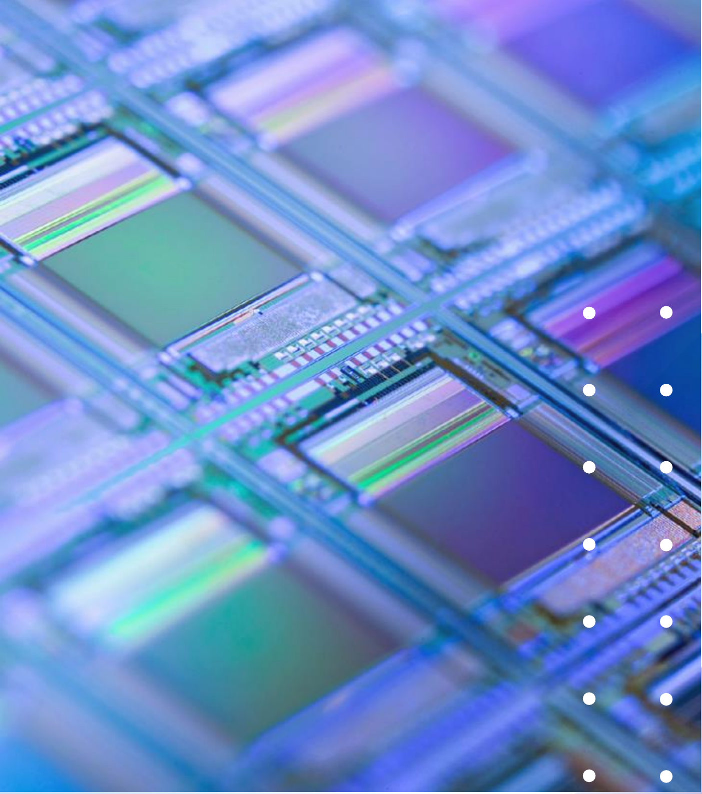

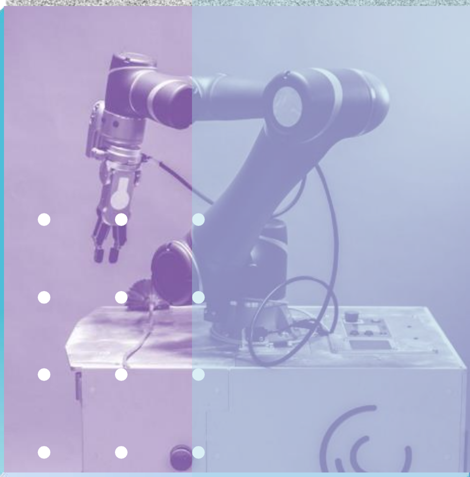

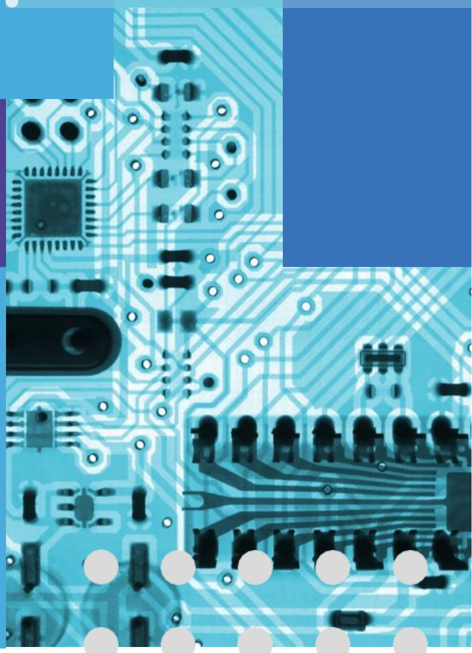

THE SERIES
«SOURCES OF NEW INDUSTRIES»

ISSUE 3

ARTIFICIAL INTELLIGENCE IN INDUSTRY

SAINT PETERSBURG

2022

SOURCES OF NEW INDUSTRIES. ISSUE 3. ARTIFICIAL INTELLIGENCE IN INDUSTRY

Expert report

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The basis was the Foresight project “Frontiers in New Sciences”. The aim of the project was to identify longterm trends and prospects for the development of new industrial and technological markets; to identify on this basis the most promising areas of research and development in the so-called “frontier” areas of R&D – advanced chemistry, synthetic biology, artificial intelligence and environmentally friendly industrial technologies.

The methodological basis of the project is based on the analysis of the results of a foresight session with the participation of leading and young scientists, the processing of scientific data, a series of interviews with leading researchers, the evaluation of strategies of large industrial concerns.

The report consists of four sections, which include:

— risks of AI industry development in the current environment;
— the impact of artificial intelligence technologies on the current technological paradigm and modes of production;
— necessary measures to launch programs for the reengineering of AI hardware and software;
— St. Petersburg's role as a center of expertise in artificial intelligence.

The report describes the main factors in the development of advanced AI technologies:

1) one of the most important growth drivers of the artificial intelligence market is manufacturing;
2) the main frontier tasks for AI science lie in the area of computing and data handling;
3) development of AI technologies in Russia depends on the availability of its own hardware and software.

The results of the project formed the basis of the activities of the Association “Artificial Intelligence in Industry”.

The series "Sources of new industries"

Design: M. I. Petrova on demand of the Innovations and Youth Initiatives Support Fund of St. Petersburg

Saint Petersburg 2022

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Introduction

At the time of writing, the Russian Federation was under pressure from an unprecedented number of international economic sanctions. First and foremost, they have affected high-tech industries and supply chains. In these conditions, the question of further evolution of artificial intelligence (AI) technologies in our country becomes topical. Artificial Intelligence, as represented by the authors of the report, is a breakthrough technology for the economy that can play a crucial role in the development of the Russian industry. In the short term, AI can become a key tool for solving the problems of reengineering and import substitution, and ensure the outstripping development of certain areas of domestic industry.

Over the last 50 years a new technological structure of modern society has been formed. A significant increase in scientific work in computer science (and in particular artificial intelligence) has created the necessary prerequisites for the emergence of a number of closing technologies that can change the global balance of power and complete the transition from the industrial to the digital age.

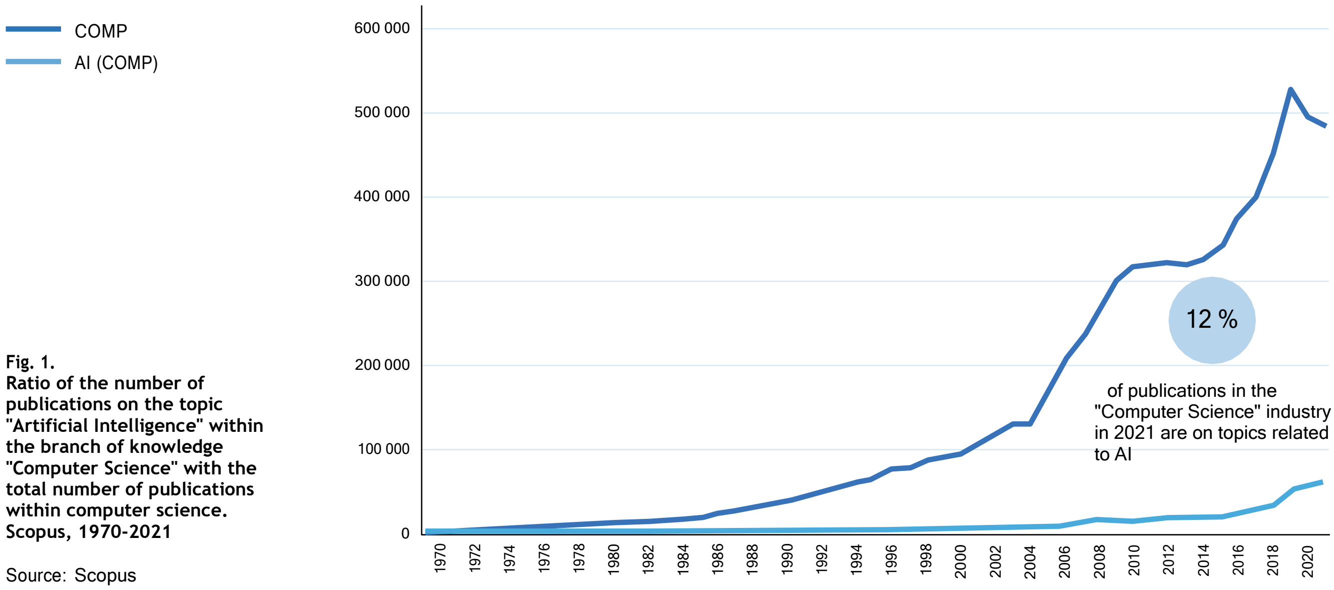

Fig. 1.
Ratio of the number of publications on the topic "Artificial Intelligence" within the branch of knowledge "Computer Science" with the total number of publications within computer science. Scopus, 1970-2021

Source: Scopus

The new digital environment has significantly increased computational power and the volume of stored knowledge, and has become the foundation for the market expansion of AI technologies in various sectors of the economy, from industrial engineering tasks to the widest commercial applications. AI has become the backbone of industrial and technological policy in the developed world.

