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ARTIFICIAL INTELLIGENCE AND ARTIFICIAL NEURAL NETWORKS IN HEALTHCARE

Pavel Ignatiev, Anastasia Levina ✉

Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia

✉ alyovina@gmail.com

Abstract. The healthcare industry makes one of the main components of the productive forces of the state. Therefore, the well-being and welfare of the entire society in the future depend on its thriving development. Despite significant accumulated knowledge in medicine, there are still some white spots that are difficult to analyze and predict. The use of artificial intelligence and neural networks in healthcare can significantly expand the analytical apparatus and radically change the existing approaches to scientific research. This article discusses the results of the practical application of artificial intelligence and artificial neural networks in healthcare. The research aims to demonstrate the prospects and advantages of using these information technologies in medicine; identify problems in the implementation of AI technologies in medical practice and offer possible solutions to some of them. The authors provide a comprehensive literature review on the issues of artificial intelligence and neural networks, consider successful examples of the AI use in pharmacology, forecasting, and research of various types of diseases, including cardiovascular system, dermatology, and oncology. A significant part of the research is devoted to ethical and legal concerns, as well as problems associated with the practical use of artificial intelligence. As a result of the research, the authors suggest the models of the IT architecture of a medical information system and data flows, based on the TOGAF standard.

Keywords: healthcare, artificial intelligence, artificial neural networks, diagnosis and prediction, TOGAF standard, medical information system

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ИСКУССТВЕННЫЙ ИНТЕЛЛЕКТ И ИСКУССТВЕННЫЕ НЕЙРОННЫЕ СЕТИ В СФЕРЕ ЗДРАВООХРАНЕНИЯ

Павел Игнатьев, Анастасия Лёвина ✉

Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия

✉ alyovina@gmail.com

Аннотация. Отрасль здравоохранения является одной из главных составных частей производительных сил государства, поэтому от её развития зависит благополучие и благосостояние всего общества в будущем. Несмотря на значительный пласт накопленных знаний в области медицины, существуют трудно анализируемые и трудно прогнозируемые области. Применение искусственного интеллекта и нейронных сетей в здравоохранении способно существенно расширить аналитический аппарат и коренным образом изменить существующие подходы к научным исследованиям. В статье рассматриваются результаты практического применения искусственного интеллекта и искусственных нейронных сетей в сфере здравоохранения. Цель исследования – показать перспективы и преимущества использования данных информационных технологий в медицине, выявить проблемы при внедрении технологий искусственного интеллекта в медицинскую практику и предложить возможные варианты решения части этих проблем. В статье приведен обзор литературы по проблематике искусственного интеллекта и нейронных сетей, рассматрены примеры успешного применения искусственного интеллекта и нейронных сетей в фармакологии, прогнозировании и исследовании разных типов заболеваний: сердечно-сосудистой системы, дерматологии, онкологии. Вторая часть исследования посвящена этико-правовым аспектам и проблемам практического использования искусственного интеллекта. В качестве основных результатов исследования представлены разработанные в соответствии со стандартом TOGAF модели IT-архитектуры медицинской информационной системы и потоков данных.

Ключевые слова: здравоохранение, искусственный интеллект, искусственные нейронные сети, диагностика и прогнозирование заболеваний, стандарт TOGAF, медицинская информационная система

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Introduction

The healthcare industry is actively developing thanks to the introduction of modern IT solutions. For instance, telemedicine has made it possible to receive high-quality medical counselling in remote regions; modern computer screening techniques now allow detecting and treating rare and severe diseases at early stages. The application of computer technologies facilitates creation of medication with unique pharmacological properties and significantly reduces the cost of their development. Accordingly, these developments make drugs more available for the population.

Currently, many positive trends can be specified: higher life expectancy, better quality of health care, and medical services provided to the population. At the same time, new challenges that require up-to-date approaches arise. A possible response to this demand is the introduction of artificial intelligence (AI) and artificial neural networks (ANN) as basic tools of the support system and medical decision-making. The AI and ANN are expected to transform information according to the emerging requirements. In order to do so, the neural network is trained using a special algorithm, which shapes connections of individual neurons and modifies them, so that the final output signal corresponded to the desired command. Thus, the task of these technologies is reduced to finding solutions to certain problems, especially when the user is not fully aware of the internal processes involved.

