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# A System for Classification of Technologies in the Field of Artificial Intelligence for Personnel Forecasting

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**Abstract.** The development of the Russian economy, including through large-scale introduction of digital technology and artificial intelligence technology, requires appropriate resources. Qualified personnel is one of them. The need for trained specialists poses important questions to state institutions – whom to train and in what quantity; this, in turn, demands a detailed elaboration on the issue of staffing requirement. The article presents the results of development of a classification system of artificial intelligence technology for solving personnel forecasting problems. Theoretical significance of the research findings consists in the creation of a classification system that structures existing knowledge about technologies in the field of artificial intelligence and has the potential to gain new knowledge. The novelty of the approach to the classification of artificial intelligence technologies consists in using a three-component structure of technologies "methods – tools – application areas" and adjusting the classification to suit the tasks of forecasting the demand of the economy for personnel with competencies in the field of artificial intelligence. The classification is based on the results of analysis of scientific publications on AI (journals of the first quartile Q1 and conferences of the A/A* level). "The Systematic Literature Review" method was used for their research. All thematic publications indexed in Scopus were also analyzed. Practical significance of the results is revealed in relation to the tasks of personnel forecasting in the field of artificial intelligence. The developed classification makes it possible to structure the personnel need at different levels of refinement of artificial intelligence technologies. Another direction in the development of the proposed classification is to compare competencies (knowledge, skills and practical experience) in popular groups of professions with components of artificial intelligence technologies (methods, tools, applications) to design educational programs in the relevant field. The proposed classification has the potential for development: one of the ways is an expert assessment of priority areas for the development of artificial intelligence. The article presents an overview of the results of application of the classification.

**Key words:** digital economy, staffing requirement, forecasting, artificial intelligence, technologies, classification, frontiers.

## Introduction

The last few years have given a start to the accelerated introduction of artificial intelligence (AI) technologies in all areas of the Russian economy. The most important strategic documents[1] declaring the goals, main directions and tasks[2], as well as the mechanisms of implementation of the RF state policy in the field of artificial intelligence[3] development were adopted. Large-scale projects are being implemented to train personnel with AI competences: the federal project "Personnel for the digital economy"[4], the creation of NTI Competence Centers[5], and an alliance of the largest Russian companies founded to develop artificial intelligence[6]. In 2021, six AI research centers were created on the basis of the Higher School of Economics, Skoltech, Innopolis University, Ivannikov Institute for System Programming of the

[1] "On the development of artificial intelligence in the Russian Federation": RF Presidential Decree 490, dated October 10, 2019. Available at: https://www.garant.ru/products/ipo/prime/doc/72738946/ (accessed: March 1, 2022).

[2] List of instructions on the results of the conference on artificial intelligence Pr-2242, dated December 31, 2020. Available at: http://www.kremlin.ru/acts/assignments/orders/64859 (accessed: March 1, 2022).

[3] The passport of the federal project "Artificial intelligence" of the national program "Digital economy of the Russian Federation". Available at: https://ac.gov.ru/uploads/_Projects/AI_otbor/Passport.pdf (accessed: March 1, 2022).

[4] Personnel for digital economy. Available at: https://digitalskills.center/ (accessed March 1, 2022).

[5] NTI Competence Centers. *National Technology Initiative*. Available at: https://nti2035.ru/technology/competence (accessed: March 1, 2022).

[6] Forbes.ru. Available at: https://www.forbes.ru/newsroom/tehnologii/387055-v-rossii-sozdali-alyans-po-razvitiyu-iskusstvennogo-intellekta (accessed: March 1, 2022).

RAS, ITMO University, and MIPT[7]. In May 2022, the National Ethics Commission in the field of AI[8] was established.

To manage the process of accelerated technological development of the Russian Federation in the field of AI, in accordance with the Presidential Decree "On the development of artificial intelligence in the Russian Federation"[9], state institutions require current and projected indicators of staffing needs in the medium and long term, including knowledge of the current number of personnel employed in the economy and having competencies in the field of AI, as well as the required amount of specialists. Calculation of such indicators defines a practical problem, the solution of which is necessary for Russia's transition to the digital economy.

At the same time, there is an open scientific problem, namely the lack of a clear structure of AI technologies, which would regulate the relationship of technology with professions in the economy and training programs/specialties. When detailing forecast indicators, it is necessary to have a structural model of technologies in the field of AI to highlight frontiers (promising sub-technologies), as well as methods and tools for the formation of competencies in the training of specialists. Existing systems of classification of AI technologies, including international ones, are insufficient to distinguish development frontiers based on the assessment of the potential for this development.

The identified problem is accompanied by other contradictions. Thus, when developing federal state educational standards (FSES) for the new educational specialties of AI from the All-Russian Classifier of Specialties (OKSO) – 2022 it is necessary to specify the relevant technology areas, and for the basic professional educational program of higher education (BPEP) – the relationship of graduate competencies with the technology areas. When developing professional standards for artificial intelligence professions, it is necessary to specify the technology areas for which these professional standards are created.

The posed practical problem of calculating the indicators of staffing requirements in the field of AI necessitates the solution of a scientific problem to develop a new system of classification of AI technologies. The aim of the scientific research presented in this article is to form a science-based approach to the development of a classification system of AI technologies, providing a solution to the problems of personnel forecasting in the transition to the digital economy. The object of the study is the field of artificial intelligence, the subject of the study is the structural components of artificial intelligence technologies. To achieve the goal, it is necessary to solve the following tasks.

1. Analysis of existing approaches to the classification of AI technologies in order to identify problem areas that do not allow using existing classification systems for the task of forecasting personnel needs.

2. Development of a general structural model of AI technologies, providing elimination of problem areas on the basis of differentiation of AI technologies by the composition of promising methods, tools and areas of application included in each of them.

3. Construction of a private system of AI technology classification based on a structural model with the calculation of quantitative indicators assessing the current potential of development frontiers (the most promising sub-technologies) based on the data on international publication activity in the field of AI for 2016–2021.

[7] Research centers demonstrated pilot AI solutions. Ministry of Economic Development of the Russian Federation. Available at: https://economy.gov.ru/material/news/issledovatelskie_centry_prodemonstrirovali_pilotnye_ii_resheniya.html (accessed: March 1, 2022).

[8] A commission on ethics in the field of artificial intelligence has been created in Russia. *Nezavisimaya Gazeta*. Available at: https://www.ng.ru/news/740197.html (accessed: March 1, 2022).

[9] "On the development of artificial intelligence in the Russian Federation": RF Presidential Decree 490, dated October 10, 2019. Available at: https://www.garant.ru/products/ipo/prime/doc/72738946/ (accessed: March 1, 2022).

4. Application of AI technology classification system for solving the problems of personnel forecasting and determining the frontiers of the Russian Federation's development in the field of AI in the future through to 2025.

The theoretical significance of the study results lies in the creation of a classification system that structures existing knowledge about technologies in the field of AI and has the potential to generate new knowledge.

The practical significance of the results is disclosed in relation to the tasks of personnel forecasting in the field of AI.

The information base of the study includes federal documents of strategic planning in the field of artificial intelligence, international bibliographic databases WoS and Scopus, scientific publications. We give particular names and references as they are mentioned in the text of the article.

**Analysis of existing approaches to the classification of technologies in the field of artificial intelligence**

There are many scientific works in the field of artificial intelligence, and their number is increasing every year. However, the majority of both Russian and foreign studies are related directly to artificial intelligence technologies, their development, implementation and improvement. There are works on specific areas of AI, for example, we can note a number of works by Russian researchers in the field of AI – computer vision (Khokhlova et al., 2019; Bokovoy et al., 2020), biometric recognition (Vartanov et al., 2020), predictive analytics (Buevich et al., 2021), etc.

