

Metaheuristic Optimization for Modern Computational Linguistics in the Age of SHIVA and WARMI Paradigms

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Abstract. *The article considers the possibilities of using meta-heuristic optimization methods in modern machine linguistics in the conditions of SHIVA and WARMI worlds. The main meta-heuristic algorithms and their use for optimizing language models, tuning hyperparameters, and increasing the efficiency of natural language processing systems are analyzed. The prospects for integrating meta-heuristic methods with modern artificial intelligence technologies are substantiated.*

Keywords: *machine linguistics; natural language processing (NLP); meta-heuristic optimization; evolutionary computing; genetic algorithms; large language models (LLM); SHIVA-world; WARMI-world.*

Introduction. Modern machine linguistics is experiencing one of the most intensive stages of its development, due to the rapid progress of artificial intelligence, computational linguistics, big data analysis and generative technologies [1]. If for several decades the main attention was paid to the automation of individual linguistic processes - morphological analysis, syntactic parsing, machine translation or information search, now there is a transition to the creation of intelligent language ecosystems capable of performing complex processing of natural language, modeling linguistic behavior of decision-making in various subject areas = machine linguistics is gradually transforming from a relatively narrow discipline into one of the key areas of modern science of artificial intelligence [2].

At the same time, the requirements for the efficiency, adaptability, comprehensibility and computational stability of intelligent language models are growing significantly. Modern natural language processing systems operate under conditions of continuous increase in the volume of text information, high dynamics of language changes, emergence of new terminological systems, multilingualism, multiculturalism and the need to process heterogeneous data types [3]. Scaling of large language models, complication of their architectures and expansion of the spectrum of solved tasks objectively lead to a significant increase in the computational complexity of the processes of training, tuning and operation of such systems, which makes the problem of intelligent optimization [4] one of the central ones in modern machine linguistics.

The rapid development of artificial intelligence, Natural Language Processing technologies and generative language models has radically changed modern machine linguistics. If earlier the main attention was paid to increasing the accuracy of individual text analysis algorithms, today the tasks of intelligent optimization of complex multi-

level language systems operating in conditions of high environmental dynamics are becoming relevant. Such conditions are increasingly described by the concepts of the SHIVA-world (Split, Horrible, Inconceivable, Vicious, Arising) and the WARMI-world (Wickedness, Agility, Randomness, Mutability, Interdependence), which reflect a qualitatively new level of uncertainty, turbulence, nonlinearity and interdependence.

Modern language models contain billions of parameters, and the processes of their training, tuning, adaptation and application require solving large-scale optimization problems. Classical methods of mathematical optimization in many cases turn out to be insufficiently effective due to the huge dimensionality of the search space, nonlinearity of objective functions, multi-criteria and high computational complexity [5]. In these conditions, meta-heuristic optimization methods [6], based on the use of universal strategies for finding approximately optimal solutions, become particularly relevant.

The Main Part. Modern machine linguistics has long gone beyond the boundaries of classical automatic translation or morphological analysis of text: it includes intelligent processing of large data corpora, machine translation, automatic summarization, knowledge acquisition, information retrieval, sentiment analysis, text generation, question-answer systems, dialogical intelligent agents, multimodal models and large language models (LLM).

Practically each of the listed tasks involves the need to optimize a large number of parameters [7]. For example, when training neural language models, it is necessary to determine optimal architectures, select hyperparameters, minimize error functions, improve the quality of text generation, and at the same time reduce computational costs. This is where the effectiveness of traditional methods is significantly reduced due to the large number of local extrema, nonlinearity of functions and the impossibility of complete enumeration of options [8].

Meta-heuristic methods are fundamentally different in that they do not require strict mathematical models of the studied task. They use intelligent global search strategies that allow finding high-quality solutions in extremely complex state spaces. This significantly increases the efficiency of tuning modern language models.

Of particular interest are genetic algorithms that simulate the processes of natural evolution [9], they are successfully used for automatic selection of neural network architectures, selection of the most informative features, optimization of feature space dictionaries, improvement of machine translation quality and tuning of parameters of large language models.

Particle Swarm Optimization algorithms based on the collective behavior of biological populations are no less promising. Their advantage is a high convergence rate and the ability to efficiently search in multidimensional spaces. In NLP tasks, such methods are used to optimize the parameters of deep neural networks, thematic modeling, document clustering and search for optimal embeddings.

Ant algorithms demonstrate high efficiency in solving combinatorial problems of machine linguistics. They are successfully used in automatic syntactic analysis, construction of optimal text processing routes, extraction of key concepts and structuring semantic networks.

Simulated annealing algorithms allow to significantly reduce the probability of falling into local minima during training of complex language models. Due to the gradual decrease in the probability of random changes, a stable search for globally more efficient solutions is achieved.

Hybrid meta-heuristic technologies that combine several algorithms simultaneously are becoming increasingly popular [10]. For example, the combination of genetic algorithms with gradient learning allows to significantly accelerate the process of tuning neural networks, while simultaneously improving the quality of their training [11]. Particle swarm methods with differential evolution, memetic algorithms with local search, as well as evolutionary computations with deep learning technologies are combined in a similar way.

In the conditions of the SHIVA-world, the requirements for language systems become much stricter. It is necessary to quickly adapt to constantly changing information flows, quickly respond to the emergence of new language constructs, take into account the cultural and social characteristics of different regions, and ensure the resistance of models to information attacks and disinformation.

But the WARMI-world concept assumes an even greater level of complexity. Here, uncertainty ceases to be a temporary factor and becomes a fundamental characteristic of the environment. Language models must continuously retrain, independently adapt to changing conditions, work effectively with incomplete data, and maintain stability even when fundamentally new language phenomena arise.