This article reviews the results of a wide range of studies on the application of AI and ANN in several areas of healthcare and highlights the associated challenges faced by healthcare professionals in the use of these technologies. Recognizing these challenges can enable the community to direct intended effort in the attempt to overcome prospective obstacles. When considered from such an ambitious perspective, artificial intelligence and neural networks can make a win-win tool for the medical and scientific community to use.

Materials and Methods

The main method used in this research is literature review and analysis of scientific studies published in Web of Science, ResearchGate, and PubMed. Most of the examined papers were written in the period from 2013 to 2023 by foreign specialists from Spain and Turkey. Domestic studies on the IT technologies in healthcare were also analyzed.

Based on the literature review and assessment, the authors identified the main implementation prospects of neural networks and artificial intelligence. The graph by Nature in 2020 depicts an increase in the overall interest in these types of digital technologies in the medical industry. According to the results, the 2014-2019 period has seen an almost eightfold increase in the number of publications in the electronic medical library PubMed on the application of artificial intelligence and neural networks in medicine.

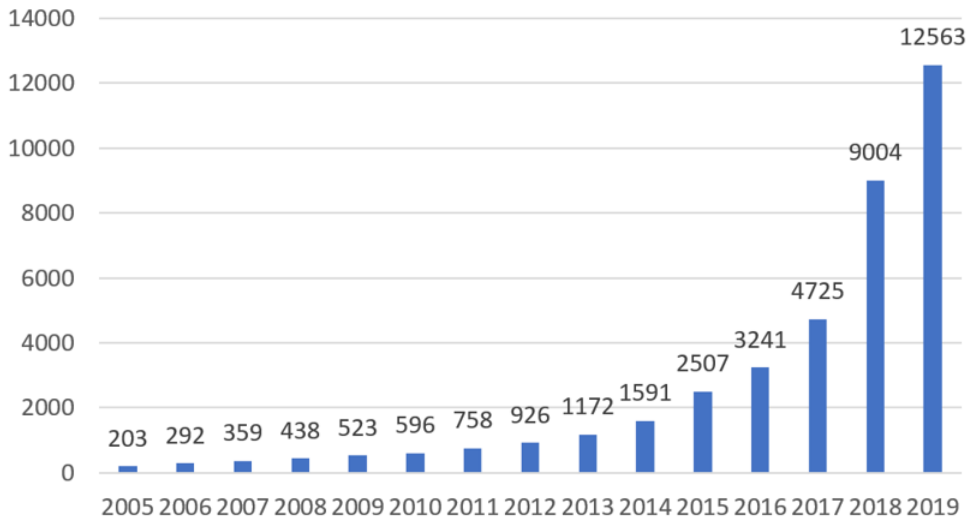

Fig. 1. Number of published AI studies.

This exponential growth in the number of studies is usually associated with the gradual mastering of technologies and, accordingly, with the expansion of the overall agenda. However, what is the reason for such excitement around artificial intelligence and its derivative tools? For many non-professional users, artificial intelligence is just a toy that can generate text of varied reliability, process images, and answer questions. Such a superficial attitude provokes a number of questions. Should AI and ANN technologies be taken seriously? Are AI and ANN the cutting-edge technologies of the future that will shape the basis of many business processes? Should companies reorganize themselves now to apply AI and ANN? This research aims to answer these questions based on the specifics of the medical industry.

A widespread expansion of artificial intelligence originates from a number of reasons:

1. The development of computer technology, in particular computer GPUs, has made it possible to obtain relatively cheap computing power, which AI and ANN calculations are based on.

2. AI is an effective tool for big data processing. Every day a large amount of both structured and unstructured data is generated and used for further analysis and management decision-making. AI makes it possible to process data at high speed, identify hidden patterns, and draw predictions.

3. AI and ANN automate many business processes that used to require direct human participation. For example, speech or image recognition.

4. AI and ANN are actively used in fundamental scientific research. ANN as an analytical tool is already showing significant results in many scientific fields. Medicine and biology make no exception.

5. The models and principles involved in the performance of AI and ANN are multifunctional and can be applied in many areas.

In the medical industry, AI's ability to analyze a large stream of data and draw logical conclusions is particularly relevant. AI can be used as a system to support medical decision-making when deciding on difficult diagnoses or predicting the course of chronic diseases. When considering the healthcare, it is impossible to neglect other related scientific areas of fundamental knowledge. AI is actively used in the development of new medications, including ones for different types of cancer; electronic histology; cytology; genetics.