Another block is formed by works revealing the concept of "artificial intelligence" and its ethical components (Razin, 2019; Lyubimov, 2020). A number of studies address the relationship between human cognitive functions and artificial intelligence technologies (Gust, Kühnberger, 2006; Lu, Li, 2019; Jin, 2020).

The field of artificial intelligence is also considered through the prism of economic research. O.A. Romanova and A.O. Ponomareva raise the topic of digital transformation and artificial intelligence (Romanova, Ponomareva, 2020), V.N. Leksina presents the role of artificial intelligence in the economy in a series of articles (Leksin, 2020). There are also works on human resources for digital transformation (Kolin, 2019; Kuznetsov et al., 2020).

There are analytical papers that address a broader range of problems in this area. A series of analytical reports published by Stanford University, the AI Index Report (2017–2022), is authoritative in the international community[10]. The reports contain an analysis of research and development, the state of the labor market and the education system in the field of AI, as well as strategies for the development of AI in individual countries. In Russia, similar reports are published by the Center for National Technological Initiative at MIPT, the Almanac "Artificial Intelligence"[11]. Large-scale research of the AI field is conducted by international consulting companies IDC[12] and Gartner[13]. A number of countries produce white papers on AI technology, one of which was published in Russia[14].

However, not much is being done to classify AI technologies, including the problem of human resources in the implementation of plans for the development of the AI field.

Among the existing developments we can point out the scheme of AI technologies used at the National Technology Initiative Center at MIPT –

[10] The AI index report. Available at: https://aiindex.stanford.edu/report/ (accessed: March 22, 2022).

[11] Almanac "Artificial Intelligence". Available at: https://aireport.ru/ (accessed: March 22, 2022).

[12] Research by International Data Corporation, an international consulting company, "Worldwide artificial intelligence spending guide". Available at: https://www.idc.com/tracker/showproductinfo.jsp?containerId=IDC_P33198 (accessed: March 22, 2022).

[13] A study by the international consulting company Gartner "Hype Cycle for Artificial Intelligence", 2021. Available at: https://www.gartner.com/doc/reprints?id=1-27ILFEVT&ct=210923&st=sb#cppdip.747735 (accessed: March 22, 2022).

[14] White Paper: Development of selected high-tech areas. (2020). Available at: https://www.economy.gov.ru/material/file/ba6a7585c4b23c85931aaee99682ad30/belaya_kniga_2022.pdf (accessed: March 16, 2022).

in the Almanac "Artificial Intelligence"[15]. A basic model of AI Alliance professions and competencies has been developed[16]. The AI maps were developed by the company IP Laboratory[17] and the publication of technology and business RB.RU[18]. At the same time, the proposed approaches to classification allow forming only a general picture of the state of AI technologies, not directly applicable to the tasks of personnel forecasting.

As part of the classification of AI technologies presented by the authors of the almanac *Artificial Intelligence*[19], a chain of AI technologies of the following type is built: "cognitive function – topical applied development areas". In the classification there is no possibility of building a connection of technologies with professions in the economy and with specialists' training programs.

The closest for the tasks of personnel forecasting is the basic model of professions and competencies of the AI Alliance. It identifies six professional roles and the required level of mastery of each of the 36 key competencies. This model describes the required competencies for the professions: it illustrates what university graduates must be able to do in the development and application of AI technologies. At the same time, the model is not sufficient for planning the volume of training and forecasting the staffing needs of the economy, because it presents technologies in terms of tools. There is no reference to other constituent elements of any technology – methods and areas of application.

The AI Alliance's basic model of professions and competencies also identifies six major groups of professions needed to develop AI technologies. However, it is necessary to train not only AI product developers, but also those who use individual AI technologies or tools in their professional activities.

The classification of AI technologies used in the "Map of Artificial Intelligence of Russia", as the authors themselves point out, consists of two parallel classifiers – function (vision, speech, etc.) and application (finance, industry, etc.)[20], and has not yet been merged into a single system. A qualitative description of the state of technology is presented, but the capabilities of the model are insufficient to obtain quantitative indicators of technology development.

The national strategy for the development of artificial intelligence for the period through to 2030[21] defines AI technologies as "technologies based on the use of artificial intelligence, including computer vision, natural language processing, speech recognition and synthesis, intelligent decision support, and advanced artificial intelligence methods". Undoubtedly, the development of any technology depends significantly on the promising methods that make up that technology. At the same time, forecasting the workforce requires an understanding of the promising and potential development of technology-related tools and applications.

Summarizing, we can conclude that the presented classification systems of artificial intelligence technologies are sufficiently advanced and solve individual industry problems, but they are not suitable for the task of personnel forecasting. For example, classifications do not have ways to

[15] Artificial Intelligence. The current state in Russia and the world. Russia's strategy (2019): Almanac. *National Technological Initiative Center at MIPT for Artificial Intelligence*, 1, Moscow. Available at: https://aireport.ru/review (accessed: March 3, 2022).

[16] Basic model of professions and competencies. *AI Alliance*. Available at: https://a-ai.ru/education/#methodology-proffession-model (accessed: March 3, 2022).

[17] "Airussia" Artificial Intelligence Map of Russia. Available at: http://airussia.online/ (accessed: March 3, 2022).

[18] Artificial Intelligence Edition Map. *RB.RU*. Available at: https://rb.ru/ai/ (accessed: March 3, 2022).

[19] *Artificial Intelligence. The current state in Russia and the world. Russia's strategy (2019): Almanac*. Available at: https://aireport.ru/review (accessed: March 3, 2022).

[20] Available at: http://airussia.online/#opis (accessed: March 22, 2022).

[21] The national strategy for the development of artificial intelligence for the period through to 2030 "On the development of artificial intelligence in the Russian Federation", approved by Presidential Decree 490, dated October 10, 2019. Available at: https://www.garant.ru/products/ipo/prime/doc/72738946/ (accessed: March 1, 2022).

quantify the essential features of technology, which would allow us attributing professions or types of economic activity to a particular technology.

**Structural model of artificial intelligence technologies**

In order to develop the classification system required in the tasks of predicting personnel in the field of AI, we propose a structural model based on the following properties.

1. Hierarchy of AI technologies from the general (cognitive function) to the particular (specialized technologies), similar to the "cognitive function – topical applied development areas" chain from the almanac *Artificial Intelligence*.

2. The qualitative composition of each technology is determined by its constituent methods, tools, and applications.

3. The quantitative assessment of the essential features of each technology corresponds to the potential of technology development and is determined by the prospects of the methods, tools and areas of application used.

**Hierarchy of artificial intelligence technologies**

Nowadays, the term "artificial intelligence" has many definitions. Thus, the "AI development roadmap" defines artificial intelligence as "*a set of technological solutions that imitate human cognitive functions (including self-learning and search for solutions without a predetermined algorithm) and allow the performance of tasks to achieve results at least comparable with the results of human intellectual activity. A set of technological solutions includes information and communication infrastructure, software, including machine learning methods, processes and services for data processing and decision making*"[22]. Hussein Abbas, editor of IEEE Transactions on Pattern Analysis and Machine Intelligence, defines AI as *"social and cognitive phenomena that allow a machine to integrate into society to perform competitive tasks that require cognitive processes and communicate with other actors in society by exchanging messages with high information content and shorter representations"* (Abbass, 2021).

