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Specific Features & Distinctive Aspects of Mathematical Modeling Types in Computational Linguistics within the SHIVA and WARMI Philological Environment

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Abstract. *The article considers the main types of mathematical modeling used in modern machine linguistics in the conditions of uncertainty, turbulence and systemic risks of the SHIVA and WARMI worlds. Their features, advantages and areas of application in solving natural language processing problems are systematized. It is shown that the most promising direction is the use of hybrid mathematical models that combine methods of machine learning, artificial intelligence and mathematical optimization.*
Keywords: *machine linguistics; mathematical modeling; natural language processing; machine learning; artificial intelligence; neural networks; hybrid models; SHIVA-world; WARMI-concept.*

Introduction.

Modern machine linguistics is developing in the context of the rapid complication of the information space [1], the exponential growth of text data volumes, the global digitalization of communications and the active implementation of artificial intelligence technologies in almost all spheres of social activity. Against the background of the transition of the world economy and science from the VUCA concept to more complex models of the SHIVA and WARMI worlds, the external environment is characterized by high dynamics of change, uncertainty [2], nonlinearity of processes, systemic risks, high speed of emergence of new knowledge and the need for constant adaptation of intelligent technologies to new operating conditions. In such conditions, the importance of mathematical modeling as a universal tool for research, analysis, forecasting and automatic processing of all types of big data [3] (structured, semi-structured and unstructured = natural language) is increasing.

Modern machine linguistics has long gone beyond the boundaries of classical computer text analysis. Today it is an interdisciplinary field of knowledge that combines the achievements of applied mathematics, artificial intelligence, computational linguistics, mathematical statistics, probability theory, graph theory, information theory, optimization, evolutionary computing and deep learning. Solving the problems of automatic translation, analysis of the semantic content of texts, intelligent information search, natural language generation, knowledge acquisition and construction of large language models is impossible without the use of different classes of mathematical models.

It should be noted that there is no universal mathematical model that equally effectively solves all the problems of machine linguistics. Each group of problems requires the use of its own class of mathematical apparatus, which differs in the level of abstraction, computational complexity, interpretability of results, data requirements and resistance to uncertainty. That is why there is a need to systematize existing types of mathematical modeling, determine the features of their application, advantages, limitations and prospects for further development in the conditions of increasing complexity of the modern digital environment.

The purpose of the article is to systematize the main types of mathematical modeling used in modern machine linguistics, as well as analyze the features of their application in solving intellectual linguistic problems, especially in the conditions of the SHIVA and WARMI worlds.

The Main Part.

Mathematical modeling is the process of formalizing linguistic phenomena using mathematical constructs that allow describing, analyzing, predicting, and optimizing natural language processing processes. In modern machine linguistics, several main types of mathematical modeling can be named: statistical; probabilistic; algebraic; graph; network; optimization; evolutionary; simulation; agent; cognitive; neural network; hybrid. And each of the above classes of models is oriented towards solving a certain range of problems and has its own mathematical features.

1. Statistical modeling.

Statistical modeling is historically one of the first areas of machine linguistics. It is based on methods of mathematical statistics, analysis of frequency distributions, regression analysis, methods of parameter estimation and statistical inference [4]. Such models are widely used in the study of text corpora, the construction of frequency dictionaries, the determination of patterns of the use of linguistic units, the automatic classification of documents and the detection of statistical dependencies between linguistic objects. The main advantage of statistical models is the relative simplicity of implementation and high interpretability of the results. However, when working with multidimensional linguistic structures, their effectiveness gradually decreases due to the complexity of accounting for semantic relationships.

2. Probabilistic modeling.

Probabilistic models allow us to describe linguistic processes as random variables and random processes. The most famous representatives of this direction are Markov models, hidden Markov models, Bayesian networks and various probabilistic linguistic models. The probabilistic approach is especially effective in speech recognition, automatic morphological analysis, machine translation, word sequence prediction and assessment of natural language ambiguities. The advantage of such models is the possibility of quantitatively describing uncertainty, which is a natural characteristic of language processes.