In the domestic studies, one of the most fundamental research on neural networks in medicine was carried out by N.V. Ivanov (Ivanov, 2018). The author describes the basic structure of neural networks, their principles, and existing training algorithms. What is more, N.V. Ivanov specifies the advantages and disadvantages of using neural networks. Here is the range of the emphasized advantages:

1. The possibility of solving problems with implicit or unknown regularities. Traditional mathematical and analytical methods are unsuitable for analyzing this type of data.

2. Resistance of algorithms to noise in the input data – the ability to work with uninformative noisy incoming signals by screening them automatically in the course of the algorithm.

3. Adaptability of models to changes in the external environment. Neural network algorithms can be sufficiently adaptive to changes in the analyzed signals in time. In addition, neural networks are retrained on the go in real time.

4. Potential fast performance and fault tolerance.

N.V. Ivanov also groups many factors as disadvantages:

1. Neural networks require a significant dataset for successful training and operation.

2. Creating neural networks is a labour-intensive and time-consuming process.

3. Possible mathematical errors in the model, including inaccurate definition of local extrema, excessive growth of weight coefficients at the sigmoidal character of the transfer function of the neuron, unsuccessful choice of the input variables.

4. Neural network problem solving is not explicit for the user, as transformations inside the hidden layers of the network occur covertly.

5. The data should be similar to those that the network was originally trained on. Otherwise, the predicted values may be inaccurate.

The research by Filippo A. and co-authors (Filippo, 2013) is dedicated to the application of ANN in diagnostics. The researchers consider the main directions of diagnostics of various diseases, where ANNs show highly reliable results.

In the cardiovascular diagnosis, the best results were shown with the ANN for non-invasive detection of coronary heart disease. Based on cholesterol, patient's age, and arterial hypertension, the neural algorithm produced a diagnosis with the 91.2% accuracy.

At the same time, the neural network was able to recognize the most frequent risk factors for the disease (Karabulut, 2013). In addition to coronary heart disease, neural networks can detect heart rhythm disorders. In his work, H. Uguz (Uguz, 2013), describes the application of neural networks in analysis of audio recordings of heartbeats. The results obtained show 99% accuracy in recognizing sounds, which is significantly higher than standard stethoscopy.

The application of neural networks in the diagnostics of oncological diseases has shown significant efficiency as well. Every year more than 300 000 people die of cancer in Russia, so the speed of analysis and its accuracy play a vital role in diagnosing cancer at early stages. The first neural networks capable of determining the type of cancer appeared in the late 1990s. Since then, approaches to cancer cell screening have been significantly improved. One of the promising methods of cancer detection is microwave radiothermometry, which allows detecting temperature deviations in the affected areas. The most important disadvantage of the method is the imperfections of human interpretation of the obtained results.

The work of A.G. Losev and D.A. Medvedev (Losev, 2019) focuses on the application of ANN as an analytical tool and decision support method for diagnosing breast cancer by radiothermometry. According to the results, the neural network developed by the authors gives a correct, and most importantly, fast result with a probability of more than 84%.

Similar results were shown in the work by A. Tate. The neural network was trained to recognize different types of ovarian cancer by analyzing the results obtained from a mass spectrometer. The accuracy of 96% significantly outperforms classical statistical methods of cancer typing, such as Student's t-test. D. Brougham (Brougham, 2011) and the team of researchers applied the neural network developed by A. Tate to process the results of lung MRI. The achieved accuracy of 100% in classifying lung adenocarcinomas indicates a high degree of applicability of the A. Tate's neural network. Thus, the joint efforts of several research groups have proved that the same neural network can be used to analyze different forms of tumours.

The next important area of diagnosis is diabetes. According to statistics, by the end of 2021, more than 5 million people suffering from various types of diabetes had been recorded in Russia. The type 2 diabetes is the most common. In this type the response of cells to insulin is disturbed, leading to impaired tissue homeostasis and hyperglycemia. At the moment it is not so difficult to recognize diabetes. It is detected by the level of glucose in the blood and the test can be taken in an ordinary district clinic or with a simple glucometer. Nevertheless, since diabetes is accompanied by many associated complications, it is necessary to anticipate patients' conditions based on their medical records and regularly updated blood tests.