AI has become the backbone of industrial and technological policy in developed countries, opening up new opportunities for the implementation of a full-scale smart factory concept and even AI-centric manufacturing. At the same time, some states rely on it as a critical technology for their development, which limits its dissemination abroad. For example, in the U.S., Bill 1260[1] was issued in 2021, which defined restrictions on the transfer of knowledge and technology related to AI for a number of countries (including Russia). Now these challenges are worsening, making the domestic economy more sensitive to global development trends. The Russian AI industry is facing the threat of isolation of our researchers from global science, developers are beginning to feel the shortage of hardware, and attempts are being made to completely block the industry's activities (including blocking GitHub accounts)[2].

1 S.1260 – United States Innovation and Competition Act of 2021 // Congress.gov,2021. — URL: congress.gov/bill/117th-congress/senate-bill/1260.

2 GitHub started blocking accounts of Russian companies and developers // BFM.ru, 2022. — URL: bfm.ru/news/497819. (in Russian)

As a result, there is a demand to move from a state of shock to a state of new openness, which means creating new international scientific partnerships and striving to achieve the necessary level of technological autonomy. It is worth paying attention to the risk of a new "winter of AI" in the use of individual tools and reduced access to hardware (similar to the situation in the 1980s). This circumstance may be particularly significant for the Russian Federation, which has been isolated from many technological chains for an indefinite period of time. Moreover, the "winter of AI" may turn out to be the main limiting factor for the recovery and growth of the domestic economy. After all, it is AI that can become the basis of modern reengineering technologies – the cornerstone of the new architecture of import-substituting programs.

Despite the fact that AI technologies are developing in different regions of the country, we believe that St. Petersburg can become one of the main platforms for the introduction of artificial intelligence in industry and create a stack of specialized technologies for the development of industrial AI, focused on supporting industry specialists who have to make decisions in conditions of uncertainty and incomplete data. The city already has a well-developed ecosystem for the development of promising solutions and systems, as well as the cooperation of a productive professional expert community with consumers – various industries. The ecosystem includes leading universities and research organizations of the city, the Association "AI in Industry," companies and development institutions actively investing in artificial intelligence. The report considers the mechanisms of industrial AI development through the efforts of the professional community and the Government of St. Petersburg.

PART 1

FROM SHOCK TO NEW OPENNESS

1.1 NEW RISKS OF THE AI MARKET

In an unstable geopolitical environment, the development of artificial intelligence technology in Russia is threatened by isolation. As a result of sanctions, funding is reduced, component supply chains are disrupted, and cooperation with Russian scientists is withdrawn 3. In an unstable geopolitical environment, the development of artificial intelligence technology in Russia is threatened by isolation. As a result of sanctions, funding is reduced, component supply chains are disrupted, and cooperation with Russian scientists is withdrawn. The sanctions are particularly painful with regard to the supply of dual-use products, such as chips and semiconductors. Hardware for the AI industry is extremely important. According to the estimate of the All-Russian Academy of Foreign Trade of the RF Ministry of Economic Development, the volume of imports of semiconductor products that fall under sanctions will be about $470 million in monetary terms - about a quarter of all imports of this type of products.

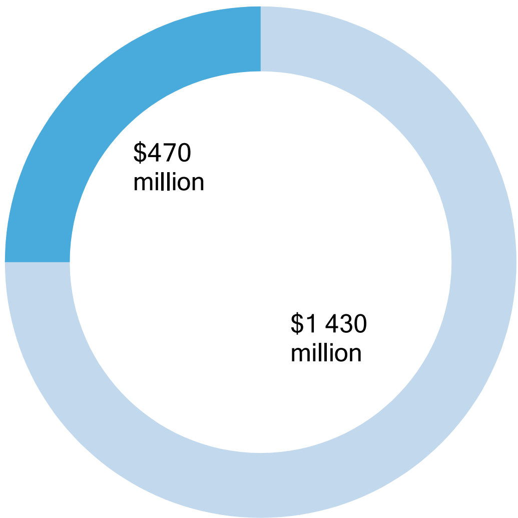

Fig. 2.
The volume of semiconductor imports to Russia that will be affected by economic restrictions

Source: BABT

The imposed restrictions affect almost all strategically important industries of the country: defense, aviation, shipbuilding, financial technology, telecommunications, etc. The withdrawal from the Russian market of the largest software suppliers (EPAM, Oracle, Microsoft and SAP), as well as the denial of service, will increase the vulnerability of industrial companies and increase the number of errors that complicate their work [4].

AI, while subject to similar restrictions, can nevertheless become one of the main mechanisms for the development of Russian industry in these conditions. It is seen as a tool for reengineering technologies in the real sector of the economy for the tasks of substituting import substitution. For example, the use of generative design methods makes it possible to reproduce and speed up the product creation cycle, taking into account the properties of materials, product load and other parameters [5]. AI also opens up opportunities for advanced import substitution, creating fundamentally new digital technologies in industries traditionally based on experimental approaches. Experts predict that by 2025, 30% of new drugs and materials will be designed using generative AI methods [6].

3 Nicholson C. EU blocks new Russian research deals and payments / C. Nicholson // ResearchProfessional News, 2022. — URL: researchprofessional news.com/rr-news-europe-politics-2022-3-eu-blocks-new-russia-research-deals-and-payments.

4 Gribov M. Import Substitution in IT: Digital Transformation in Russian Software / M. Gribov // RB.RU, 2022. – URL: rb.ru/opinion/importozameshenie-v-it. (in Russian)

5 Ayvazyan D. The future of engineering: what is generative design and how to use it / D. Ayvazyan // RB.RU, 2022. - URL: rb.ru/opinion/generativnyj-dizajn.(in Russian)

6 Goasduff L. The 4 Trends That Prevail on the Gartner Hype Cycle for AI, 2021 / L. Goasduff // Gartner, 2021. — URL: gartner.com/en/articles/the-4-trends-that-prevail-on-the-gartner-hype-cycle-for-ai-2021.

However, under conditions of restricted access to scientific and technical information (in particular, the withdrawal of WoS and Scopus [7] from the country) the infatuation with "one's own way" increases the risk of isolationism, which worsens the quality of research and aggravates the technological lag. Adapting the industry to the new reality implies building new international partnerships, changing cooperation formats and managing the protection of intellectual property rights. In any case, closure from the global scientific and technological community is not an acceptable strategy for the Russian AI sphere.

Supporting the scientific sector of the industry is of great importance. Four main risks can be identified here.

1 Risks of limiting the bilateral exchange of scientific and technical information

It is important to maintain cooperation with neutral platforms and highly ranked journals. The peculiarity of modern science is that breakthrough research and development arise predominantly in extensive multidisciplinary and interdisciplinary superclusters and networks. The risks include explicit and implicit restrictions on access to international abstract systems and databases, obstacles to the publication of articles in leading international journals, arising at the level of reviewing, opinions of members of the editorial board and chief editors. Such actions generate a backlash in the form of the refusal of domestic research teams to publish articles in the world's leading journals, the use of international databases, including WoS and Scopus, and the associated risk of loss of relevance and quality of research. From 1996 to 2021, 1,553 scientific papers written in collaboration with foreign researchers were published in Russia (19.8% of the total number of publications on AI).

The example of the development of Chinese science is illustrative. While under sanctions, China not only did not give up publishing in international journals, but also increased the volume of its presence in them. Separately, it should be noted that Decree No. 414 of the Government of the Russian Federation does not limit the use of foreign databases and the right of scientists to publish in highly rated journals [8].