It follows that AI technology allows delegating tasks that were previously performed by humans to a machine. A distinctive feature of such tasks is the presence of cognitive functions, and individual technologies of artificial intelligence in the presented definitions are determined by information and communication technologies (ICT). Thus, each AI technology has the following characteristics:

1) ensuring the realization of human cognitive functions;

2) implementation of these functions is based on the use of ICTs.

Consequently, at the top level of the hierarchy there should be a classification according to the attributes associated with cognitive functions. At the next levels the classification according to the ICT-oriented way of implementation is performed. Let us distinguish three levels in the hierarchy of AI technologies.

1. First level: substitutable cognitive function.
2. Second level: AI technology areas.
3. Third level: private technologies (sub-technologies) of AI.

There are three types of human cognitive function realization (Baksanskii, 2005):

1) recognition as perception of information;

2) comprehension as processing and analyzing information, remembering and storing, sharing information;

3) action as the construction and implementation of a program of action.

They represent a nested structure, where each successive view includes the functions of the previous one.

When applied to the field of AI, the presented types of implementation of cognitive functions

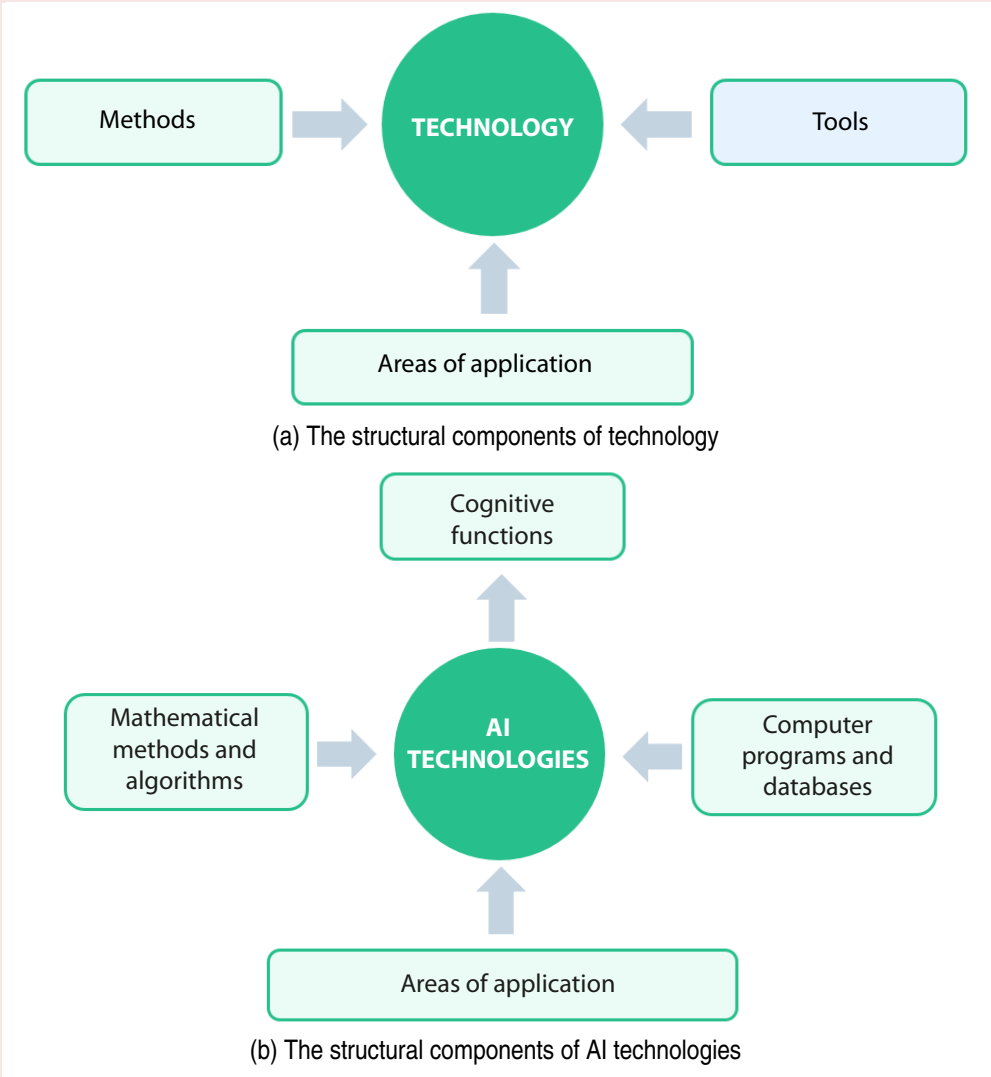
[22] A roadmap for the development of "end-to-end" digital technology "Neurotechnology and Artificial Intelligence". Ministry of Digital Development, Communications and Mass Media of the Russian Federation. Approved October 10, 2019. Available at: https://digital.gov.ru/ru/documents/6658 (accessed: March 1, 2022).

determine the extent to which AI delegates (replaces) those functions that were previously performed by humans. Determines what functions (competencies) can be freed from a person through the use of individual AI technologies. In general, competence is the ability of a specialist to solve a class of professional tasks (knowledge, experience, skills). Consequently, competencies are included in both methods, tools, and applications (Migurenko, 2016; Kalinovskaya, 2021), as defined in the second and third levels of the proposed AI technology hierarchy.

**Qualitative structure of artificial intelligence technologies**

In general, technology contains three components (Ushakov, 2017): methods (scientific knowledge that provides a solution to the problem); tools (means for applying the method to solve the problem); applications (source of practical tasks). The overall component structure of the technology is shown in *Fig. 1(a)*. For AI technology, these three components that determine the composition of its methods, tools and applications will be as follows: methods – these are mathematical methods

Figure 1. Structure of technology components and AI technology components




(a) The structural components of technology

(b) The structural components of AI technologies

Source: own compilation.

and algorithms; tools – computer programs and databases / knowledge bases; areas of application of AI – sectors of the economy. The component structure of artificial intelligence technologies is shown in *Fig. 1(b)*.

The AI technology areas (the second level of the hierarchy) provide sets of methods and algorithms, tools and applications for the field of AI. For each type of implementation of cognitive functions, sets of AI technologies (names, including synonymous ones) falling into this type were expertly determined. For the component "Mathematical methods and algorithms" allocated 10 items; for the component "Computer programs and databases" – 18 items; for "Areas of application" – 21 items. They are presented in the form of directories, which have a two-level structure of keywords.

1. The name of the object from the set (in Russian and English), including equivalent names.

2. Key words for each object in the set (in Russian and English) detailing the elements of specialization of the corresponding object.

As a result, we developed four reference titles: a) AI technology areas; b) mathematical methods and algorithms; c) computer programs and databases / knowledge bases; d) AI application areas. The handbooks are auxiliary internal materials, they are designed to quantify the essential features of AI sub-technologies (the third level of the hierarchy); they were formed based on expert analysis of fundamental documents in the field of AI, as well as scientific publications in leading journals.

**Assessment of AI technology attributes based on scientific publications**

For personnel forecasting tasks, the main attribute of AI technology is its development potential, so it is required to assess the promising areas of AI technology based on the promisingness of the AI sub-technologies included in the field. The promising nature of a sub-technology is determined by the promising nature of the methods, tools, and applications used. It is necessary to identify which specific methods, tools and applications define the sub-technology.