In their study, A.G. Trofimov et al. consider the application of self-learning neural networks in determining the dosage of glucose in patients with type 1 diabetes mellitus. Continuous glucose measurement systems were used, as well as insulin pumps that administer subcutaneous insulin automatically when necessary. The models of the glucose control system are based on the mechanism of glucose processing by body cells under the action of insulin. Since analyzing this mechanism is rather complex, parameters are normally estimated individually for each patient, which significantly reduces the accuracy of predictions. The neural network developed by the authors allows for a mathematical evaluation of glucose processing. The results obtained show high accuracy of the predicted values. Similar studies were conducted by other authors, including Klimonotov V. (Klimonov, 2021).

ANN algorithms are also employed in prediction of diseases associated with diabetes mellitus. S. Safarova (Safarova, 2023) described an ANN predicting bone metabolism in diabetes. As input data for the neural network she used sex, age, and duration of the condition. The output data were represented by variables reflecting the state of bone metabolism: bone mineral density and markers of bone remodeling. The developed system predicted the correct development of reparative osteogenesis with a probability of 92.86%. In his turn, E. Dobrov (Dobrov, 2022) describes the use of ANN for the diagnosis of diabetic retinopathy.

In addition to the conditions described above, ANNs are used in the diagnostics of many other diseases:

1. Ophthalmologic diseases;
2. Skin autoimmune diseases. The TzanckNet neural network developed by American scientists diagnoses diseases based on smear images with 94.3% accuracy;
3. Skin cancer. A neural network developed by American researchers from Stanford University is able to predict skin cancer with 72% probability based on images, which is 6% higher than the conclusion of dermatologists based on empirical data.
4. Skin rash. The AI Skin mobile app uses a neural network to analyze skin rashes from a photograph, followed by a preliminary diagnosis.
5. Respiratory diseases. The mobile application “AI Resp” can analyze a person's breathing patterns and detect respiratory diseases.

Many studies are devoted to the specific practical application of artificial neural networks in medicine. The work by Y.A. Sergeev, E.A. Sterleva, and D.A. Niazian (Sergeev, 2021) provides a description of a three-layer recurrent neural network capable of predicting pathologies of therapeutic profile.

Diagnostics of diseases is not the only medical area for AI and ANNs to be actively used. ANNs make a serious contribution to pharmacology in the development of new medication. The main methods for searching for pharmacologically active compounds today are virtual screening methods and classification and regression algorithms. The application of artificial neural networks is a fundamentally new but no less effective method. Since 2021, many approaches have been developed to produce new drugs and repurpose existing ones using artificial intelligence methods. Artificial neural networks are used to guide the search for new compounds with the desired type of pharmacological activity while achieving significantly higher accuracy.

There are three main areas in pharmacology for the neural networks to be applied:

1. Predicting which medication has better qualities to reverse the negative effects of a disease;
2. Creation of new molecules;
3. Predicting the chemical properties of compounds: absorption, distribution, metabolism.

One of the brightest examples of an already finished product used in practical pharmaceutics is the “AlphaFold2” system. An aggregate of various neural networks, “AlphaFold2,” predicts the three-dimensional structure of a protein based on the primary sequence of amino acids. The Skolkovo Institute project “BiteNet” uses deep learning and machine vision algorithms to analyze proteins and identify potential drug targets.

The most striking result was achieved by Insilico Medicine, a Chinese pharmaceutical company, which developed a compound to treat idiopathic pulmonary fibrosis using AI. The main tool was a platform of three digital systems with AI tools: PandaOmics for data analysis, Chemistry42 for molecular design, and InClinico's clinical trial prediction engine. The system based on AI tools reduced the drug development period to 18 months and reduced costs by 170 times.

At the moment, the Russian Federation is a leader in the development and implementation of artificial intelligence systems in healthcare, with about 16% of medical institutions using AI.

Unfortunately, it is still difficult to talk about a full-fledged transition of healthcare. The largest test region is Moscow, where the following technologies are used: artificial vision to analyze medical images (CT, MRI, X-rays, mammograms); a support system for medical decision-making and selection of a diagnosis in accordance with anamnesis (SPPVR); a chatbot to collect complaints before a doctor's examination; and AI analysis of echocardiogram results.

Based on the results of the implementation of AI tools in medicine, the significant benefits that AI tools provide can not be neglected. Artificial intelligence helps to reduce the burden on medical staff and expand opportunities of basic medical research. Nevertheless, at the current stage of development, a number of serious barriers arises. In this paper we will try to touch upon a part of them. First of all, the application of AI in medicine raises ethical issues. Who will be held responsible in case of misleading forecasts that harm a patient? According to Federal Law No. 2129-p from 19.08.2020, by 2024 a program should be developed to define ethical rules for the development, implementation, and use of AI in healthcare in accordance with the human-centred approach. Now, however, more attention is paid to the material side of the technology.

