metaheuristic algorithms for network weight selection were examined, and the impact of various activation functions on the learning process and network performance was investigated. An analysis of the impact of the

random weight initialization method on its effectiveness was also carried out. The doctoral student applied ELM in practice in the analysis of microbiological images, demonstrating the effectiveness of the method and the developed library.

Based on the presented collection of publications, it can be concluded that the research hypothesis presented in the thesis has been proven.

Evaluation of the applied research methods

The first part of the thesis is focused on developing modern programming tools. The author has developed the TfELM library in Python, integrated with TensorFlow, CUDA, and Scikit-learn libraries. The software is open source and available for free in popular Python library repositories. The software supports many ELM variants and, importantly, is consistent with the usage convention found in the Scikit-learn package. This significantly facilitates the practical application of the library. As I mentioned earlier, I rate the developed software very highly and consider it to be the most important contribution to the field of machine learning.

The second part of the objective is algorithmic optimization. The publications presented in the dissertation show the results of research of the influence of various ELM parameters on the learning process and network performance. Alternative learning techniques based on metaheuristic algorithms were also investigated, thanks to which the quality of network performance was improved.

The research was carried out very carefully and methodically. The results of the research were presented (mostly) correctly and clearly, confirming the conclusions drawn by the candidate.

Comments on the thesis and issues for discussion

1. The ELM theory presented in Introduction is described too briefly. In practice, the description of how the network works was limited to excerpts from several articles that are part of the doctoral thesis. In my opinion, this description is insufficient. The disadvantage of the doctoral thesis in form of a collection of articles, is that a large part of the text is repeated many times. For example, practically every article contains information about the operation and learning of ELM. Unfortunately, there is the same short section describing ELM in the Introduction. Articles in journals, and even more in conference proceedings, have a limited number of pages, so such a short form is understandable. However, the author was not limited in any way in his thesis, and the description of ELM could have been longer and more complete.

2. The symbols used for variables on page 16 (e.g. weights and bias) are inconsistent with those used in Fig. 1 and on page 15. When composing the Introduction from several articles that make up his doctoral thesis, the author failed to ensure consistency in the use of symbols.
3. On page 16, in Introduction, the author wrote: 'The input layer of the network consists of *d* neurons, corresponding directly to the dimensionality of the input feature space.' Please explain how the 'neurons' on the input layer work. How exactly do they process the signal?
4. Why do neurons in the output layer not have bias? What would happen if they have it? Could this improve the performance of ELM?
5. In Introduction, the author wrote that the ELM concept was introduced in 2004 by G.B. Huang. However, the idea of random initialization of parameters in the hidden layer of a network is older. It is used, for example, in RBF networks, where the centers of RBF neurons in the hidden layer are determined randomly. This type of approach was described in articles by D. Broomhead and D. Lowe as early as 1988, as well as in the Polish book by Prof. S. Osowski: 'Sieci neuronowe w ujęciu algorytmicznym' (Neural Networks in Algorithmic Perspective) from 1996. In my opinion, this type of model is conceptually closest to ELM, and it is a little unfortunate that the conducted research did not include a comparison with it.
6. Remarks on the article: TfELM: Extreme learning machines framework with Python and TensorFlow

   Is the execution time shown in Fig. 1 the learning time? It is not clear here what exactly was measured. What exactly was the calculation scenario for which time was measured?

   Table 4 compares the execution time of various ML methods with ELM. Unfortunately, there is no information about the parameters of particular methods, which means that the comparison is not entirely reliable. In fact, we do not know exactly what we are comparing ELM with.
7. Remark on the article: Performance of selected nature-inspired metaheuristic algorithms used for extreme learning machine

   This remark is similar to the one above. The author examined a large number of methods classified as MA. They are only briefly mentioned at the end of section 4. Each of these algorithms has a number of specific parameters that often need to be carefully selected because MAs are usually quite sensitive to changes in them (e.g., in ACO – pheromone evaporation rate, in GA – crossover and mutation probabilities, and many others). We do not know their values, which makes it impossible to reproduce the results obtained by the author. In my opinion, it would have been better to examine a smaller number of algorithms, but describe them more precisely.
8. Remarks on the article: Performance evaluation of activation functions in extreme learning machine

The authors performed an analysis to determine which activation functions yield the most advantageous results for ELM used in classification tasks. Would the functions identified as the most advantageous also be selected if ELM were used in regression tasks?

Did the author ask himself why he obtained these particular results? Why, for example, was the *cosine* function among the least effective in every study, while the *mish* function was among the most effective? What characteristics of a function determine its beneficial properties for ELM?

9. Remark on the article: Metaheuristic algorithms in extreme learning machine for selection of parameters in activation function

   Could more "classical" optimization methods (e.g., gradient methods) have been used instead of metaheuristic algorithms, and would they have been more effective? In my opinion, the article lacks a comparison of optimization based on metaheuristic algorithms with "classical" methods.

10. Remark on the article: Identification of soil bacteria with machine learning and image processing techniques applying single cells' region isolation

    The article does not specify which features were identified as most important for classification. In my opinion, this information could be interesting for the reader, but only the number of analyzed features is provided. Specifying the identified important features could indicate which stages of feature preparation are most important for subsequent classification.

11. Remark on the article: Automated identification of soil Fungi and Chromista through Convolutional neural networks

    The article is very interesting and well written, but unfortunately it is not related to the topic of the thesis. It is unclear why it was included in the collection of articles that make up the dissertation.

12. Remark on the article: Extreme learning machine for identifying soil-dwelling microorganisms cultivated on agar media.

    The article has a rather unusual structure. After Introduction, the authors first present the Results and Discussion, and only then discuss the methods, data used, and how they were preprocessed. Since the results use many concepts, symbols, and abbreviations that are only introduced later, the first reading of the article is quite confusing. Only after reading the final sections and rereading the description of the results, the content become more understandable. If the authors' intention was to make the reader read the article twice, then in my case they succeeded.

Conclusion

In my opinion, the objective of the doctoral dissertation has been fully achieved. The doctoral student has demonstrated very good theoretical knowledge in the field of machine learning and proven his ability to conduct independent scientific work. The doctoral dissertation presents an original solution to a scientific problem and, at the same time, documents its practical application.

Despite a number of comments mentioned in the previous section, my overall assessment of the work is **positive**.

Taking into account the results presented in the reviewed doctoral dissertation by M.Sc. Eng. Karol Struniawski, I conclude that, in my opinion, this work **meets the requirements** for doctoral dissertations set by the Act on Academic Degrees and Titles currently valid in Poland. **I hereby request for its acceptance and admission to further stages of the doctoral procedure.**