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July 2, 2021

Review of Doctoral Thesis titled *Control Parameter Adaptation in Differential Evolution*

This is a review of the doctoral thesis titled *Control Parameter Adaptation in Differential Evolution* submitted by Ing. Adam Viktorin in fulfillment of requirements of Doctor of Philosophy in Engineering Informatics at Tomas Bata University in Zlin, Czech Republic.

The thesis is based on the development of a number of novels aspects, namely, control parameter adaptivity, population dynamic analysis tool, multi chaotic framework for parent selection, distance based parameter adaptation and finally an improved DE algorithm termed DISH. This algorithm is applied to an industrial waste management problem as a proof-of-concept with excellent results.

The thesis has a very comprehensive literature review spanning from 2004 till 2019, encompassing the most relevant publications on Differential Evolution algorithm.

A significant number of experimentations have been conducted on standard benchmark test-beds to validate the research and a very through comparison has been conducted with published literature. A practical application to a sustainable waste-to-energy facility location problem lends substantial weight to the practicality of the developed and modified DISH algorithm.

The results of this dissertation have been internationally published in peer-reviewed publications including three journal articles and twenty-nine conference proceedings, which is a phenomenal achievement. The candidate is part of a very strong research team with a very high research output portfolio.

Some of the questions for oral defense are:
1. Justification of using binomial crossover for the DISH algorithm .
2. Balance between exploration and exploitation, and the level of stochasticity this involves.
3. Level of Genetic drift employed in the algorithm for exploration.
4. Discussion on the complexity of the DISH algorithm.

Based on the review of the thesis and its research output in terms of publications, I believe the topic is applicable for a doctoral thesis, the aims of the thesis have been fulfilled, the candidate has made original contribution to knowledge in this domain and the thesis has practical applications. Therefore, I **strongly recommend this thesis to defense**.

Yours faithfully,

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Dissertation thesis review

The dissertation thesis entitled „**Control Parameter Adaptation in Differential Evolution**", submitted by **Ing. Adam Viktorin**, summarizes the author's research and results in the field of self-adaptive evolutionary computation, in particular, the differential evolution (DE) algorithm. The topic as well as the goals of the thesis are fully in line with current research trends in population-based metaheuristics and provide a valuable contribution to this scientific field. It lies mainly in the design and assessment of several novel schemes for DE parameter self-adaptation based on the use of deterministic chaos ('multi-chaotic adaptation', MC-SHADE) and heuristic analysis of the movement of individuals in the search space ('distance-based adaptation', Db_SHADE, Db_LSHADE, DISH, DR_DISH). The thesis has undisputed qualities: the research is innovative and has merit, the results are comprehensive and well justified, and the application to a real-world problem is convincing. Moreover, the text of the manuscript is well-written and reads well. The use of the English language is on a high level and clearly represents a strong aspect of the work.

The manuscript is structured into 9 chapters. The organization is reasonable and the chapters logically follow one after another. They provide the reader with an overview and taxonomy of metaheuristic optimization, evolutionary computation, the DE algorithm, and adaptive DE variants. Unfortunately, it is quite questionable whether a taxonomy based on a 1997 article (ref. [1], the citation is BTW malformed) is still up-to-date in 2021. Next, the author outlines some of the research done in the past 15 years and details his own contribution to this field. The overview is undoubtedly comprehensive and very well illustrates the development of the target field in the past one and a half decade. However, due to the long time span it covers and the number of covered algorithms, it is also hard to follow. A visual illustration of the relationship of the algorithms (which is based on which?), the improvements, and the results they achieve would be a very suitable addition to this chapter. A standalone chapter is dedicated to SHADE and L-SHADE, two self-adaptive DEs exceptionally successful in solving artificial benchmarking problems such as the CEC Benchmark on Numerical Optimization.