7 Multi-Publisher Statement 31 March 2022 // Mailchimp, 2022. — URL: mailchi.mp/4851e2a74119/joint-publisher-statement.

8 Russian Federation. Decrees. On Some Issues of Application of Requirements and Target Values of Indicators Related to Publication Activity : Decree No. 414 : [adopted by the Government of the Russian Federation March 19, 2022]. – URL: ips.pravo.gov.ru:8080/default.aspx?pn=0001202203210040. (in Russian)

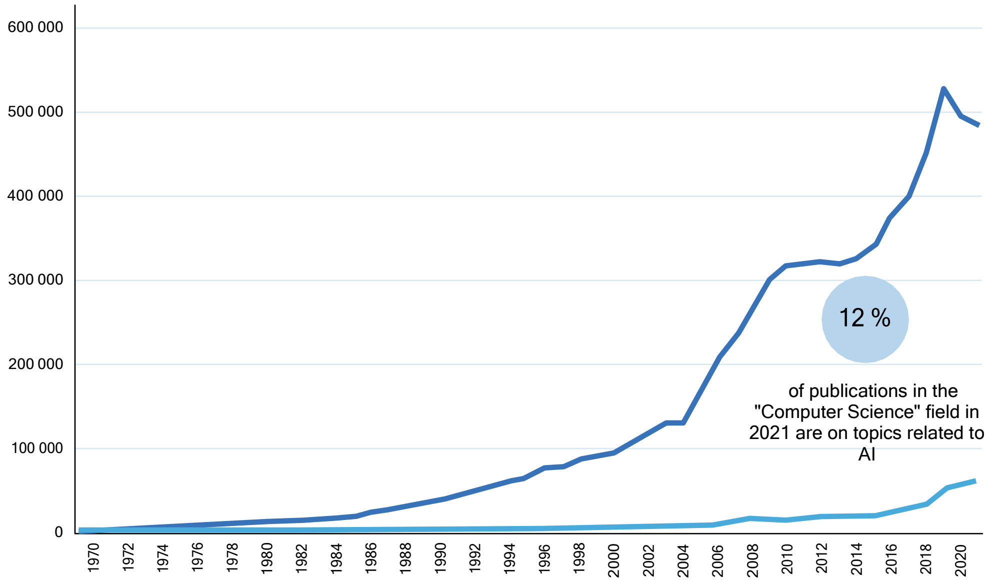

Fig. 1.
Соотношение количества публикаций по теме «Искусственный интеллект» внутри отрасли знаний «Компьютерные науки» с общим количеством публикаций внутри компьютерных наук. Scopus, 1970-2021

Source: Scopus

2 Risk of loss of quality of expertise of scientific projects

In order to maintain a high level of expertise, it is necessary to form an effective and independent internal system of research evaluation by experts working in the industry. Such an initiative has already been implemented by the Analytical Center for the Government of the Russian Federation for a grant competition for the creation of AI research centers. An Expert Council was formed to select applications and determine which centers have a chance for maximum development and specific results [9].

[9] Six AI research centers will receive federal grants of up to 1 billion rubles // Analytical Center for the Government of the Russian Federation, 2021. — URL: ac.gov.ru/news/page/6-issledovatelskih-centrov-po-ii-polucat-federalnye-granty-do-1-mlrd-rublej-27059. (in Russian)

3 Risk of reduced cooperation in the scientific sector (even within the Russian Federation)

There may be a decrease in the resources available for AI research and a loss of research guidance among those teams that were involved in international collaborations that have ceased operations. It is necessary to involve the six AI research centers created in 2021, the specialized STI competence centers, and all interested universities and industry associations in cooperation. Collaborations can be formed by: creating an internal repository of research (including open source); developing a format for grants and programs focused on interinstitutional cooperation; and establishing a specialized journal capable of reaching the level of highly ranked publications (Q1) in the world in the future.

4 The risk of reducing the effectiveness of state support in the field of AI

The scope of the research tasks is broad, and resources are limited. It would be reasonable to focus on tasks and super-tasks of great public importance. Regular evaluation of research results would help to identify risks of losing priorities and threats to the interests of the state. Commissions have been established in the UK with similar objectives. In addition to the bibliometric review, an expert commission meets every three to four years to evaluate previously published scientific articles according to the level of significance (world significance, national, regional, not significant publication). Every 15 – 20 years a commission is formed to study the national publications in the fundamental fields of knowledge.

In a situation when many technologies will be inaccessible for Russian enterprises, the issue of own advanced developments that will be able to ensure efficient functioning of production facilities, reduction of production costs, digital transformation of existing approaches and solution of new tasks in key sectors of the economy will become acute. However, transferring, for example, all mechanical engineering products in Russia to the domestic electronic component base will require large time and financial expenses. AI will be a necessary component of such technologies. It is extremely important that investments in artificial intelligence in the coming years have a sufficient volume and focus on technologies that provide breakthroughs in manufacturing, scientific and design developments and consumer services in Russia.

1.2 IS A NEW "AI WINTER" POSSIBLE?

Despite the significant potential for the further application of AI, there are serious challenges that could limit the further expansion of this market. Experts are admitting that a new "winter of AI" is coming. The main reason is the hardware limitations caused by supply chain breakdowns and reaching the limits of computational capabilities.

Over the past 10 years, we have seen the third wave of large investments in AI. From 2012 to 2020, the cumulative amount of investment in AI was about $346.4 billion. Compared to 2012, the volume of investment has increased 26-fold [10]. AI is present in almost every product in the Google ecosystem (Search, Cloud, Gaming) [11]. In 2020, a Gartner study found that 66% of companies surveyed have increased or not changed their investments in artificial intelligence since the COVID-19 pandemic began [12]. It can be argued that companies see AI primarily as a tool for solving specific application problems [11].

But for all the investment, high rate of development and adoption of AI technologies, there are still no reliable and mass solutions in the field of unmanned cars, autonomous control systems for smart devices, self-learning digital assistants [13]. In 2016, Business Insider predicted that 10 million unmanned cars will be on the road by 2020 [14]. In 2019 Elon Musk was sure - in a year there will be 1 million autonomous taxi in the world [15], and in 2022 there will be a robot with strong AI [16]. None of these predictions have come true yet. Excessive optimism about the progress of artificial intelligence is dangerous: if technology development fails to meet existing expectations (and investments), a new "winter of AI" may ensue, with an outflow of funds and research from the industry, similar to past stages of AI development [17, 13].

In the 1960s, the first AI researchers believed that it would be some 10 years before there were intelligent machines capable of human-level thinking [18]. Nevertheless, even now algorithms are far from reproducing human thinking. Researchers were interested in using deductive learning methods. American scientists created a mathematical model of the human brain neuron, the first neural network (perseptron) and the first neurocomputer that recognized Latin letters [19]. In the mid-1970s, British scientist James Lathill and the DARPA research organization issued parallel reports questioning whether AI research would benefit in the near future [20, 21].

In the 1980s, AI was based on two technologies: 1) rule-based expert systems; 2) neural networks, which emerged from the emergence of new learning algorithms [19]. And at the end of the decade, a series of events (the collapse of the LISP * machine market, the lack of meaningful results in the Fifth Generation Project) led to the "winter of AI," an outflow of investment and research from the industry. The deductive approach turned out to be a dead end due to the lack of necessary capacities, the complex system of rules, the impossibility of creating a knowledge base for new areas of science [22].

During the "winter of AI," machine learning (ML) was developing; it started as statistical learning theory, then moved to inductive inference methods [23]. By the 2010s, this wave received a strong impetus with the emergence of neural networks learning from large data sets [18].

The main driving force behind modern machine learning is deep learning, the deployment of more extensive neural networks on faster computer hardware that can collect and process large amounts of training data. This strategy of "scaling up" has evolved since ImageNet (2012), which launched the deep learning revolution [24].

10 Total VC investments in AI by country and indus- try // OECD.AI, 2022. — URL: oecd.ai/en/data?selectedArea=invest- ments-in-ai&selectedVisualization=total-vc-invest-ments-in-ai-by-country-and-in- dustry

11 Artificial Intelligence Software Revenue to Reach $59.8 Billion Worldwide by 2025 // Businesswire, 2017. – URL: businesswire.com/news/home/20170502006394/en/Artificial-Intelligence-Software-Revenue-to-Reach-59.8-Billion-Worldwide-by-2025-According-to-Tractica.

12 Gartner Survey Reveals 66 % of Organizations Increased or Did Not Change AI Investments Since the Onset of COVID-19 // Gartner, 2020. — URL: gartner.com/en/newsroom/press-releases/2020-10-01-gartner-survey-revels-66-percent-of-orgnizations-increased-or-did-not-change-ai-investments-since-the-onset-of-covid-19#:~:text=October%201%2C%202020,Gartner%20Survey%20Reveals%2066%25%20of%20Organizations%20Increased%20or%20Did%20Not,the%20Onset%20of%20COVID%2D19.

13 Mitchell M. Why AI is Harder Than We Think / M. Mitchell // Arxiv, 2021. – URL: arxiv.org/pdf/2104.12871.pdf.

14 10 million self-driving cars will be on the road by 2020 // BI Intelligence, 2016. – URL: businessinsider.com/ report-10-million-self-driving-cars-will-be-on-the-road-by-2020-2015-5-6.

15 Funding a Revolution: Government Support for Computing Research // National Academy Press, 1999. — URL: web.archive.org/web/20080112001018/http://www.nap.edu/readingroom/books/far/ch9.html.

* Lisp – a programming language that uses expert systems methods.