For this purpose, the method of Systematic Literature Review (Snyder, 2019), based on the analysis of scientific publications on the topic of AI, in our case in the journals indexed in the international databases (IDB) Scopus and Web of Science, as well as in the publications indexed in Russian Science Citation Index (RSCI). Within the framework of this method, a list of journals containing only leading publications (journals of the first quartile Q1 and conferences of the A/A* level) in the field of AI was used to identify priority areas of development (frontiers) of artificial intelligence. The list of such publications was approved by the Ministry of Economic Development of Russia as part of the AI Centers competition in 2021[23].

The methodology for analyzing publication activity is as follows. AI experts selected for each year in the period 2016–2021 all articles in Q1 journals and the first 100 articles from conference proceedings in the field of AI A/A*. Performing text analysis in the title, abstract, and keywords of the publication, experts generated a list of private AI technologies (AI sub-technologies), the first level of the technology guide. Then a list of keywords of the second level of the technology guide was formed. Similarly, sets of used methods and tools were formed, as well as keywords for method and tool guides. The first level (names) in the guide to the fields of application is created on the basis of the Russian Classifier of Economic Activities[24]. Thus, the directories are lists of keywords for each of the technology area components.

[23] Documentation for the selection of recipients of support for research centers in the field of artificial intelligence, including "strong" artificial intelligence, trusted artificial intelligence systems, and ethical applications of artificial intelligence. Available at: https://ac.gov.ru/uploads/_Projects/AI_otbor/DocumentsWord.docx (accessed: February 1, 2022).

[24] OKVED 2. Russian Classifier of Economic Activities OK 029-2014. Available at: https://classinform.ru/okved2.html (accessed: February 1, 2022).

To obtain quantitative characteristics of the degree of use of various components (methods, tools, applications) and their individual subcomponents, we applied the following algorithm based on queries to the Scopus / WoS IDB:

1) to find $K_c$ the number of publications in which any words from the set of keywords of specific components are used.;

2) to find the $K_{sc}$ number of publications that use the keywords of specific subcomponents;

3) to find the proportion of subcomponent publications in the component publications $K_p$:

$$K_p = K_{sc} / K_c .$$

This algorithm is of a general nature and does not require expert analysis. A specific variant of the algorithm implementation will be presented in the article below on the basis of the Scopus IBD for the period 2016–2022.

**Artificial intelligence technology classification system**

Using the methodology of expert analysis of scientific publications, we conducted a sample study of leading publications (first quartile Q1 journals and A/A* level conferences) in the field of AI for 2016–2021 (2426 publications). Based on the expert analysis of names and keywords, we formed 96 private technologies (sub-technologies) of AI, which constitute the third (lower) level of classification. For each sub-technology, we evaluated its frequency of occurrence (number of publications) using Scopus IBD queries (69571 publications). At the same time, experts have also done work on the formulation of names of sub-technologies, taking into account other sources, in particular the Development Strategy of AI[25].

[25] The national strategy for the development of artificial intelligence for the period through to 2030 "On the development of artificial intelligence in the Russian Federation", approved by Presidential Decree 490, dated October 10, 2019. Available at: https://www.garant.ru/products/ipo/prime/doc/72738946/ (accessed: March 1, 2022).

Next, the experts grouped AI sub-technologies to form the second level of classification – consolidation into AI technology areas. Each such area represents a certain main direction of AI development. The perspective score of a technology area is calculated as the sum of the scores included in the sub-technology area. This grouping of sub-technologies by experts is based on Russian and foreign industry sources and documents. As a result, fifteen names of AI technology areas have been formed with preservation of the established terminology.

To form the first level of classification, we structured these fifteen areas according to three basic cognitive functions. Four technology areas are assigned to recognition (perception), six areas are assigned to comprehension, and five areas are assigned to action.

*Table 1* shows the presence of fifteen AI technology areas in the fundamental Russian documents in the field of AI. It is worth noting that the presented technology areas do not cover the entire sphere of AI. They identify promising areas of development, where perspective is assessed on the basis of mentions in leading scientific publications in the field of AI.

As we have already noted, the quantitative indicator characterizing the importance of the technology area (perspective from the point of view of development) is the number of publications on the subject of AI technologies in Q1 journals and proceedings of A/A* conferences in the field of AI for 2016–2022. In general, we have studied 2,426 publications (expert analysis) and 69,571 publications (automatic occurrence analysis). Based on their analysis, 96 private AI technologies (sub-technologies) were formed and 15 areas of AI technology. To illustrate the relationship between three levels of "cognitive function – technology area – sub-technology", *Table 2* shows an example of the AI technology area "Machine translation, natural language dialogue".

Table 1. Intersection of artificial intelligence technology areas with key AI documents and sources

| Artificial intelligence technology areas | RF Presidential Decree 490, dated October 10, 2019 "On the development of artificial intelligence in the Russian Federation", the National Strategy for the Development of Artificial Intelligence for the period through to 2030 | Order of the Ministry of Economic Development of RF, dated July 14, 2021 "Documentation of the selection of support recipients for research centers in the field of artificial intelligence including in the field of "strong" artificial intelligence, systems of trusted artificial intelligence and ethical aspects of the use of artificial intelligence" | Order of the Ministry of Economic Development of RF 392, dated June 29, 2021 "On approval of criteria for determining whether projects belong to projects in the field of artificial intelligence" | Roadmap for the development of "end-to-end" digital technology "Robotics and sensor components" | Roadmap for the development of "end-to-end" digital technology "Neurotechnologies and artificial intelligence" | Analytical collection "Almanac artificial Intelligence, no. 1. AI market Overview Russia and the World" (MIPT) | Analytical collection "Almanac artificial intelligence no. 8. Index 2020" (MIPT) | Report of the research and consulting company Gartenr "Hype Cycle for Artificial Intelligence" (July 2021) |
|---|---|---|---|---|---|---|---|---|
| Computer vision | Yes | Yes | Yes | | Yes | Yes | Yes | Yes |
| Biometric recognition | | Yes | | | | Yes | | |
| Intelligent sensor technology (information from sensors) | | Yes | | Yes | | Yes | Yes | |
| Speech analysis and synthesis | Yes | Yes | Yes | | Yes | Yes | Yes | |
| Information search | | | | | | Yes | | Yes |
| Machine translation, natural language dialogue | Yes | Yes | Yes | | Yes | Yes | | Yes |
| Expert and recommendation systems | Yes | Yes | Yes | | Yes | Yes | Yes | Yes |
| Knowledge ontologies: representation, interpretation, learning | Yes | | Yes | | Yes | Yes | | Yes |
| Predicative analytics | | Yes | | | | Yes | | |
| Data mining | | Yes | Yes | | | Yes | | Yes |
| Process automation | Yes | | Yes | | | | Yes | Yes |
| Software agents | | | | | | Yes | | Yes |
| Industrial robots | | Yes | | | | Yes | | |
| Drones and autonomous robots, swarm intelligence | | Yes | | Yes | | Yes | Yes | Yes |
| Responsible artificial intelligence (ethics and philosophy, legal norms, security) | | Yes | | | | | | Yes |
| Source: own compilation. | | | | | | | | |