The description of the original research itself is summarized in chapter 7 and onwards. It introduces a novel self-adaptive DE scheme that uses multiple chaotic maps to select parents during the evolution and another algorithm that uses the knowledge about the distance between the trial and the target vectors to alter the parameter adaptation procedure. Both proposed ideas were investigated by the candidate, implemented, and evaluated on artificial test problems (CEC2015 Benchmark). The results of the initial evaluation were published in scientific proceedings and the algorithms took part in the CEC Competitions, where they ranked well. These achievements illustrate the validity of the proposed approach and the maturity of the author's research. The experimental results are a big advantage of the thesis. What is lacking, on the other hand, is a survey of the state of the art in all the related domains. Although the author did a good job surveying self-adaptive DEs, he should dedicate a similar effort to the study of the applications of deterministic chaos and search space geometry/topology in evolutionary computation. A well-done state-of-the-art overview would also prevent the author from some incorrect claims. For example, the idea to use deterministic chaos for pseudo-random number generation is attributed to Pluhacek (2015) ref. [67]. It can be easily verified that well-developed approaches to this task were proposed as early as 1993 [R6]. In fact, deterministic chaos has been used extensively for evolutionary and swarm algorithms [R1-R4] and in general to generate pseudorandom numbers [R5-R7]. The control of evolutionary algorithms based on exploitation/exploration trade-off has been studied in the past as well. The self-adaptive frameworks, designed in the candidate's work, should benefit from these past research efforts, too.

Several remarks can be addressed to the technical quality of the thesis. Although generally very good, some parts could be significantly improved. For example, the majority of figures is of very low graphical quality (why not in vector format?) and with insufficient description (e.g., on fig 6.1: what is on the x-axis? What is represented by the lines? Are the plotted values averages over multiple runs or only a single run?). The convergence plots would be more helpful with confidence intervals included. It is not clear what are the values in some tables (e.g., Tab. 6.3: what score? How is it defined?). The good overall quality of the thesis is unnecessarily compromised by the lack of attention in this matters.

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That being said, it is my pleasure to conclude that as a whole, the thesis is of high quality, and the contribution of the author to science in the target field is well justified. This is further emphasized by the bibliography of the author. He co-authored 4 articles in journals with impact factor, 4 articles in journals indexed on Scopus, and 100 contributions to conference proceedings. This highly exceeds the usual requirements on doctoral candidates and underlines the performance of the author.

In light of this proficiency and despite the remarks summarized above, it is my pleasure to, **recommend the thesis for defense** and Ing. Adam Viktorin for the academic degree of ***doctor philosophiae*** **(Ph.D.)**.

Questions for defense:
Provided the timeline of DEs with deterministic chaos (e.g., during the last decade [R8, R9]), where can be MC-SHADE placed in the context of other algorithms (i.e., which methods are similar, which are different, and how)?

Can you clearly, in one place, summarize the original methods proposed in the thesis? In particular, what is the difference between Db_SHADE, Db_LSHADE, and DISH?

Pavel Krömer, Ph.D.
In Ostrava, 25. 5. 2021

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Review of the Ph.D. thesis

„Control Parameter Adaptation in Differential Evolution“

by Ing. Adam Viktorin

The main aim of the Ph.D. thesis was to propose methods for parameter adaptation control in Differential Evolution-based algorithms, verify their effectiveness on CEC benchmarks of test functions, achieve competitive results, and also show applicability for discrete combinatorial optimization problems, expressed by mixed integer programming models.

Since the defined class of problems covers a wide range of applications, in the latter case NP-hard or NP-complete tasks, which for large instances cannot be solved by classical methods in a reasonable amount of time, it can be stated that the **topic meets requirements for the doctoral dissertation** and is also important for the development of engineering informatics.

The Ph.D. thesis is logically structured into chapters and subchapters. It has a theoretical and practical part. Given the focus of the work, Chapter 3 provides a brief description of differential evolution as proposed by Storn and Price in 1995, and a key analysis of its modifications follows in Chapter 4. This part is comprehensive and provides a great overview of the latest sources dealing with updated versions of differential evolution and their parameter settings. Finally, it is clearly summarized in Table 4.1.