Eleven years later, deep learning still dominates the development of machine learning: 2021 was the year of "monster AI models [25].

Deep learning has been criticized for being too resource intensive. According to optimistic forecasts, to get the error rate of 5% for the ImageNet database, it is necessary to increase calculations by 105 gigaflops. Costs would increase by 1010 dollars, CO2 emissions would increase by 104 lbs [26].

16 Musk announced the creation of humanoid robot Tesla Bot // Forbes, 2021. — URL: forbes.ru/newsroom/milliardery/437783-mask-obyavil-o-sozdanii-chelovekopodobnogo-robota-tesla-bot.

17 The dark ages of AI: A panel discussion at AAAI-84 / McDermott D., Waldrop M. M., Schank R. [et al.] // AI Magazine. – 1985. – № 8–3. – С. 122–134.

18 Brooks R. An Inconvenient Truth About AI – AI won't surpass human intelligence anytime soon / R. Brooks // IEEE Spectrum, 2021. — URL: mordorintelligence.com/industry-reports/natural-language-processing-market.

19 Yasnitsky L. Winter is comin. Why artificial intelligence may lose popularity / L. Yasnitsky // NRU HSE, 2019. – URL: https://iq.hse.ru/news/298467405.html.

20 Nield T. Deep Learning Already Hitting its Limitations? / T. Nield // Towards Data Science, 2019. – URL: towardsdatascience.com/is-deep-learning-already-hitting-its-limitations-c81826082ac3.

21 Funding a Revolution: Government Support for Computing Research // National Academy Press [сайт], 1999. — URL: web.archive.org/web/20080112001018/http://www.nap.edu/readingroom/books/far/ch9.html.

22 Hawkins A.J. Here are Elon Musk's wildest predictions about Tesla's self-driving cars / A.J. Hawkins // The Verge , 2019. – URL: theverge.com/2019/4/22/18510828/tesla-elon-musk-autonomy-day-investor-comments-self-driving-cars-predictions.

23 Based on an interview with L.V. Utkin (SPbPU) // CSR "North-West" Foundation, 2021.

24 Ford M. Rule of the Robots: Warning Signs / M. Ford // IEEE Spectrum , 2021. – URL: spectrum.ieee.org/rule-of-the-robots-book.

25 Heaven W. D. 2021 was the year of monster AI models / W. D. Heaven // MIT Technology Review, 2021. – URL: technologyreview.com/2021/12/21/1042835/2021-was-the-year-of-monster-ai-models/?truid=&utm_source=the_download&utm_medium=e-mail&utm_campaign=the_download.unpaid.engagement&utm_term=&utm_content=12-22-2021&mc_cid=eced389005&mc_eid=fdfcf859c6.

26 The Computational Limits of Deep Learning / N. C. Thompson, K. Greenewald, K. Lee, G. F. Manso / arXiv , 2020. — URL: arxiv.org/abs/2007.05558.

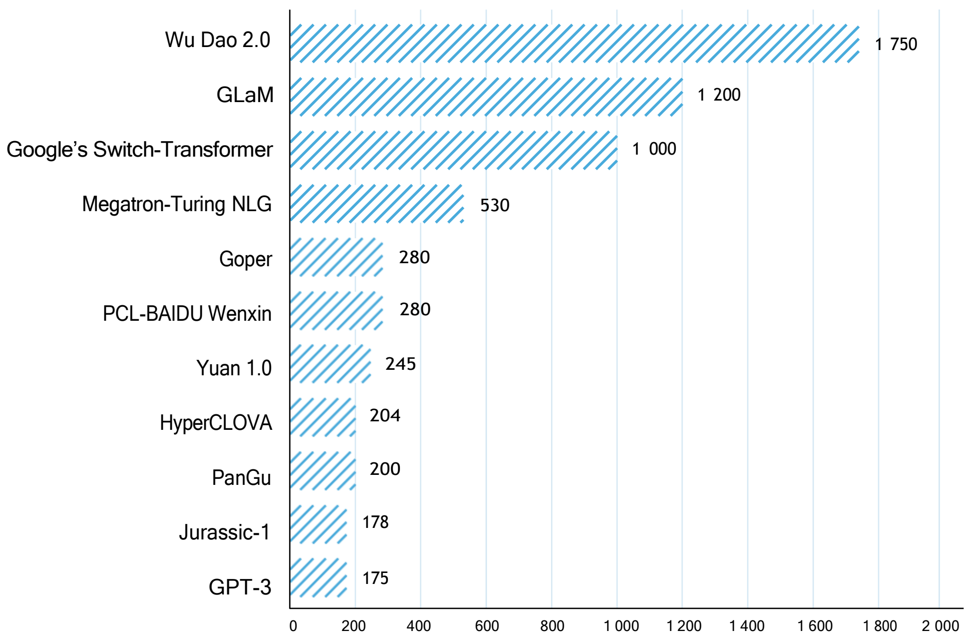

Fig. 4.
Number of parameters of modern AI models, billion parameters

Source: MIT Technology Review

In addition to the resource cost, further development of deep neural networks is hindered by the following limitations [27, 24].

— "fragility" – the system is incapable of adapting to small changes in input data;
— the quality of neural networks depends on the quality and quantity of incoming data;
— catastrophic forgetting – when neural networks learn a new task, old tasks are forgotten;
— inability to explain the results of problem solving using neural networks in high-risk situations;
— "self-reliance" of machine learning algorithms – the AI must understand when it is unsure of results or does not have enough knowledge about an object, and act accordingly (e.g., transferring control of a car to a human when a completely new object on the road is detected);
— the AI's lack of common sense - the ability to assess circumstances and act in accordance with them;
— neural networks are not good at solving mathematical problems.

In addition, there are mathematical constraints in the form of the question about the equality of P and NP complexity classes. In case of a positive answer (P equals NP) many complex problems will be solved much faster than now [28]. Half a century after the problem was formalized, more and more scientists are inclined to believe that P does not equal NP. This barrier to AI research may never be overcome, and the complexity of algorithms will always limit our ability to [20].

Despite a number of global preconditions that could bring the AI market into a state of "winter," it is unlikely that this will happen to all of its segments. Only some of them will be slowed down. Specialists believe that the industry will come to a deviation from the strategic direction of deep learning: once research moved away from expert networks, and now they will be able to move away from ML, relying entirely on neural networks [23].

For the Russian market, the situation of "winter AI" may be associated with a shortage of hardware due to the breakdown of supply chains, fundamentally important for working with large neural networks. This may lead to a focus of available resources on tasks secured by an order in a limited range of industries.

27 Chivers T. How Deepmind is Reinventing the Robot / T. Chivers // IEEE Spectrum [сайт], 2021. — URL: spectrum.ieee.org/how-deepmind-is-reinventing-the-robot.

28 Equality of P and NP classes // Academic: Academic Dictionary, 2010. — URL: dic.academic.ru/dic.nsf/ruwiki/93836. (in Russian)

1.3 INDUSTRY IS THE MOST IMPORTANT DRIVER OF MARKET GROWTH

Businesses and organizations in all industries are increasing their investments in AI in order to maintain competitiveness and improve efficiency. For example, a Harvard Business Review study found that increased robotic transactions through the use of AI leads to increased sales. According to reports from consulting firms, the number of robotic transactions is expected to reach the $10.1 billion mark in 2019 [11]. Overall, spending on AI systems is projected to grow from $85.3 billion in 2021 to $204 billion in 2025, at an average annual growth rate of 24.5% [29].

The accumulated potential of Industry 4.0, which over the past decade has contributed to the automation and digitalization of industry, opens up opportunities for the development of AI. The information that is accumulating in industrial databases suggests that industry will be one of the key drivers of AI development. By 2027, the maximum growth rates of AI application will be in the production sphere - at the level of 31.1% CAGR. This is followed by logistics (CAGR of 24.7%), healthcare (CAGR of 22%) and the financial sector (CAGR of 21%) by a wide margin.

29 Investment in Artificial Intelligence Solutions Will Accelerate as Businesses Seek Insights, Efficiency, and Innovation, According to a New IDC Spending Guide // International Data Corporation, 2021. — URL: idc.com/getdoc.jsp?containerId=prUS48191221.