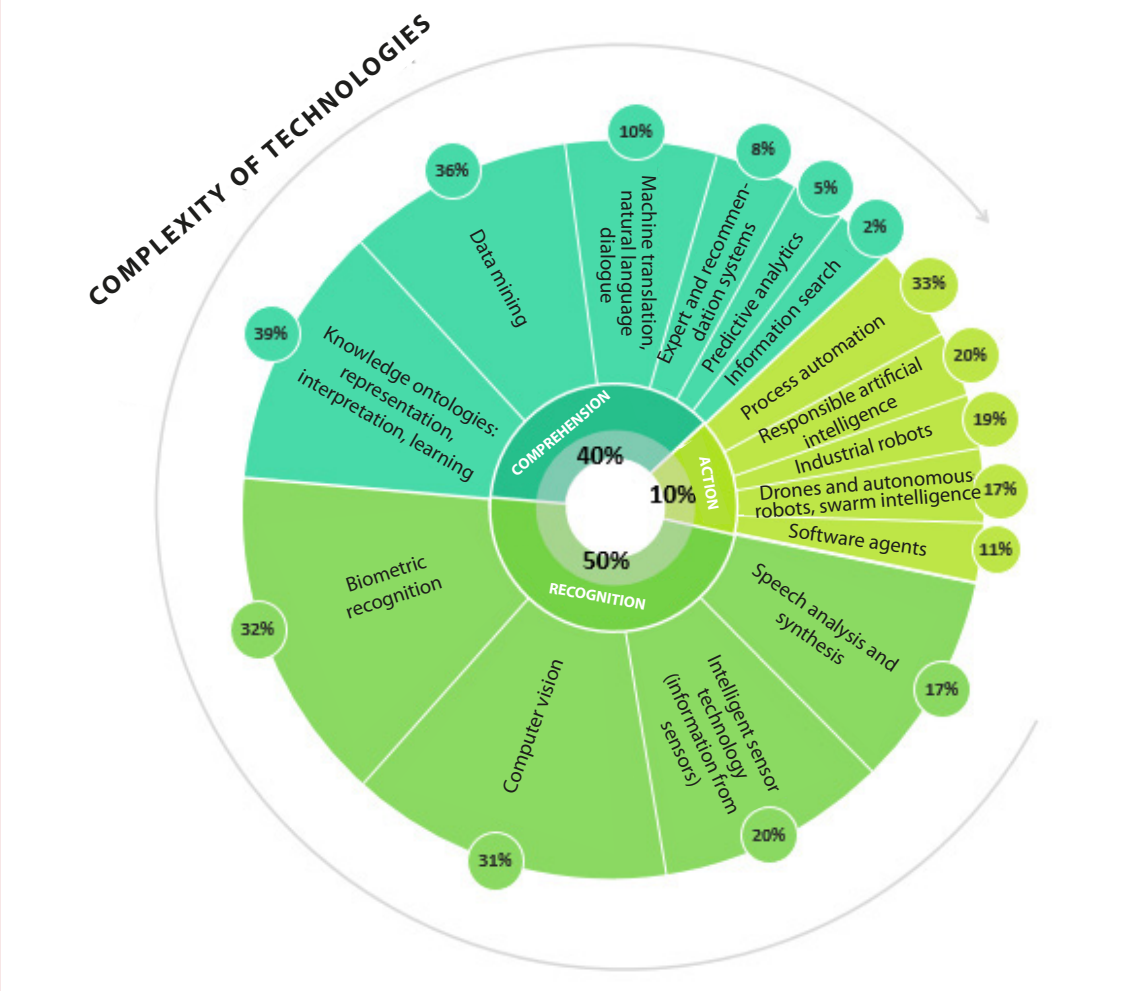
Table 2. Scheme "cognitive function – technology area – sub-technology"

| **Cognitive function: comprehension** (processing and analysis of information; memorization and storage; information exchange) | |
|---|---|
| AI technology area | Sub-technologies (private technologies) |
| Machine translation, natural language dialogue | 1. Multilingual automatic machine translation system<br>2. Machine representation of texts (neuro symbolic model, thematic modeling, language-neutral models, multilingual models)<br>3. Dialog systems with personalized natural language response generation<br>4. Program code generation<br>5. Generating images by text<br>6. Annotation (abstracting, summarizing) of texts<br>7. Text mining for text classification (attribution, spam recognition, sentiment analysis, authorship, style compliance, error checking, etc.)<br>8. Subject-oriented virtual assistants implementing conversational AI<br>9. Paraphrasing the text<br>10. Text (synthesis) augmentation for solving machine learning problems |
| Source: results of the conducted research. | |

*Figure 2* shows the distribution of the share of publications on cognitive functions and AI technology areas. We have found that the proportion of the identified publications on each of the cognitive functions differs significantly decreasing as the complexity of the implementation of the cognitive function increases.

About half of the publications studied account for the basic cognitive function "Recognition" which is responsible for the information perception. This function includes biometric recognition, computer vision, speech analysis, and synthesis technologies. The next level of increasing complexity is "Comprehension" which includes processing, analysis, storage and exchange of the received information. At the technological level, this includes the fields of technology, knowledge ontology, machine learning, predictive analytics, etc. The share of publications on this function is 40%. The maximum complexity level is "Action"; this function is based on "Recognition" and "Comprehension" of information. The technology areas that relate to this function account for only 10% of the identified publications.

Figure 2. Distribution of the number of publications on cognitive functions and AI technology areas




Share of publications is calculated in relation to the total number of publications, for sub-technologies – in relation to the number of publications on cognitive function.

Source: own compilations.

We should note that the most "advanced" (from the point of view of product creation) AI technology areas according to the model of the "Hype cycle of artificial intelligence technologies for 2021"[26] are computer vision and semantic search corresponding to the cognitive function "Recognition". In other words, AI technology areas that are more studied by the criterion of "number of publications" and relate to the basic cognitive function of "Recognition" also turn out to be technologically more mature[27].

Each of the identified fifteen areas of AI technology is characterized by a unique set of methods (mathematical methods and algorithms), tools (computer programs and databases / knowledge bases) and applications (economic sectors). To identify this set, we have carried out an automatic occurrence analysis for the entire array of publications in the Scopus database for 2016–2021. The queries used the names of the required components and key words in accordance with the developed reference books. We have analyzed 2.6 million publications. The transition from samples of publications in leading scientific publications Q1/A* to a complete sample from the Scopus database is due to the need to have statistically significant indicators when detailing the components of AI technologies.

It is known that the entire array of publications in the Scopus database is characterized by the presence of a large number of publications that are not essential for development in the field of AI. To assess the correctness of using the entire Scopus database array in comparison with publications in leading publications Q1 and A*, we have carried out a comparative analysis of publication activity in the AI technology areas with samples of publications from both databases – complete and only Q1 and A* – for Russia, China and the USA.

Based on the collected data (using information on all AI technology areas), we have calculated Pearson correlation coefficients *corr* between the total number of publications in the Scopus database and the total number of publications in leading publications Q1 and A*:

$$corr = \frac{\sum_{i=0}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=0}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=0}^{n}(y_i-\bar{y})^2}},$$

where $x_i$ – number of publications on $i$-th ($i$ = 1, 2, ..., $n$) from $n$ AI technology areas in the Scopus database, $y_i$ – number of publications on $i$-th ($i$ = 1, 2, ..., $n$) form $n$ AI technology areas in leading publications Q1 and A*, $\bar{x}, \bar{y}$ – corresponding averages. For Russia, the value of such a correlation coefficient is 0.89, for the USA it is 0.86, for China – 0.96, which allows concluding that there are similarities between the two sources of publications and use samples from the entire array of publications of the Scopus database along with samples from publications in leading scientific publications Q1/A*.

For each AI technology area, a set of publications has been formed in which a given area is affected. In the generated set of publications, a key word search was performed, each of which characterizes one of the components of AI technology: "Mathematical methods and algorithms" (methods), "Computer programs and databases / knowledge bases" (tools), "Economic sectors" (application areas).