The SHADE algorithm, which was proposed with a self-adaptive mechanism of its parameters, is selected among them, and described in more detail in Chapter 5, including mathematical formulations.

The original methods of the author and their applications are presented in Chapter 6. The author discusses the causes of suspicion that the differential evolution method converges to local optima. He presents a clustering method to identify convergence to the same point in the search space, and a way to increase population diversity. Belonging to the same cluster is evaluated using the Chebyshev distance.

As Pseudo-Random Number Generators (PRNGs) for parent selections, chaotic maps are used, and their types are summarised in Tab. 6.1. One of them is Lozi's map, which was personally presented by the author at (for us) well-known MENDEL conference.

These approaches were implemented and statistics from 51 runs were evaluated using CEC benchmark sets. The results show that the Multi-Chaotic (MC) SHADE algorithm outperforms the SHADE algorithm on two test functions.

The distance-based (Db) adaptation of the Tanabe and Fukunaga algorithm was another presented and implemented approach. It is derived from the Euclidean distance between the trial and the target individual.

DISH (Distance based parameter adaptation for Success-History based differential evolution) algorithm was introduced by the author (and co-authors) in 2018 and published in 2019 and all its parameter settings are described in Section 6.4. As the author remarks on page 59 "*DISH algorithm was submitted for the CEC 2019 competition – 100-Digit Challenge*" and "*It was shown, that the DISH algorithm is capable of obtaining competitive results and ended on joined 1st and 7th place out of 18 contestants.*" This can be considered as evidence of a successful modification of differential evolution and at the same time one of the main contributions of the dissertation.

Chapter 7 summarizes all the contributions to the development of the field of engineering informatics in terms of theory and practice. As for the theory, the population dynamic analysis, based on clustering and population diversity, avoids convergence to local optima. The practical use is demonstrated on the sustainable waste-to-energy facility location task.

The final part of the thesis contains appendices with the notation of algorithms in pseudo-codes and tables of results for CEC benchmarks.

I have only two comments on the Ph.D. thesis, but they are not substantial:

- In Section 1.1 the author deals with the complexity of problems and mentions, among other things, the number of optimized parameters, but it is also significantly influenced by the number and type of constraints.
- Page 16: "Due their stochastic nature, metaheuristics do not guarantee a finding of the global optimum." In fact, for large instances of problems (e.g., factorial complexity tasks), metaheuristics can only pass through parts of the search space, although the "intelligence" of these methods is able to focus on promising areas.

The language in which the Ph.D. thesis is written and its typographical standard are excellent, the text contains no misprints.

Questions:

1. Specify test functions in CEC benchmark in more detail.
2. How to choose the maximum number of objective function evaluations for the termination criterion?
3. Describe the mathematical model of the sustainable waste-to-energy facility location problem, which is characterized in Section 7.3.1 only verbally.
4. Representations of some combinatorial problems (e.g., Knapsack Problem and Set Covering Problem) in iterations of heuristic algorithms generate infeasible solutions and it is necessary to either penalize them or define a repair operator. How is the situation handled here?

Conclusion:

In my opinion, Ing. Adam Viktorin has proved to be capable of solving difficult research problems. He proposed the original modification of differential evolution, the quality of which was confirmed by demanding tests on a representative class of benchmarks of the prestigious CEC conference and was able to win in strong competition.

The Ph.D. thesis satisfies conditions of the Czech Act, parts of the thesis have been published in more than 100 papers, registered in Web of Science and SCOPUS databases, and four of them are in journals with an impact factor, therefore

I recommend

Adam Viktorins's Ph.D. thesis to be accepted by the Committee to be presented and defended in the Engineering Informatics study branch.

As to the Ph.D. thesis summary, I state that it contains all the substantial results of the dissertation work and also has the required form.

Brno, May 31, 2021

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