Software and IoT K
Cybersecurity
Defense sector
Financial sector
Manufacturing
Health Care
Transportation and Logistics
Retail
Other

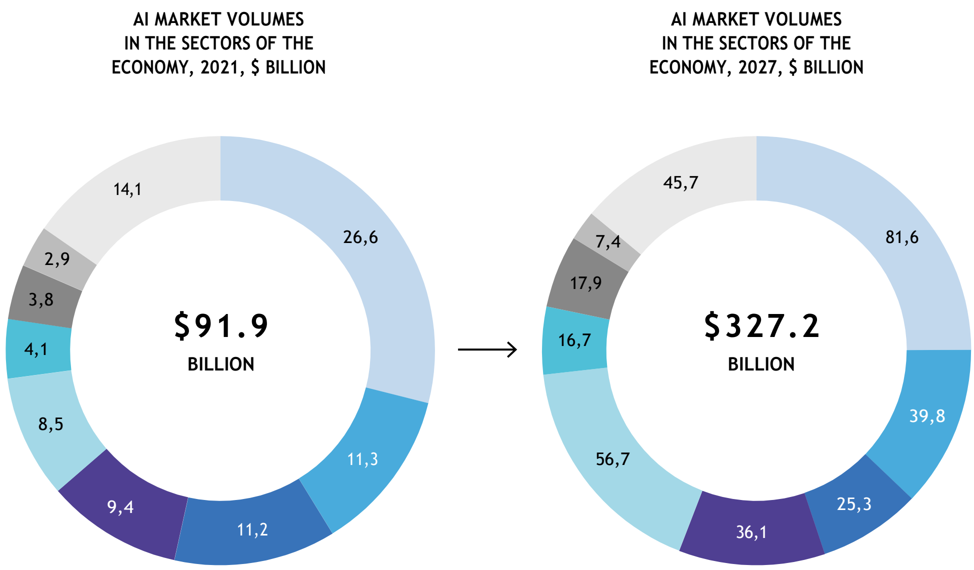

Fig. 5.
Volume of AI markets in economic sectors, 2021-2027, billion dollars

Source: CSR "North-West" Foundation according to data from 360iResearch,IMARC Group, Mordor Intelligence

Industry is among the drivers of the AI market in the US, China, the UK, India, South Korea and EU countries. It will also become one of the main customers for artificial intelligence and related research in Russia.

However, unlike in many developed countries, where the key roles belong to companies specializing in AI (e.g., DeepMind), in our country the oil and gas business will be of great importanceв [30, 31, 23]. This is explained by its high resistance to sanctions, as well as the need for industry solutions at different technological stages (including metal processing, machine building, construction, logistics, etc.). Along with metallurgy, the chemical industry and some other manufacturing industries, it is the oil and gas sector that claims to be the most active industry interested in the development of the AI technology market. Companies of the sector initiate large-scale cooperative projects and commission research and development in this area. In 2021 the Association "Artificial

30 Based on an interview with V. V. Klimov (MEPhI) // CSR "North-West" Foundation, 2021.

Intelligence in Industry" was created (founded by PJSC "Gazprom Neft", later joined by PJSC "Tatneft"). The Association supports research centers and teams of scientists engaged in AI, implements educational programs for university students and employees of industrial enterprises, and holds events to develop the market of AI technologies.

The oil and gas industry also plays a significant role in the global AI market. The focus of developed countries on decarbonization, increased competition on the market of oil and gas raw materials - under these conditions, great hopes are pinned on artificial intelligence. Companies are joining consortia, directing their joint efforts to create large-scale AI technologies that help solve operational and production efficiency issues. One of the most vivid examples is the consortium of Shell, Baker Hughes, C3 AI and Microsoft, implementing the Open AI Energy Initiative [32].

31 Based on an interview with M. V. B Bolsunovskaya (SPbPU) // CSR "North-West" Foundation, 2021.

32 Shell, C3 AI, Baker Hughes, and Microsoft Launch the Open AI Energy Initiative, an Ecosystem of AI Solutions to Help Transform the Energy Industry // C3.ai, 2021. — URL: c3.ai/shell-c3-ai- baker-hughes-and-microsoft-launch-the-open-ai-energy-initiative-an-ecosystem-of-ai-solutions-to-help-transform-the-energy-industry.

UPSTREAM

AI IN GEOLOGICAL RESEARCH
— Formation analysis
— Seismic data acquisition
— Seismic data processing
— 3D imaging of seismic data

AI IN EXPLORATORY DRILLING
— Well planning
— Drilling rig automation
— Drilling monitoring
— Drilling optimization in real time
— Well testing with intelligent sensors
— Equipment failure forecast

AI IN THE EVALUATION
— У Geological and geophysical data management
— Digitization of well logs
— Interpretation of well logs
— Estimation drilling calculations
— Reservoir simulation
— Reservoir characterization

AI IN FIELD DEVELOPMENT
— Location of wells and optimization, control of well functioning, etc.

AI IN OIL PRODUCTION
— Providing reservoir pressure, safety control, layer behavior prediction, etc.

MIDSTREAM

AI IN THE CONSTRUCTION OF PIPELINES
— Optimization of the pipeline construction route
— Determination of terminal locations and pipeline connections

AI IN TRANSPORTATION
— Calculation of the most economical route
— Autopilot and docking systems
— Tanker monitoring

AI IN THE OPERATION OF PIPELINES
— Compressor station automation
— Early warning of malfunctions
— Corrosion monitoring and diagnostics

AI IN RESOURCE ALLOCATION
— Analysis of economic and weather conditions to forecast demand
— Storage optimization

DOWNSTREAM

AI IN PETROLEUM REFINING
— Automation and asset optimization of refinery processes
— Use of sensors and microcontrollers for infrastructure maintenance and early warning of accidents

AI IN THE MANAGEMENT OF THE OIL STORAGE FACILITY
— Predictive analytics and predictive control algorithms
— Reduction of warehouse operating costs
— Efficient equipment maintenance

AI IN SAFETY AND ENVIRONMENTAL PROTECTION
— Remote monitoring of storage areas and equipment
— Leak detection
— Equipment deformation detection

Fig. 6.
Typical applications of AI in the oil and gas industry

Source: CSR "North-West" Foundation according to data from King's College London, European Centre for Energy and Recourse Security

Metallurgy is paying a lot of attention to AI applications. Even today, the range of AI applications is quite wide. Just like in the oil and gas industry, it covers all the main technological process stages: mining, ore processing, iron and steel production, rolling, logistics, sales and marketing. Metallurgical companies are actively developing partnerships in this area. NLMK Group has entered into a strategic partnership agreement with the Association of Artificial Intelligence Laboratories, planning to expand cooperation in the digitalization of various production processes, including Internet of Things and artificial intelligence technologies [33].

33 NLMK Group tests Internet of Things and Artificial Intelligence innovations // NLMK, 2021. — URL: nlmk.com/ru/ media-center/press-releases/ nlmk-pilots-iot-and-ai- innovations. (in Russian)