*Figure 3* shows an example of the identified composition of such AI technology area as "Biometric recognition" in terms of its constituent methods, tools, applications and AI sub-technologies *(presented example details Fig. 1 (b))*. We should note that the component is included in the composition provided that it is highly common

[26] Hype Cycle for Artificial Intelligence (2021), July. *Gartner*. Available at: https://www.gartner.com/doc/reprints?id=1-27ILFEVT&ct=210923&st=sb#cppdip.747735 (accessed: March 16, 2022).

[27] *White Book: Development of Certain High-Tech Areas* (2020). Available at: https://www.economy.gov.ru/material/file/ba6a7585c4b23c85931aaee99682ad30/belaya_kniga_2022.pdf (accessed: March 16, 2022).

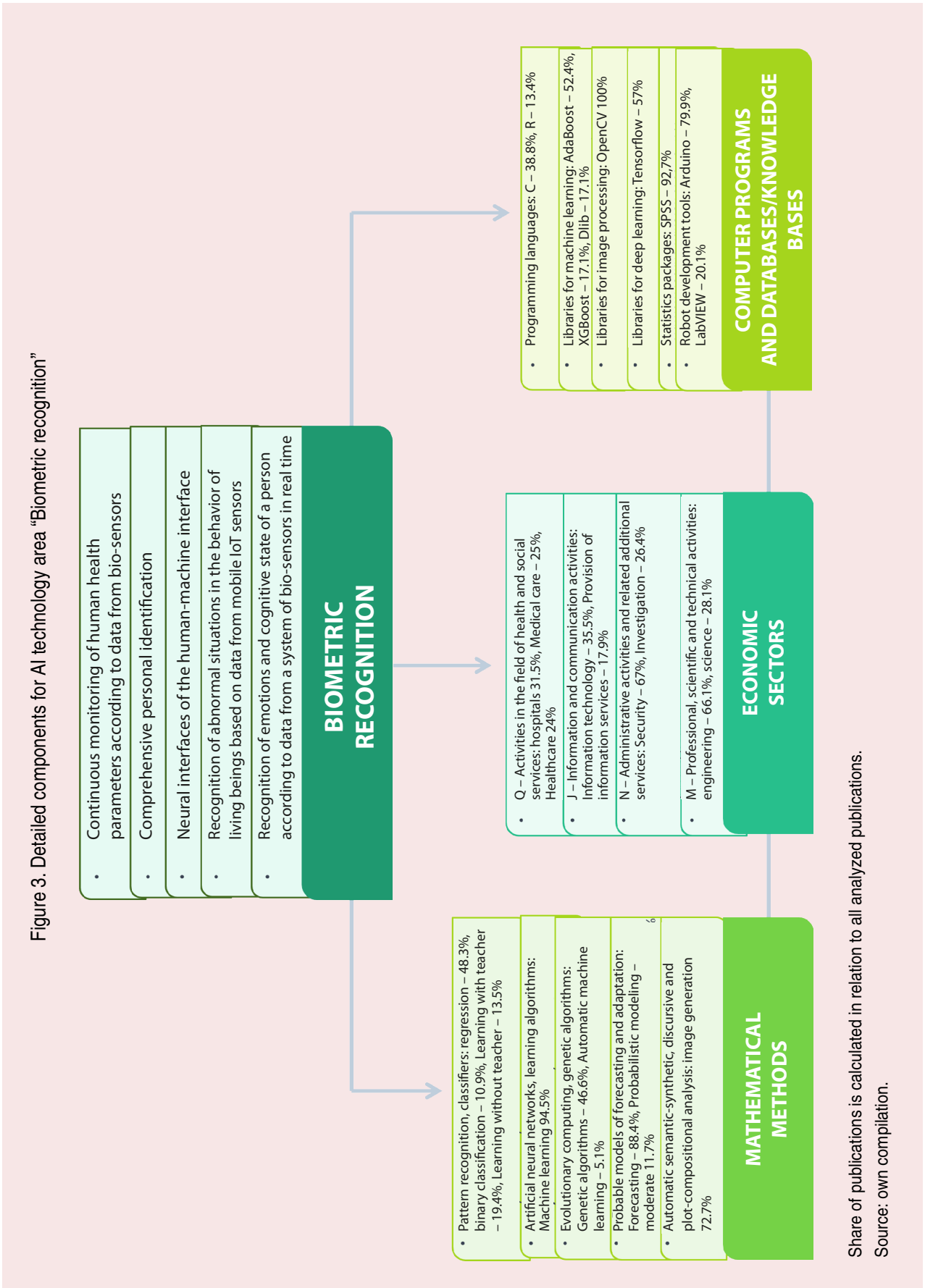



Figure 3. Detailed components for AI technology area "Biometric recognition"

Share of publications is calculated in relation to all analyzed publications.
Source: own compilation.

in scientific publications. Thus, the proposed classification system not only determines the unique qualitative composition of AI technology, but also provides a way to quantify the essential features of the technology coming from its complex composition. Such an opportunity is necessary to solve the problems of personnel forecasting.

For this AI technology area, we have analyzed 50,650 publications. In the central part of Figure 3, a list of sub-technologies is indicated including human sensory, emotion analysis, personality identification, analysis of human and animal behavior, neurointerfaces of human-machine interface.

The left part of Figure 3 "Mathematical methods and algorithms" gives the key methods for the technology "Biometric recognition"; we have indicated the share of publications for each of them in which they have been mentioned. In particular, among these methods, the most important are probabilistic forecasting and adaptation models; automatic semantic-syntactic, discursive and plot-compositional analysis; pattern recognition; classifiers.

The right part of Figure 3 shows the key tools – "Computer programs and databases / knowledge bases" for the AI technology area "Biometric recognition", as well as the share of publications where they were mentioned. In particular, among the tools in the technology area "Biometric recognition", the most common are software tools "OpenCV" (image processing), "AdaBoost", "XGBoost", "Dlib" (machine learning); programming languages C and R, robot development tools "Arduino". However, it is worth noting the absence of Python in this list; its individual libraries are more often mentioned (for example, "OpenCV").

The central part of Figure 3 lists the types of economic activities in which the AI technology area "Biometric recognition" is used. This technology is actively mentioned in publications in conjunction with such types of economic activities as "Administrative activities and related additional services" (security, investigations), "Professional, scientific and technical activities", "Activities in the field of health and social services".

Separately, we should note that the sets of components for each of the technology areas are unique, thereby characterizing this area. *Table 3* shows an example of the names of components with the maximum contribution for three technology areas; the share of publications in which one or another component occurs is indicated.

In general, the proposed new classification system of AI technologies systematizes promising AI technologies on three levels (cognitive functions – technology areas – sub-technology). The prospects are determined by the scientific interest degree in the technology and its components. The system details each structural level by three components: methods, tools, and applications. The details are based on quantitative estimates of the prospects determined

Table 3. Example of unique components for AI technologies

| AI technology area | Mathematical methods and algorithms | Computer programs and database | Application areas – types of economic activity |
|---|---|---|---|
| Computer vision | Automatic semantic-syntactic, discursive and plot-compositional analysis – 60.6% | Programming languages – C – 33.4% | Section M – Professional, scientific and technical activities – Engineering – 77.8% |
| Industrial robots | Fuzzy knowledge, reasoning in conditions of uncertainty – 86.2% | Programming languages – MATLAB – 28.1% | Section C – Manufacturing – Production –Machinery – 27.2% |
| Data mining | Artificial neural networks, learning algorithms – 97.6% | Programming languages – Python – 38,2% | Section J – Information and communication activities – Information technology – 34.1% |
| Source: results of the conducted research. | | | |

by the number of scientific publications. The classification system allows automatic regular updating, based on accounting for outgoing scientific publications. Updating the qualitative structure of the classification system (names of technologies and their components) requires expert participation.