An equally important problem is the issue of trust in neural networks, both on the part of doctors/patients and private investors, who are reluctant to invest in their design and development due to the lack of substantial evidence of clinical efficacy.

The third challenge is the quality and quantity of data. Quality training of neural networks requires data with a high degree of purification from noise, so before training networks, it is necessary to first collect a dataset, which is not always fast.

The next barriers are related to the challenges of the architecture layer of healthcare provider applications. Most medical institutions have already automated their business processes, so integrating AI without the ability to scale to the entire healthcare system will be very difficult, especially if the architecture of medical information systems is designed as a monolith rather than a set of microservices.

The final challenge is the computing power required to run artificial intelligence. Most of the computing equipment used in medical institutions does not meet the minimum requirements for even the simplest computations.

Structurally, a neural network consists of an input layer, which receives primary signals (in disease diagnosis – the parameters under study), one or more hidden layers, and an output layer (results). Figure 2 schematically depicts an example of a neural network in the form of a black box with hidden layers, taking into account the inputs and outputs of medical information.

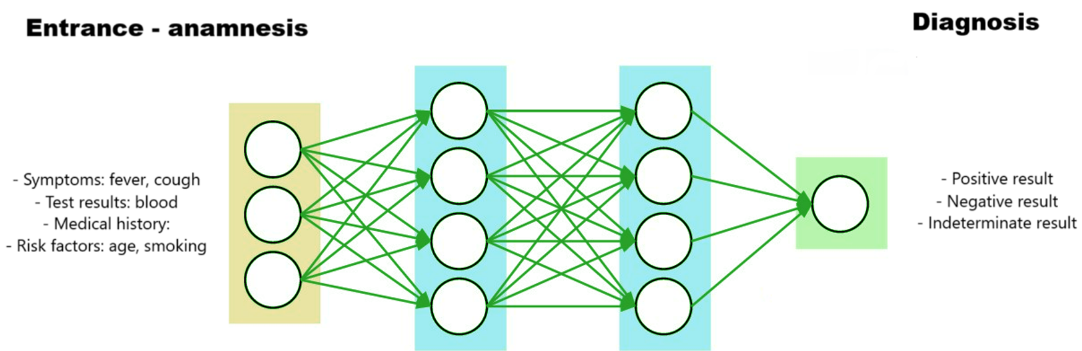

Fig. 2. Inputs and outputs of a medical ANN.

In order to ensure training and further work in the neural network, it is necessary to create a database. The classical format of the database is the relational form, which allows the neural network to unload data in the form of a matrix. However, for a number of ANNs it is more preferable to use document-oriented databases. If a single-table database is used, normality violations are possible, but otherwise the issue of data demoralization or the use of additional DBMS functions may arise, increasing the ANN's running time and efficiency. For more complex ANNs, the database may have a different structural form, such as a classical snowflake. Figure 3 shows the data table for one of the simplest forms of neural networks—perceptron, capable of determining the presence of coronary heart disease. This neural network outputs only 2 values as a result: positive and negative.

coronary heart disease	
Patient ID	*Int4*
Age	*Int4*
Cholesterol levels	*Int4*
Arterial hypertension	*Bool*
Maximum blood pressure	*Int4*
Minimum blood pressure	*Int4*

Fig. 3. Database for perceptron neural network operation.

In practice, all data come from different sources. Inorder to collect the necessary information about a patient, it is necessary to perform a complex query combining data from several databases and tables. In practice, the process of combining data from different databases can be complicated by many factors: data incompatibility (differences in syntax), data inconsistency, lack of access to a particular database, database dependencies, etc. Thus, when applying neural networks in medical organizations, it is important to consider the current architecture, database compatibility, and so on.

The architecture of a medical organization has a complex structure and can vary greatly depending on the type of medical institution (hospital/state clinic/private clinic). In this regard the creation of a typical architecture of a medical organization is possible using the TOGAF design standard. The Content Framework component of the TOGAF standard acts as the basis for representing the architecture of a medical organization. According to the framework, the representation consists of five related architectures or perspectives. The business perspective includes three types of business processes: core, supporting, and management processes. The information layer also includes the information flow diagram, reflecting the information architecture. The technology layer combines data architecture and process architecture, reflecting the flows between different databases.