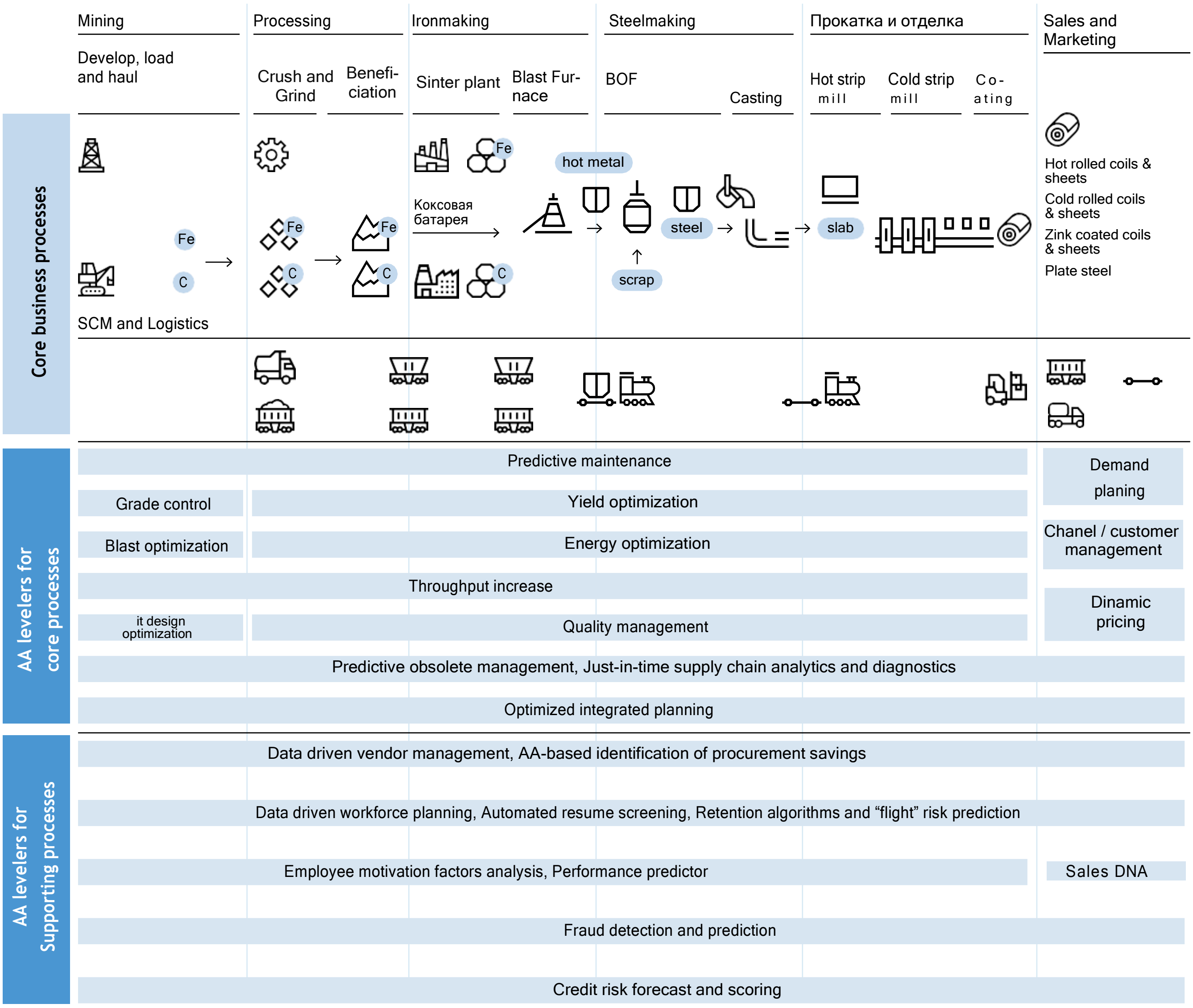

Fig 7.
Typical applications of AI in the metallurgical industry

Source: NLMK [34]

34 Arshavsky A. Artificial Intelligence in Metallurgy / A. Arshavsky // NLMK,2018. – URL: cloud-digital. ru/sites/default/files/13.25-13.45_arhavsky_nlmk_new.pdf. (in Russian)

Similar trends are observed in other industries, which indicates the potential of the sector, as well as the specifics of the domestic AI market. In the context of sanctions restrictions and the breaking of international technological chains with the participation of Russian enterprises, Russian industry faces systemic challenges related to the search for ways to achieve technological autonomy and self-sufficiency. Domestic solutions in the field of artificial intelligence are one of the most important means to move in this direction.

PART 2

LONG-TERM AI PERSPECTIVES

2.1 THE FUTURE OF AI COMPUTING

The science of artificial intelligence relies heavily on advances in related fields - computing and data manipulation. Since these fields of knowledge form the basis for the development of AI, they should be considered in the first place. Overcoming a number of fronts in these areas can provide significant progress in the field of artificial intelligence.

The stormed zones are called differently in different research teams and countries - increasing the parameters of AI models, increasing the complexity of algorithms, reverse brain engineering, conversational intelligence, etc. [35]. For the Russian AI market, the specifics of the frontier zone may not coincide with the global one.

Frontiers in computing technology

1 Quantum computing

Quantum artificial intelligence, i.e., an AI whose calculations are performed by a quantum computer [36], is still far from being realized: 8-cubic and 16-cubic quantum computers are used in basic science, but they do not bring significant results in the science of artificial intelligence [37].

Most of the classical AI algorithms have already been translated for quantum computers, so the main frontier at the moment is to create a quantum computing system that can be used in machine learning tasks with greater efficiency than traditional computing hardware [31].

To do this, quantum computing systems must become more error stable and more powerful. It is necessary to create frameworks for modeling and training AI systems, which would become generally accepted at the expense of open source and contribute to the development of the developer community and the emergence of new scenarios of quantum AI applications [31].

35 Shumsky S. A. Raising Machines: A New History of Mind / S. A. Shumsky. – Moscow: Alpina Non-Fiction, 2021. – 174 p. (in Russian)

36 Dilmegani C. In-Depth Guide to Quantum Artificial Intelligence in 2022 / C. Dilmegani // AI Multiple, 2022. – URL: research.aimultiple.com/quantum-ai.

37 Based on an interview with A.A. Filchenkov (ITMO) // CSR "North-West" Foundation, 2021.

2 Distributed systems

Traditionally, AI models are trained on high-performance SIMD-architecture systems (servers with graphics cards). However, working with large-scale AI models and, most importantly, with big data requires the development of specialized distributed systems that include geographically dispersed computing systems of different architectures, which may belong to different owners. For these systems the task of model training becomes hierarchical. The main problem in such distributed systems is porting machine learning model architectures to them, especially with respect to data placement. It is also necessary to develop methods to implement parallel computing in these systems, including scheduling and resource management [31].

Solving the above tasks will significantly improve the ability to collaborate scientific groups and facilitate access to data located in distributed sources [31].

3 Neuromorphic computing

Modern computing is based on von Neumann architectures, which involve the movement of data between physically separated processor and memory. In such an environment, processor power downtime is inevitable during intensive computations, especially in artificial intelligence tasks, which are more dependent on large amounts of data than others.

The answer to this challenge will be the transition of the computing hardware used to run AI models to neuromorphic systems, whose structural elements can simultaneously store and process data like brain neurons. The systems are based on spiking neural networks, which act as a substitute for modern processors. Instead of transistors, artificial neurons are used, each of which is capable of functioning independently and sending signals to other neurons in the network. By coding information in the signals themselves and their periodicity, spiking neural networks mimic natural learning processes in response to external stimuli.

There remain limitations in the development of neuromorphic computing systems due to the high cost and complexity of scaling. Although many neuromorphic systems enable real-time training, the initial training of AI models still has to be done on traditional architectures. Neither have instruction set architectures (ISAs) been developed for neuromorphic processors that can realize their full potential. Another promising direction is the development of task-specific artificial intelligence models, which are built directly into the hardware of neuromorphic systems - analog AI.

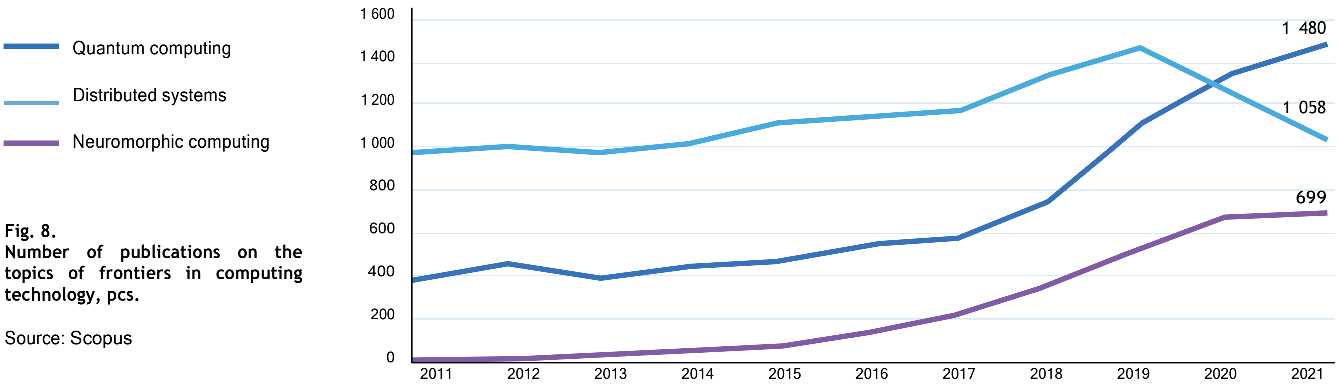

Fig. 8.
Number of publications on the topics of frontiers in computing technology, pcs.

Source: Scopus

AI methodological frontiers and data handling

1 Integration of neural network and cognitive approaches

The knowledge-based approach to AI is called cognitive (symbolic) [38]. It was the basis for the expert systems that were developed in the 1980s. At present, there is renewed interest in this area because it is knowledge, rather than data, that can be the basis for autonomous decision-making by artificial intelligence [39] and the transfer of experience from one task to another [40]. This will allow the application of AI in unformalized areas and the creation of multilayer artificial intelligence systems for business, consisting of multiple agents acting on the basis of knowledge (emergent intelligence systems) [39]. However, the problem of integrating knowledge into the architecture of existing neural networks remains unresolved [38].

2 Hybrid intelligence systems

Hybrid intelligence involves creating systems in which artificial intelligence works in conjunction with natural intelligence, empowering humans without giving full control to the machine [41].

The frontier in creating hybrid intelligence systems is ensuring the interoperability of natural and artificial intelligence [41].

Overcoming this obstacle depends on progress in understanding the laws of human intelligence, the development of tools to transfer information from human to machine and vice versa, and the development of hybrid intelligence ecosystems that would allow easy integration of new products [42].