**Using classification system for personnel forecasting purposes**

Further, we will present details of methods, tools, application areas in the field of AI and options for applying the classification system to the tasks of personnel forecasting.

**Component content: detailing methods, tools, application areas**

The set of component contents – "Mathematical methods and algorithms" (methods), "Computer programs and databases" (tools), "Economic sectors" (application areas) – is unique for each of the AI technology areas. At the same time, individual components (elements) of each of the three components may occur in different technologies. A software package was developed in the Python programming language which, using selenium tools and generated sets of key words, allowed automating the sending of requests to the Scopus database and processing responses in order to obtain the number of publications in the Scopus database corresponding simultaneously to a certain method or tool, or application area and a certain AI technology.

To identify the priority of the component elements, we have carried out an additive convolution for each of the three components of AI technology areas. For example, for AI technology component "Mathematical methods and algorithms", we have calculated the number of publications containing key words corresponding to this component during convolution.

*Tables 4, 5, and 6* present the results obtained. Table 4 shows a fragment of the original matrix with the key elements of the "AI Methods" component, where key words are given for each method, the number of the fields of AI in which the method is used, as well as the total number of mentions of the element in the analyzed publications, which reflects

Table 4. AI Methods: mathematical methods and algorithms

| Name of the elements of the component "Mathematical methods and algorithms" | Key words for detail | Number of AI areas in which the method is applied | Number of mentions in publications | Share of mentions, % |
|---|---|---|---|---|
| Artificial neural networks, learning algorithms | Machine learning | 15 | 434,586 | 35.24 |
| Probabilistic forecasting and adaptation models | Forecasting | 13 | 219,336 | 17.79 |
| Pattern recognition, classifiers | Regressions | 14 | 137,058 | 11.11 |
| Graph representation of knowledge, data markup | Ontologies | 7 | 75,260 | 6.10 |
| Pattern recognition, classifiers | Learning with teacher | 12 | 67,738 | 5.49 |
| Fuzzy knowledge, reasoning in conditions of uncertainty | Autonomous systems | 10 | 43,450 | 3.52 |
| Pattern recognition, classifiers | Learning without teacher | 9 | 37,949 | 3.08 |
| Artificial neural networks, learning algorithms | Reinforcement learning | 4 | 36,419 | 2.95 |
| Evolutionary calculations, genetic algorithms | Genetic algorithms | 15 | 36,281 | 2.94 |
| Automatic semantic-syntactic, discursive and plot-compositional analysis | Image generation | 4 | 35,663 | 2.89 |
| Source: results of the conducted research. | | | | |

Table 5. AI Tools (computer programs and databases / knowledge bases)

| Name of the elements of the component "Computer programs and databases / knowledge bases" | Key words | Number of AI areas with the usage of tools | Number of mentions in publications | Share of mentions, % |
|---|---|---|---|---|
| Programming languages | C | 15 | 95,679 | 49.82 |
| Programming languages | R | 15 | 53,813 | 28.02 |
| Libraries for machine learning | XGBoost | 15 | 5,911 | 3.08 |
| Libraries for machine learning | AdaBoost | 13 | 5,865 | 3.05 |
| Robot development tools | Arduino | 10 | 4,985 | 2.60 |
| Libraries for deep learning | Tensorflow | 8 | 4,142 | 2.16 |
| Programming languages | MATLAB | 4 | 4,119 | 2.14 |
| Statistics packages | SPSS | 7 | 3,935 | 2.05 |
| Libraries for natural language processing | Word2Vec | 6 | 3,015 | 1.57 |
| Libraries for machine learning | Weka | 8 | 2,390 | 1.24 |
| Source: results of the conducted research. | | | | |

Table 6. AI application areas (economic sectors by the type of economic activity)

| Name of the elements of the component "Application areas" | Key words | Number of AI areas with the usage of tools | Number of mentions in publications | Share of mentions, % |
|---|---|---|---|---|
| M - Professional, scientific and technical activities | Technical | 14 | 286,781 | 25.37 |
| P – Education | Education of schoolchildren and students | 2 | 187,404 | 16.58 |
| M - Professional, scientific and technical activities | Scientific | 13 | 120,406 | 10.65 |
| J – Information and communication activities | Information technology | 15 | 116,449 | 10.30 |
| Q – Healthcare and social services activities | Healthcare | 7 | 70,588 | 6.25 |
| J – Information and communication activities | Provision of information services | 14 | 57,120 | 5.05 |
| Q – Healthcare and social services activities | Medical care | 7 | 36,954 | 3.27 |
| F – Building | Reconstruction | 2 | 36,184 | 3.20 |
| N – Administrative activities and related additional services | Ensuring security | 3 | 29206 | 2.58 |
| R – Activities in the field of culture, sports, leisure and entertainment | Libraries | 4 | 12,779 | 1.13 |
| H – Transportation and storage | Transportation | 2 | 7,745 | 0.69 |
| Source: results of the conducted research. | | | | |

its "weight" in relation to other elements. The key word "Machine learning" means that of the many other key words for the element "Artificial neural networks, learning algorithms", the proportion of mentions of the phrase "Machine learning" in publications is the highest.

The analysis of convolution indicators shows that the most common (often encountered) are mathematical methods such as artificial neural networks, learning algorithms, pattern recognition, classifiers, probabilistic forecasting and adaptation models.

Table 5 presents a fragment of the results of a similar convolution procedure for the component "Computer programs and databases / knowledge bases".

The most common elements of the "Computer Programs and databases/knowledge bases" component are programming languages (C, R, MATLAB, Python, Java) and libraries for machine learning (XGBoost, AdaBoost, Weka, LightGBM, Dlib).

Table 6 presents a fragment of the results of the convolution for the component "AI application areas (by type of economic activity)".

The most common elements of the "AI application areas" component were the types of economic activities "Information and communication activities" and "Education". Separately, it is worth noting the relatively low popularity of the use of AI technologies in the real economy.

**Classification system applied to the tasks of personnel forecasting**

The proposed classification system of artificial intelligence technologies can be used to detail the indicators of personnel forecasting in the filed of AI. The detailing of the annual additional staffing requirement (AAR) of the economy is usually carried out by types of economic activity, professions and educational specialties.

In relation to the filed of artificial intelligence, this triad can be supplemented with details on AI technology areas. According to the author's estimate, the AAR in the field of AI for 2022 is 25.7 thousand people[28]. To detail the AAR on AI technologies, we can use the proportion of publications within each of the three classification levels (cognitive function – technology area – sub-technology). For example, if we take into account the share distribution of publications, shown in Figure 2 for the field of computer vision technologies, then the AAR value will be 7.9 thousand people.

Another important indicator of the detail of the personnel forecast is the training in the context of educational specialties of graduates with competencies in the field of artificial intelligence. These competencies are formed as a result of the implementation of educational programs (Gurtov et al., 2013). For example, master's programs should have at least seven disciplines that provide professional competencies in the field of AI. Examples of such competencies are for the "Mathematical methods and algorithms" component – the "Artificial neural networks, learning algorithms" element; for the component "Computer programs and databases / knowledge bases" is the element "Programming languages C, R".