In their nature, neural networks are information systems, so it is reasonable to consider their design within the framework of IS and data architecture, paying attention to the technological architecture. As mentioned earlier, a medical organization has a complex architecture due to its purpose, but the medical information system (MIS) is used as the basis of the information system. Thus, most of the information infrastructure and service architecture is built around it. Figure 4 shows the recommended structure of the future mMIS developed by the specialists of the Pirogov National Medical and Surgical Centre.

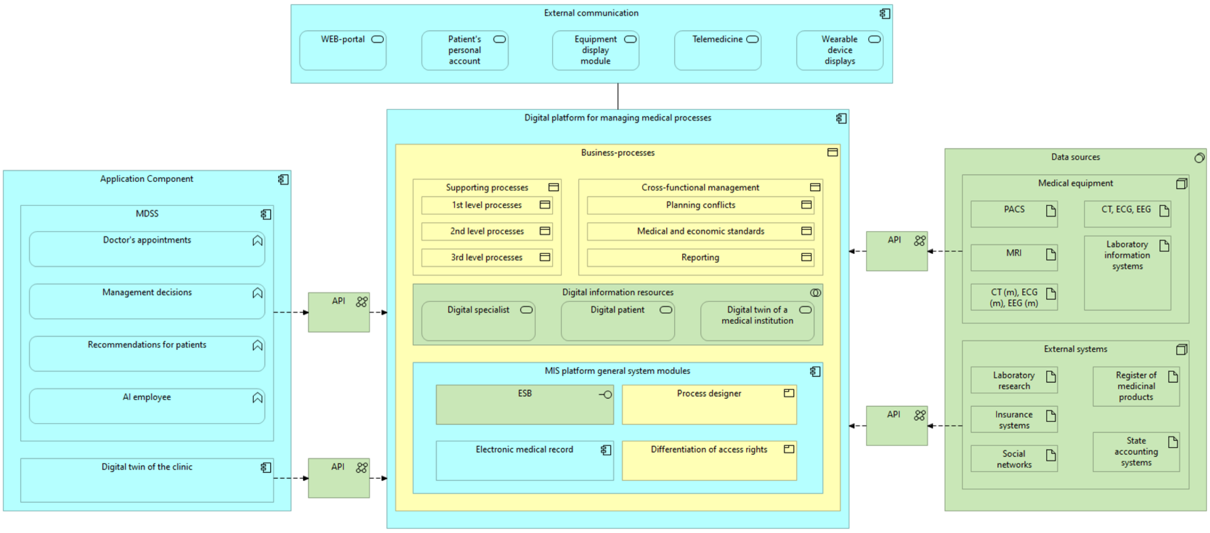

Fig. 4. Recommended MIS architecture.

The considered model of the future MIS structure is still imperfect at the moment, but it largely explains the architecture of MIS as an electronic system. According to Figure 4, AI tools make part of the interface of smart clinic applications and often perform the functions of a medical decision support system. Therefore, they can be implemented as a service or program. Many medical applications used in practical medicine have already been developed, including TzanckNet, AI Skin or AI Resp. Nevertheless, quite often, ANNs are presented as a program code in one of the programming languages. Interaction with the core of the MIS is implemented through APIs. In order to ensure full understanding of data exchange between ANN and MIS core, it is necessary to take into account the peculiarities of data architecture of each medical institution. For example, if all data are stored on one server and managed by one DBMS, then HTTP/HTTPS data protocols are used for data exchange between MIS databases and ANN service databases; data are freely moved in XML or JSON format. This format of data architecture organization significantly reduces data integrity errors and simplifies data access.

Results and Discussion

The introduction of artificial intelligence and neural networks into medical organizations is associated with a number of both legal and ethical concerns, as well as integration problems related to the peculiarities of the architecture of IS and data structure. Inspite of the fact that it is not possible to directly influence the laws, we can still figure out the constraints that medical information systems impose. Figure 5 shows the IT architecture of a medical organization that the authors have developed in accordance with the TOGAF standard.