3 Generative Artificial Intelligence

Generative AI systems have the potential to enable automatic creation of new artificial intelligence systems, as well as different creative content. Key frontiers in generative AI are formalization of uncertainties associated with calculating the probability of response to generated content, and search space traversal problems - new optimization algorithms for content generation [43].

4 Reinforcement learning

Current reinforcement learning methods are at a standstill because their application to real-world problems faces the problem of needing a large number of error-free iterations, which requires long-term training. The frontier will be improving the robustness of reinforcement learning methods to errors and anomalies in the data [23].

38 Based on an interview with A. V. Samsonovich (NRNU MEPhI) // CSR "North-West" Foundation, 2021.

39 Based on an interview with P. O. Skobelev (IPUSS RAS) // CSR "North-West" Foundation, 2021.

40 Based on an interview with A. L. Tulupiev (SPbU) // CSR "North-West" Foundation, 2021.

41 Based on an interview with K.V. Krinkin (SPbETU "LETI") // CSR "North-West" Foundation, 2021.

42 Co-evolutionary hybrid intelligence (preprint) / K. Krinkin, Y. Shichkina, A. Ignatyev // arXiv, 2021. — URL: arxiv.org/ftp/arxiv/papers/2112/2112.04751.pdf.

43 Based on an interview with A. V. Bukhanovskii (ITMO) //CSR "North-West" Foundation, 2021.

5 Explainable Artificial Intelligence

The decisions that almost all AI models make defy explanation and interpretation. At the same time, for many applications, it is crucial to understand what makes a decision [23]. The frontier is not only to develop methods to explain AI decisions, but also to evaluate and test the workability and suitability of these methods for real-world problems [44].

44 Das A. Opportunities and Challenges in Explainable Artificial Intelligence (XAI): A Survey / A. Das, P. Rad // arXiv, 2020. – URL: arxiv.org/pdf/2006.11371.pdf.

6 Artificial Intelligence Error Correction

Data-driven artificial intelligence can make errors that are difficult to track. The greater the dimensionality of an AI model, the greater its error risk and the lower its suitability for making risky decisions [45]. Separate systems should appear in the architecture of artificial intelligence models that will track and correct errors and "unlearn" AI models [45, 39].

45 Based on an interview with A. N. Gorban (University of Leicester, UK) // CSR "North-West" Foundation, 2021.

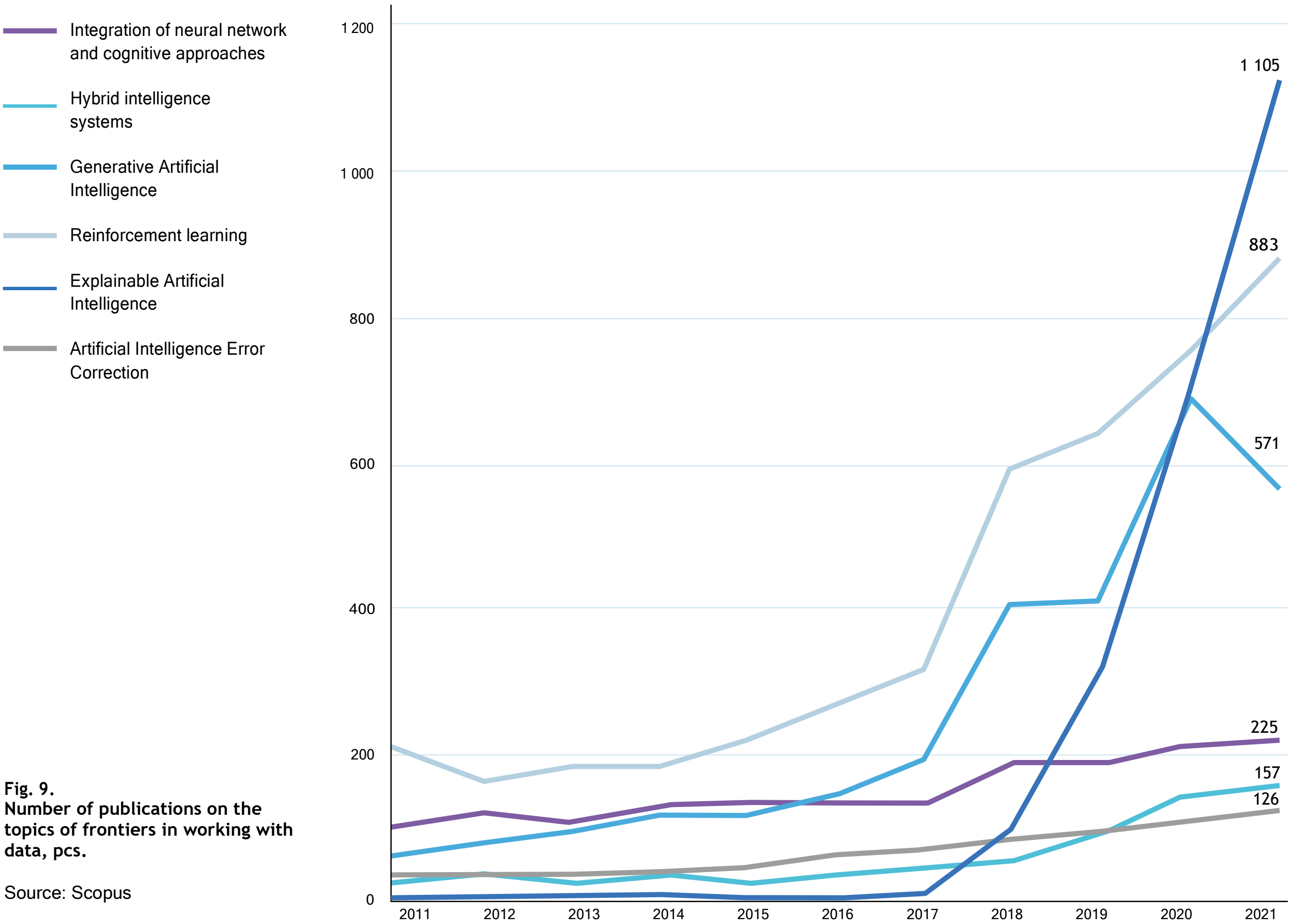

Fig. 9.
Number of publications on the topics of frontiers in working with data, pcs.

Source: Scopus

2.2 CHALLENGES OF AI HARDWARE DEVELOPMENT

By the early 2020s, humanity is close to the threshold of Moore's Law*. It is expected that in the first half of the decade, the leaders of the semiconductor industry will launch chips with processor dimensions of 3-4 nm or less. For now, this remains the frontier of semiconductor industry development, but it is already clear that this level will be reached.

This level of dimensionality opens up new computational opportunities for the IT industry. AI systems are becoming more and more productive. At the same time, they have a similar rate of development as the chip size growth. According to Google programmer Cliff Young, the number of internal projects focused on AI at Google doubles every 18 months [46], which corresponds to the growth rate of the number of transistors placed on an integrated circuit chip - 18-24 months (Moore's law).

At the same time, another empirical law, named after Jensen Huang, the CEO of NVIDIA, has been actively used in the discussion of computational prospects for AI systems. According to Huang's law, graphics processing units (GPUs) are progressing much faster than central processing units (CPUs), and the performance of the silicon chips that enable artificial intelligence is more than doubling every two years [47]. Compared to Moore's Law, which focuses solely on CPU transistors, Huang's Law encompasses the totality of advances in architecture, interconnects, memory technology, and algorithms.

Discussions about AI hardware (including Huang's Law) in the last two years have increased the intensity of the search for the frontier of silicon electronics development. Whether microelectronics will find an alternative to the silicon platform or enter new technological solutions to maintain performance growth at the right level of energy efficiency of computing systems (including for AI) is the main scientific frontier of hardware development for the next 15 years. It is artificial intelligence that is driving the demand for more high-performance computing systems. Watching the direction of artificial intelligence development is key to understanding the trend of computing systems in general.

A new generation of self-learning neuromorphic processors

The most important frontier of hardware development for AI systems is the search for new computing architectures. One of the central focuses of this development is the creation of neuromorphic processors, which will enable biosimilar neuromorphic computing with increased efficiency.

In 2017, Intel developed the Loihi neuromorphic digital processor with on-chip learning capability. Loihi works on the same principles as the human brain and contains 130 thousand artificial neurons and 130 million synapses [48], and learning takes place using different types of feedback.

In 2021, a second-generation processor (Loihi 2) and an open-source Lava programming environment were introduced to create applications for neuromorphic 49 processors, a development that helps significantly increase the speed and energy efficiency of AI. Improvements to the Loihi 2 architecture enable new classes of neuromorphic algorithms and applications, providing up to a 10x improvement in processing speed [49]. Nephromorphic chips solve a wide range of tasks: application of computer vision, voice and gesture recognition, search and optimization (local search).

