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Machine Learning and Artificial Intelligence in the Works of V.A. Yakubovich

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Abstract—This note precedes the republication of the article 'Machine-Learning Pattern Recognition" by V.A. Yakubovich, which was first published by Leningrad University Press in the collection *Methods of Computation* in 1963.

Keywords: history of mathematics, machine learning, artificial intelligence

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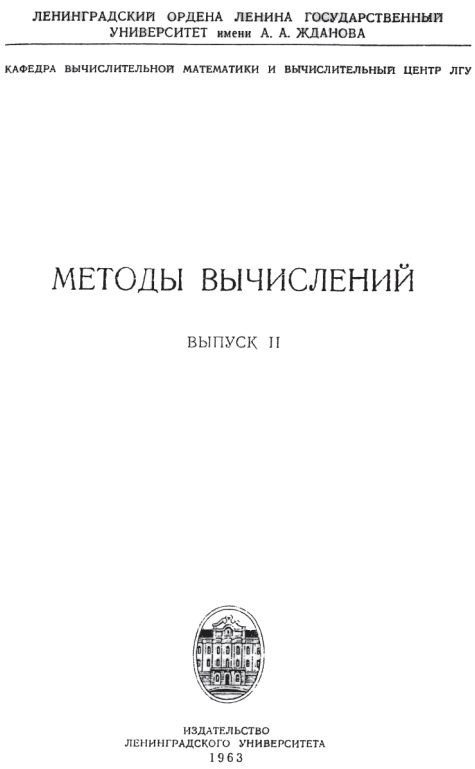
One of the first challenges that revealed a real need to construct artificial-intelligence systems was that of pattern recognition, which originated in the mid-20th century in the United States. The first answer to this challenge was the so-called "perceptron," which was proposed in 1957 by the U.S. scientist F. Rosenblatt. The key element of the perceptron was an algorithm to adjust the parameters (weights) of the functional converter that classifies input signals. Claimed to be a cybernetic model of the brain, the perceptron became the ancestor of modern artificial neural networks.

In 1963, Vladimir Andreevich Yakubovich, the founder of the Department of Theoretical Cybernetics at Leningrad State University (now St. Petersburg State University) and one of the founders of modern cybernetics, published an article [1] in the collection *Methods of Computation* published by the Leningrad University Press, where they provided the first rigorous mathematical formulations and results on learning machines to recognize patterns. In fact, it was the first mathematical work in the field of machine learning in the Soviet Union and Russia, ahead of the publications of the Moscow mathematicians V.N. Vapnik and A.Ya. Chervonenkis, who are considered two of the founders of machine-learning theory in the Soviet Union and in the world in general [2]. Paradoxically, the titles of Vapnik's 1973 [3] and Yakubovich's 1963 papers coincide! Later, Yakubovich published several more articles on this subject [4–6] and, then, suggested using learning (tuning, adaptation) algorithms as algorithms of regulator adaptation for controlling a priori unknown dynamic systems. This approach was developed at the Yakubovich's scientific school and led to the appearance in the 1960s of the first mathematical theory of adaptive control systems [7, 8]. Application of this theory leads to the construction of controllers the parameters of which are not calculated in advance according to the data of the plant known to the developer but are adjusted as the information about the plant's response to the control actions applied to its input is accumulated. On the basis of the new theory, a number of applied problems were solved [9–11].

Subsequently, the theory of learning and adaptive systems was extended to numerous problems of training and adaptation of automatic systems and became an important part of the scientific field of artificial intelligence in its modern sense. Its advantages include the fact that the algorithms developed within it, in addition to efficiency, are characterized by simplicity and ease of technical implementation. Currently, recognition systems are widely used (from the identification of a person by the photograph of their pupil to the automatic recognition of printed and handwritten texts). Artificial neural networks are actively used to solve complex problems in various branches of technology, in which a strict mathematical description is either very cumbersome or there is none at all. Machine learning based on artificial neural networks became the basis for a new wave of applications of artificial intelligence systems in many areas of science and technology, economics, medicine, etc. Adaptive systems are used to control aircraft, technological processes, robotic systems, etc. One of the first adaptive robots in the country and in the world was built at the Department of Theoretical Cybernetics of Leningrad State University under the guidance of Yakubovich back in 1974.


ЛЕНИНГРАДСКИЙ ОРДЕНА ЛЕНИНА ГОСУДАРСТВЕННЫЙ
УНИВЕРСИТЕТ имени А. А. ЖДАНОВА

КАФЕДРА ВЫЧИСЛИТЕЛЬНОЙ МАТЕМАТИКИ И ВЫЧИСЛИТЕЛЬНЫЙ ЦЕНТР ЛГУ

МЕТОДЫ ВЫЧИСЛЕНИЙ

ВЫПУСК II

ИЗДАТЕЛЬСТВО
ЛЕНИНГРАДСКОГО УНИВЕРСИТЕТА
1963

Fig. 1.

Yakubovich's 1963 article anticipated the development of a whole direction in the field of intelligent systems, which in recent years has become very important and popular. However, it has not only historical value. The author presented not only the mathematical formalism, which was new for that time, but also explained the methods of formalization: why in some cases the Hilbert space is considered and, in others, the Euclidean space, why the property of convexity of sets representing concepts is important, etc. These techniques are instructive and useful for modern researchers, while the mathematical results obtained in the article are little known today and deserve to be introduced into ~~mathematics~~. The peculiar authorial style of the classic of science is also interesting and instructive. Finally, the article discussed the recognition of not only visual and ~~auditory~~ images, which enjoyed much attention in studies of recent years, but also olfactory images, an area in which there are still very few mathematical works, and, in practice, the level of artificial intelligence systems is still far from that of service dogs.