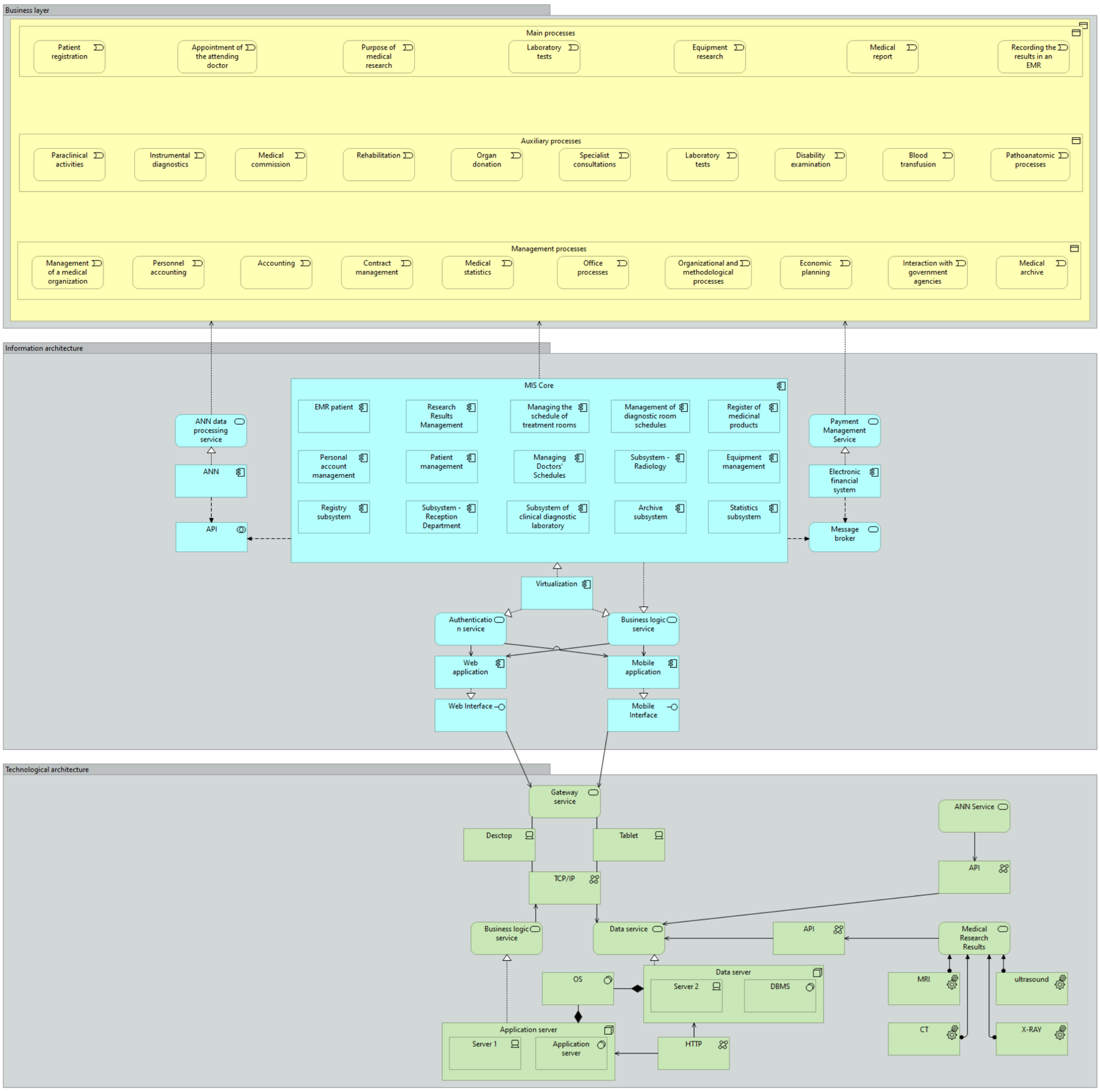

Fig. 5. IT architecture of a medical organization in accordance with the TOGAF standard.

The presented model is simple enough, however, it gives a general idea of how the investigated technologies can be realized as services. For a more detailed representation of data flows, Figure 6 depicts a more comprehensive data architecture model.