Let us note the similarity of the meaningful interpretation of the concepts of "competence" and "technology". Considering competencies as a set of knowledge, skills, practical experience, and technologies as a set of methods, tools, and application areas, we can draw an analogy where knowledge is mathematical methods and algorithms, skills are computer programs and databases / knowledge bases, practical experience is application areas (types of economic activity). Thus, the content of the technology areas serves as the basis for the formation of professional competencies.

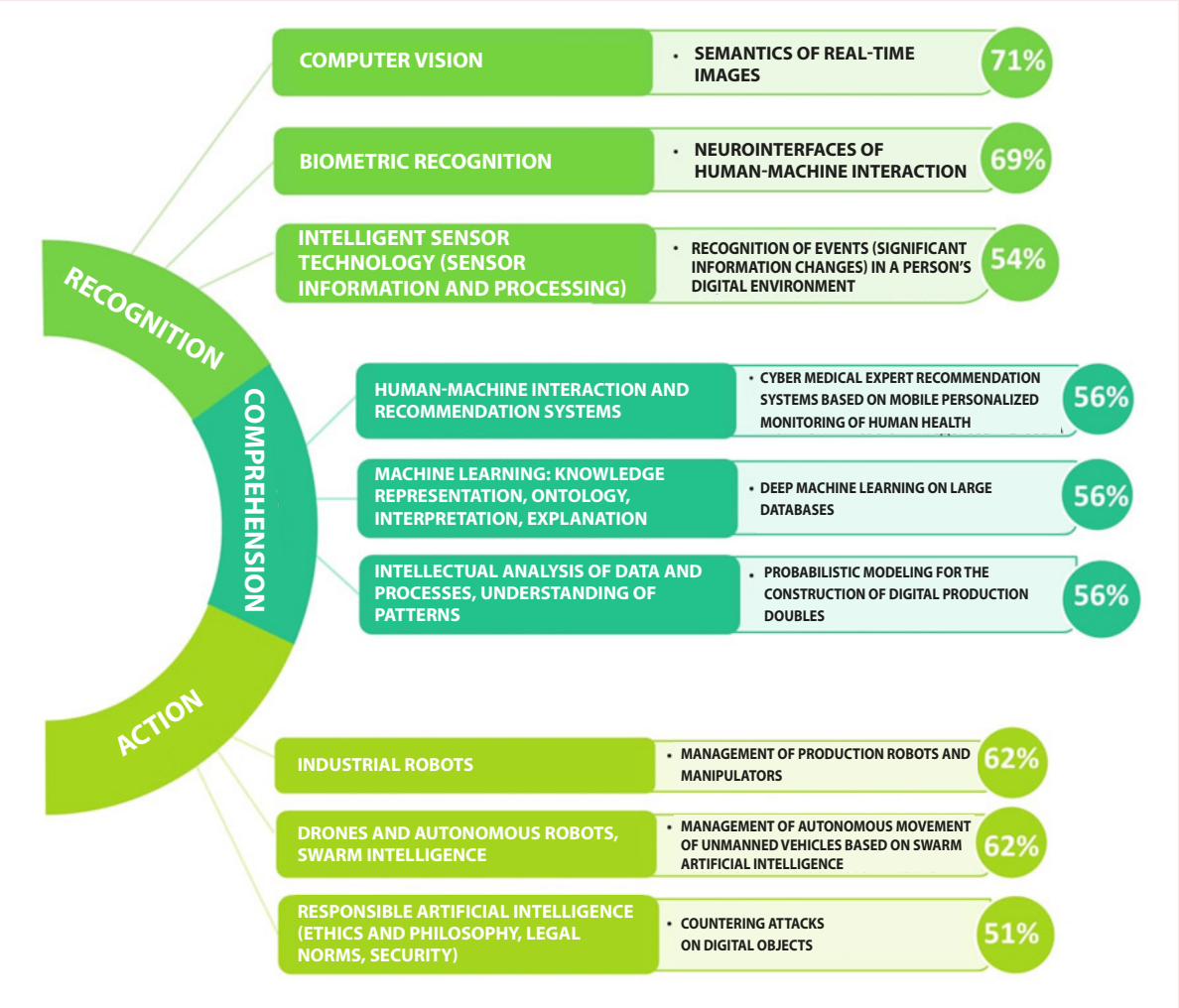
Continuing the analogy of the connection between technologies and competencies, technology areas need to be detailed to the level of sub-technologies, and professional competencies – to highly specialize professional competencies (Gurtov et al., 2015; Sigova et al., 2013).

Also, the proposed classification has the potential for the development. One of the ways is to identify priority development areas (frontiers) of artificial intelligence. AI frontiers are the most significant highly specialized areas of artificial intelligence technology development (sub-technologies) belonging to the first decile (the first 10% in the ranked distribution series) in terms of significance[29]. As we have already noted

[28] Artificial intelligence. Personnel of the highest scientific qualification: Internet portal. Available at: http://science-expert.ru/ai (accessed: March 30, 2022).

[29] Top 20 frontiers of world science. Available at: https://issek.hse.ru/news/562631350.html (accessed: May 30, 2022).

Figure 4. Frontiers of artificial intelligence technologies (fragment)




Percentage of responses is calculated from the total number of experts who answered the question.
Source: own compilation.

in the section "Methodology", for quantitative assessment when identifying priority development areas (frontiers) AI can be used by leading publications indexed in the international databases Scopus and Web of Science (journals of the first quartile Q1 and conferences of the A/A* level). The analysis of publication activity together with a survey of experts among employers, developers of educational programs in the field of AI will help to form these frontiers. During the expert evaluation of 95 sub-technologies formed, experts among employers, developers of educational programs and products in the field of AI identified those which, in their opinion, belong to the frontiers of sub-technologies[30].

*Figure 4* shows examples of frontiers with the maximum number of expert assessments (three frontiers for each cognitive function), the

[30] Artificial intelligence. Personnel of the highest scientific qualification: Internet portal. Available at: http://science-expert.ru/ai (accessed: March 30, 2022).

percentage of experts who chose one or another frontier is indicated (106 experts participated in total).

Separately, we should note that the topics of the frontiers correspond to promising areas of artificial intelligence which were designated in the RSF-2021 contests[31].

**Conclusion**

Analysis of classifications of AI technologies used in the Center of the National Technology Initiative based on MIPT, the AI Alliance group, the companies "IP Laboratory" and "RB.RU", showed that these approaches allow forming only a general picture of the structure of AI technologies. Based on the general conceptual model of technologies (methods, tools, fields of application), we have developed a structural model of AI technologies, based on their differentiation by the composition and significance of mathematical methods and algorithms, computer programs and databases, application areas. Quantitative indicators for this differentiation were obtained by analyzing publication activity in publications refereed in the Scopus database. We have been formed a unique set of components for each of the fifteen AI technology areas, an example of which is shown in Figure 3 for the technology area "Biometric Recognition".

The proposed methodology has made it possible to structure technologies by levels: cognitive functions – technology areas – AI sub-technologies. The technological maturity of AI technology areas in the context of cognitive functions differs significantly decreasing as the complexity of cognitive function increases.

The constructed three-level classification system of AI technologies allows moving from technology areas to AI sub-technologies which are highly specialized areas of AI development within each of the technology areas with the preservation of its components. The theoretical component of the classification makes it possible to gain new knowledge including identifying priority development areas (frontiers) of artificial intelligence.

The proposed classification system of AI technologies is practically applicable in the field of personnel forecasting when detailing the indicators of annual additional personnel needs by types of economic activity, professions and educational specialties.

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