This explains the importance of republishing Yakubovich's 1963 article in the Mathematical Archive section. It is also important to note that the theory of adaptive and intelligent systems, the foundations of which were laid out in this article presented to the readers of *Vestnik*, is being successfully developed at the Department of Theoretical Cybernetics of the St. Petersburg State University, at which articles, monographs, and textbooks have been published for many years [12–~~20~~].

The first part of the article by Yakubovich is published in this volume. The second part will be published in the next volume. The figures of the original article are preserved.

ADDITIONAL INFORMATION

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REFERENCES

1. V. A. Yakubovich, "Machines ~~that learn image~~ recognition," in ~~*Calculation Methods*~~ (Leningr. Gos. Univ., Leningrad, 1963), Vol. 11, pp. 95–131 [in Russian].
2. A. Ya. Chervonenkis, "Early history of support vector machines," in *Empirical Inference: Festschrift in Honor of Vladimir N. Vapnik* (Springer-Verlag, Berlin, 2013), pp. 13–20.
3. V. N. Vapnik, "Machines ~~that learn image~~ recognition," in ~~*Image*~~ *Recognition Learning Algorithms* (Sovetskoe Radio, Moscow, 1973), pp. 5–28 [in Russian].
4. V. A. Yakubovich, "Some general theoretical principles of the construction of trainable identification systems," in *Computer Engineering and Programming Issues* (Leningr. Gos. Univ., Leningrad, 1965), pp. 3–71 [in Russian].
5. V. A. Yakubovich, "Recurrent finitely convergent algorithms for solving systems of inequalities," Dokl. Akad. Nauk SSSR **166**, 1308–1312 (1966).
6. V. A. Yakubovich, "On some general principles of construction of learning identification systems," in *Self-Learning Automatic Systems* (Nauka, Moscow, 1966) [in Russian].
7. V. A. Yakubovich, "~~To the theory~~ of adaptive systems," Dokl. Akad. Nauk SSSR **182**, 518–522 (1968).
8. V. A. Yakubovich, "Adaptive systems with multistep ~~target~~ conditions," Dokl. Akad. Nauk SSSR **183**, 303–306 (1968).
9. B. N. Kozinets, R. M. Lantsman, and V. A. Yakubovich, "Forensic examination of close ~~handwriting~~ using electronic computers," Dokl. Akad. Nauk SSSR **167**, 1008–1011 (1966).
10. A. Kh. Gelig and V. A. Yakubovich, "Application of a trained recognition system to isolate a signal from noise," in *Computer Engineering and Cybernetics Issues* (Leningr. Gos. Univ., Leningrad, 1968), Vol. 5, 95–100 [in Russian].
11. V. A. Yakubovich, "On certain problem of self-learning expedient behaviour," Autom. Remote Control **30**, 1292–1310 (1969).
12. V. N. Fomin and V. A. Yakubovich, "Trainable recognition systems and recurrent finite-converging algorithms," in *Image Recognition Learning Algorithms* (Sovetskoe Radio, Moscow, 1973), pp. 29–42 [in Russian].
13. V. N. Fomin, *Mathematical Theory of Trainable Identification Systems* (Leningr. Gos. Univ., Leningrad, 1976) [in Russian].
14. S. V. Gusev, A. V. Timofeev, and V. A. Yakubovich, "Adaptation in robotic systems with artificial intelligence," in *Proc. 7th All-Union Meeting on Control Problems, Minsk, 1977* (NII NTI, Minsk, 1977), pp. 279–282.
15. B. A. Belenkov, S. V. Gusev, Yu. K. Zotov, V. I. Ruzhanskii, A. V. Timofeev, R. B. Frolov, and V. A. Yakubovich, "Adaptive control system for an autonomous mobile robot," Izv. Akad. Nauk SSSR, Teor. Sist. Upr., No. 6, 52–63 (1978).
16. V. N. Fomin, A. L. Fradkov, and V. A. Yakubovich, *Adaptive Control of Dynamic Objects* (Nauka, Moscow, 1981) [in Russian].
17. A. Kh. Gelig, *Dynamics of Impulse Systems and Neural Networks* (Leningr. Gos. Univ., Leningrad, 1982) [in Russian].
18. V. A. Bondarko, "Adaptive suboptimal systems with a variable dimension of the vector of adjustable parameters," Autom. Remote Control **67**, 1732–1751 (2006). https://doi.org/10.1134/S0005117906110026
19. A. Kh. Gelig and S. K. Matveev, *Introduction to the Mathematical Theory of Trainable Recognition Systems and Neural Networks* (S.-Peterb. Gos. Univ., St. Petersburg, 2014) [in Russian].
20. S. A. Plotnikov, D. M. Semenov, M. Lipkovich, and A. L. Fradkov, "Artificial intelligence-based neurofeedback," Cybern. Phys. **8**, 287–291 (2019).
21. A. L. Fradkov, "Early history of machine learning," IFAC-PapersOnLine **53**, 1385–1390 (2020). https://doi.org/10.1016/j.ifacol.2020.12.1888

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