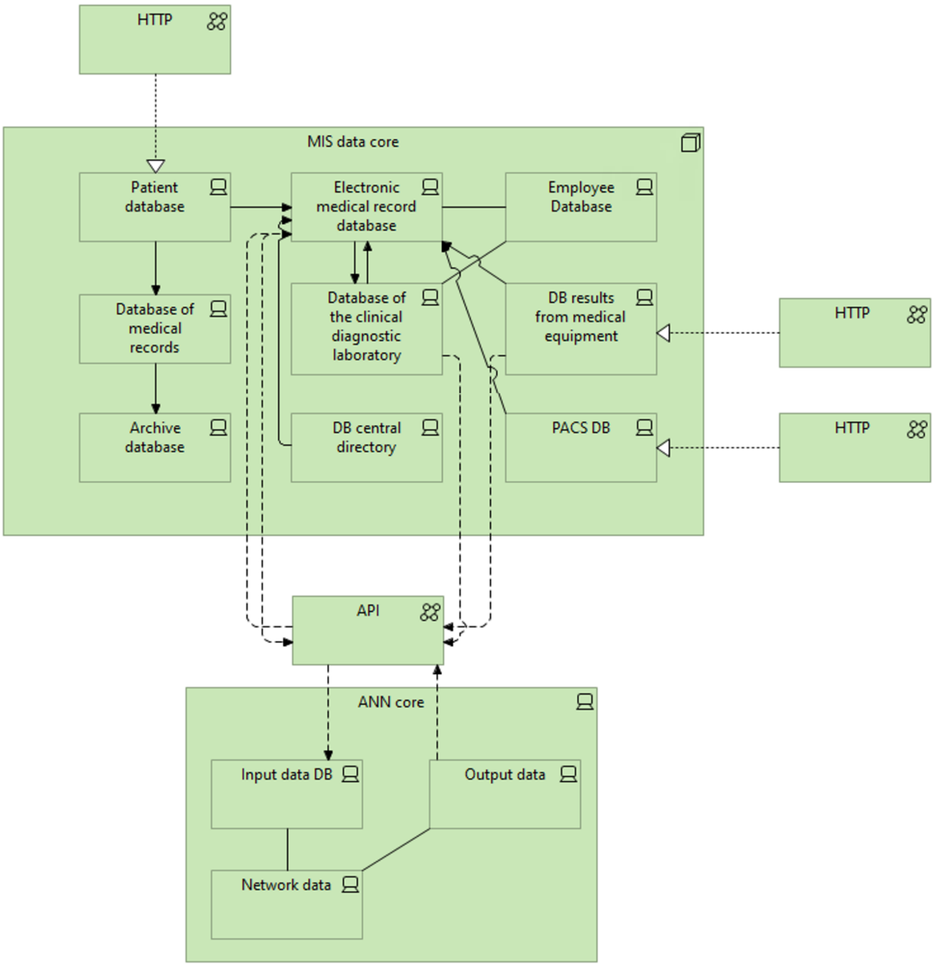

Fig. 6. IT architecture of a medical organization.

The developed model of data flows is more theoretical, as it strongly depends on the service architecture of the medical organization and the used MIS. However, at this stage even, it can be seen that it is necessary to build logical models and prepare the information infrastructure of the enterprise in advance in order to ensure a whole scale implementation of AI and ANNs.

Conclusion

Having studied a number of sources reviewed in this article, it is possible to state that artificial intelligence and neural networks represent serious tools in the development of healthcare. Due to the versatility of neural network algorithms and artificial intelligence tools, these technologies can be actively employed in various areas of healthcare, thereby expanding the instrumental and technological apparatus of doctors and researchers.

AI and ANNs allow doctors to recognize tumours at early stages and to determine the development of complex and predictable diseases with a high degree of reliability. For example, most networks have the capacity to identify heart rhythm abnormalities and ischemic heart disease with more than 90% accuracy. In its turn, breast cancer is detected with a 84% accuracy. Machine vision is actively used in medicine, which has already gone beyond doctors' offices and research centres. Thanks to enthusiastic scientists, startups such as “AI Skin” already allow ordinary users to get preliminary results of skin diseases before a doctor's appointment.

Overall, AI technologies have the potential to significantly broaden the horizons of medicine, genetics, psychology, and pharmaceuticals while reducing both costs and time to achieve the desired result. However, this mission makes no easy task. In order to integrate AI and ANN into healthcare processes, many challenges need to be addressed, including: ethical concerns and compatibility issues between AI-based applications and existing electronic health systems.

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INFORMATION ABOUT AUTHORS / ИНФОРМАЦИЯ ОБ АВТОРАХ

IGNATIEV Pavel K. – student.
E-mail: Poalignatiew@gmail.com
ИГНАТЬЕВ Павел Константинович – студент.
E-mail: Poalignatiew@gmail.com

LEVINA Anastasia I. – Professor, Doctor of Economic Sciences
E-mail: alyovina@gmail.com
ЛЁВИНА Анастасия Ивановна – профессор, д.э.н.
E-mail: alyovina@gmail.com
ORCID: https://orcid.org/0000-0002-4822-6768

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