It is meta-heuristic optimization that provides the necessary flexibility of such intelligent systems. Instead of searching for a single optimal solution, modern algorithms form a multitude of competitive alternatives, which significantly increases the resistance of language models to changes in the external environment. A particularly promising direction is the integration of meta-heuristic algorithms with technologies of self-learning, reinforcement learning, federated learning, and artificial intelligence agent systems [12]. Such hybrid intelligent complexes are able to independently choose the most effective strategies for processing speech information depending on the nature of the incoming data and the current operating conditions.

Conclusions. Meta-heuristic optimization is becoming one of the key tools for the development of modern machine linguistics. Its use allows for effective solutions to complex multi-criteria tasks that arise during training, tuning and operation of intelligent language systems, for which the use of classical optimization methods is insufficient.

In the conditions of the SHIVA and especially the WARMI world, the importance of meta-heuristic technologies is significantly increasing due to the need to ensure high

adaptability, stability, scalability and the ability of language models to function in conditions of constant uncertainty, turbulence and dynamic changes in the information environment.

Prospects for further research are related to the development of hybrid intelligent methods that integrate meta-heuristic optimization, deep learning, large language models, multi-agent technologies, reinforcement learning and self-adaptive artificial intelligence systems. It is such complex solutions that are able to provide a qualitatively new level of efficiency of machine linguistics in the conditions of the formation of a new generation global digital ecosystem.

References

1. Goncharenko S. (2025). Innovative IT technologies of computational linguistics. *Trends, Issues, and Challenges in Modern Science* : Proceedings of the 2nd International Scientific Conference (Cambridge, United Kingdom, 5 September 2025). - Lulu Press, Inc., 2025. - P. 109-113. URL: <https://test.knutd.edu.ua/handle/123456789/31072>
2. Goncharenko S. (2025). Intelligent information technologies for innovative management of advanced philology projects. *Innovations and New Directions in Scientific Research* : Proceedings of the 2nd International Scientific Conference (Manchester, United Kingdom, 20 September 2025). - Lulu Press, Inc., 2025. - P. 176-179. URL: <https://er.knutd.edu.ua/handle/123456789/31648>
3. Maxim Krasnyuk, Svitlana Krasniuk (2024). CHAPTER 6. Evolutionary technologies and genetic algorithms in machine translation. *Innovation in modern science: Education and Pedagogy, Philosophy, Philology, Art History and Culture, Medicine and Healthcare. Monographic series "European Science"*. Book 30. Part 3. 2024. pp. 91-98, Published by: ScientificWorld-NetAkhatAV, Lußstr. 1376227 Karlsruhe, Germany <https://desymp.promonograph.org/index.php/sge/issue/view/sge30-03/sge30-03>
4. Goncharenko S. (2025). Mathematical optimization as element of innovative educational management in modern complex conditions. *Science and Global Challenges in the Modern World* : Proceedings of the 2nd International Scientific Conference (Leicester, United Kingdom, 5 October 2025). - Lulu Press, Inc., 2025. - P. 90-94. URL: <https://er.knutd.edu.ua/handle/123456789/31667>
5. Krasnyuk M.T., Naumenko M.A. (2024). Efektyvne zastosuvannia henetychnykh alhorytmiv u vyrishenni bahatoekstremumnykh optymizatsiinykh zadach v menedzhmenti konkurentnoho pidpriemstva [Effective application of genetic algorithms in solving multi-extremum optimization problems in the management of a competitive enterprise]. *Grail of Science*, №41, June 2024, 65-73. URL: <https://archive.journal-grail.science/index.php/2710-3056/issue/view/05.07.2024/29> [in Ukrainian].
6. Shami, A., Al-Ayyoub, M., Jararweh, Y., & Aldwairi, M. (2024). A systematic literature review on meta-heuristic based feature selection techniques for text classification. *PeerJ Computer Science*, 10, e2145. <https://doi.org/10.7717/peerj-cs.2145>

7. Lee, H.-Y., Li, S.-W., & Vu, N. T. (2022). Meta Learning for Natural Language Processing: A Survey. *arXiv preprint* arXiv:2205.01500. <https://arxiv.org/abs/2205.01500>
8. Manzoni, L., Jakobovic, D., Mariot, L., Picek, S., & Castelli, M. (2020). Towards an evolutionary-based approach for natural language processing. *arXiv preprint* arXiv:2004.13832. <https://arxiv.org/abs/2004.13832>
9. Kulynych Y., Krasnyuk M., Krasniuk S. (2022). Efficiency of evolutionary algorithms in solving optimization problems on the example of the fintech industry. *Grail of Science*, №14-15, May 2022, (pp. 63-70) DOI: <https://doi.org/10.36074/grail-of-science.27.05.2022>
10. Ait Amine, M., Hmida, M., & Mansouri, K. (2023). Literature Review on Hybrid Evolutionary Approaches for Feature Selection. *Algorithms*, 16(3), 167. <https://doi.org/10.3390/a16030167>
11. Ojha, V. K., Abraham, A., & Snášel, V. (2017). Metaheuristic Design of Feedforward Neural Networks: A Review of Two Decades of Research. *Information Sciences*, 369, 97–116. <https://doi.org/10.1016/j.ins.2016.08.05>
12. Karabasevic, D., Stanujkic, D., Popovic, G., Brzakovic, M., & Ulutaş, A. (2022). A comprehensive survey on recent metaheuristics for feature selection. *Neurocomputing*, 494, 269–296. <https://doi.org/10.1016/j.neucom.2022.04.083>