3. Algebraic and logical-formal modeling.

This class of models is based on the use of the apparatus of mathematical logic, set algebra, formal grammars, automata, and formal language theory. Algebraic modeling is used in the construction of parsers, the formal description of grammatical constructions, modeling language rules, and the development of specialized programming languages. Despite the high degree of formalization, such models have limited flexibility in analyzing natural language, which is characterized by a large number of exceptions and contextual dependencies.

4. Graph modeling.

Modern machine linguistics is increasingly using the mathematical apparatus of graph theory. Linguistic objects are represented as nodes of a graph, and the relationships between them are represented as edges of various types. Graph models are used in the construction of semantic networks, ontologies, knowledge graphs, analysis of sentence dependencies, modeling social communications, and studying the structure of large text collections. This approach provides the ability to model complex nonlinear relationships between language units.

5. Optimization modeling.

When solving most problems in machine linguistics, there is a need to find the optimal solution among a huge number of possible options. That is why mathematical optimization occupies a special place. For these purposes, methods of linear and nonlinear programming, dynamic programming, combinatorial optimization, multi-criteria optimization, as well as various heuristic and meta-heuristic algorithms are used. Optimization models are used when choosing the most likely translation options, optimizing the architecture of language models, automatic text summarization, information retrieval, and intelligent decision-making.

6. Evolutionary modeling.

Evolutionary modeling methods are based on the principles of natural selection, inheritance, mutations, and breeding [5]. This group includes genetic algorithms, evolutionary strategies, genetic programming, differential evolution, and memetic algorithms. In machine linguistics, they are used in automatic grammar construction, selection of optimal features, optimization of neural network hyperparameters, search for the most efficient model architectures, and solving complex multi-criteria problems. Especially high efficiency of evolutionary modeling is manifested under conditions of high uncertainty, when classical algorithms become less stable.

7. Neural network modeling.

The current stage of development of machine linguistics is characterized by the dominance of deep neural networks. Transformer architectures, recurrent and

convolutional neural networks allow to automatically form multidimensional semantic representations of text, model contextual dependencies, and perform a wide range of intelligent language tasks. The advantages of neural network modeling include high accuracy of information processing, ability to self-learning, and the ability to work with extremely large data sets [6]. At the same time, such models are characterized by high computational complexity, significant requirements for training samples, and limited interpretability of internal decision-making mechanisms.

8. Hybrid mathematical modeling as a promising direction.

The practice of recent years shows that the greatest efficiency is demonstrated not by separate mathematical models, but by integration into unified intellectual systems. Modern language technologies increasingly combine probabilistic methods, graph models, neural networks, mathematical optimization methods, evolutionary algorithms and big data technologies. Such a synergistic approach allows us to simultaneously take into account statistical patterns, semantic relationships, the logical structure of language and the features of intelligent solution search. In the conditions of the SHIVA and WARMI world, it is hybrid mathematical modeling that becomes the most promising direction for the further development of machine linguistics. It provides higher stability of intellectual systems to uncertainty, incomplete data, rapid changes in the subject area and the emergence of new types of linguistic information.

Conclusions.

Modern machine linguistics is a high-tech interdisciplinary field of research, in which mathematical modeling acts as a fundamental methodological basis for intelligent processing of natural language. The complexity of the external environment, caused by the transition to the conditions of the SHIVA and WARMI world, significantly increases the requirements for adaptability, stability and intelligence of the applied mathematical models.

The systematization has shown that different types of mathematical modeling have different functional capabilities. Statistical and probabilistic models provide quantitative analysis of language patterns; algebraic models formalize the structure of language; graph models effectively describe complex semantic relationships; optimization and evolutionary methods allow finding rational solutions in multidimensional search spaces; neural network models provide the highest quality of intelligent text processing; hybrid models combine the advantages of different mathematical approaches and ensure maximum efficiency of modern intelligent linguistic systems.

Prospects for further research are related to the development of adaptive hybrid mathematical models of a new generation that integrate methods of artificial intelligence, evolutionary computing, mathematical optimization, graph technologies, probabilistic

modeling and cognitive analytics. Such intelligent models are able to ensure more effective functioning of machine linguistics systems in the conditions of increasing dynamics of uncertainty, turbulence and systemic risks of the modern digital environment.

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