* Moore's Law is an empirical observation, originally made by Gordon Moore, according to which (in the modern formulation) the number of transistors placed on an integrated circuit chip doubles every 24 months (source: Explanatory English-Russian Dictionary of Nanotechnology. - M.,B. V. Arslanov, 2009).

46 Ray T. B Google says 'exponential' growth of AI is changing nature of compute / T. Ray // ZDNet, 2018. – URL: zdnet.com/article/google- says-exponential-growth-of-ai- is-changing-nature-of-compute.

47 Mims C. Huang's Law Is the New Moore's Law, and Explains Why Nvidia Wants Arm / C. Mims // The Wall Street Journal [сайт], 2020. — URL: wsj.com/articles/huangs-law-is-the-new-moores-law-and-explains-why-nvidia-wants-arm-11600488001.

48 Intel Loihi // TAdviser, 2022. — URL: tadviser.ru/index.php/%D0%9F%D1%80%D0%BE%D0%B4%D1%83%D0%BA%D1%82:Intel_Loihi_(%D0%BD%D0%B5%D0%B9%D1%80%D0%BE%D0%BC%D0%BE%D1%80%D1%84%D0%BD%D1%8B%D0%B9_%D0%BF%D1%80%D0%BE%D1%86%D0%B5%D1%81%D1%81%D0%BE%D1%80). (in Russian)

49 Intel Loihi 2 neuromorphic processor and Lava programming environment introduced // Research and publication aspect, 2021. – URL: ixbt.com/news/2021/09/30/intel-loihi-2-lava.html. (in Russian)

Intel has already created robotic arms, neuromorphic artificial skin and an odor recognition algorithm using the Loihi chip.

The all-analog Brain-on-a-chip developed at MIT was an important step toward the emergence of portable, low-power neuromorphic chips for pattern recognition and other learning tasks. The inventors claim: This design of artificial synapses will allow for much smaller portable AI-powered devices capable of performing complex calculations that are currently only available to large supercomputers [50].

Research in the field of neuromorphic computing and processors is also underway in Russia. This area is being developed by teams from MIPT, Skoltech, ETU "LETI" and other universities and research centers.

50 Chu J. Engineers design artificial synapse for "brain-on-a-chip" hardware / J. Chu // MIT, 2018. – URL: news.mit.edu/2018/engineers-design-artificial-synapse-brain-on-a-chip-hardware-0122.

Quantum processors

There are high expectations for quantum computing: it will help to overcome the computational barriers associated with the end of Moore's Law. Qubit-level computational control can open up new opportunities for AI beyond the binary system: to reduce error and increase computational accuracy, and to improve data processing.

In 2020, IBM launched a 27-bit quantum PC. By 2023, the company plans to quadruple the capacity of its quantum computers [51]. Back in 2019, Google Corporation announced the creation of the world's first 54-cc processor. The computer based on it performed specific calculations that would take thousands or even tens of thousands of years for an ordinary PC.. The QuantWare developers, which aims to produce affordable quantum processors and related systems, believe that after 2025 [51] or maybe even earlier, quantum technologies will spread much more actively than now, and they can be used in a large number of industries.

51 Quantum processors go on sale: what they can and are for designed for? // Selectel, 2021. – URL: nanonewsnet.ru/news/2021/kvantovye-protsessory-postupayut-v-prodazhu-chto-oni-mogut-dlya-chego-sozdany (in Russian)

2.3 HOW AI WILL CHANGE INDUSTRY

As noted above, one of the key areas where AI is expected to develop rapidly is industry. McKinsey estimates that artificial intelligence could generate about $3 trillion annually in eight industries (Figure 10) [52]. In absolute values, the largest profits are expected in the automotive industry and advanced electronics. The maximum effect in relation to revenue is predicted in the high-tech sector..

52 Notes from the AI frontier: Insights from hundreds of use cases / M. Chui, J. Manyika, M. Miremadi [et al.] // McKinsey, 2018. – URL: mckinsey. com/featured-insights/ artificial-intelligence/notes- from-the-ai-frontier- applications-and-value-of-deep- learning.

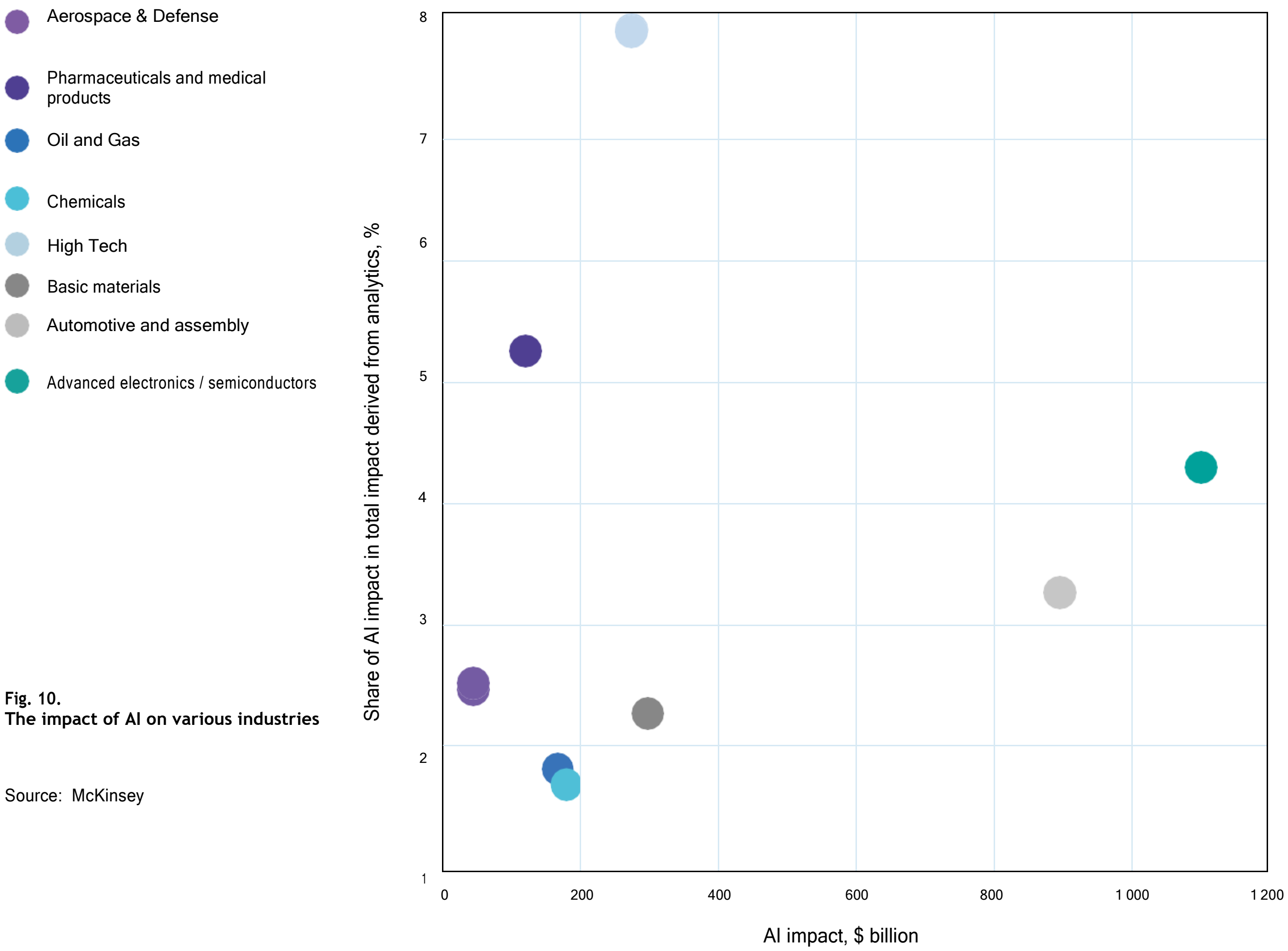

Fig. 10.
The impact of AI on various industries

Source: McKinsey

IoT Analytics, in its report on the industrial AI market in 2020-2025, highlights 33 applications of AI in enterprises using the Internet of Things [53]. For Russia, the most significant challenge is the development of engineering modeling systems, decision-making, and manufacturing systems using AI technologies. The development of these very areas could become a priority for reverse engineering support programs in the context of long-term sanctions restrictions and supply chain breakdown.

53 Rykov M. The Top 10 Industrial AI use cases / M. Rykov // IoT Analytics, 2019. – URL: iot-analytics.com/the-top-10-industrial-ai-use-cases.

AI-driven engineering

So far, AI applications have focused on smart manufacturing (increasing efficiency and reducing waste), generative design, and automated assembly robots. Typical automation does not solve the issues of individual orders of small batches (Batch Size 1 or Order of One). Automation must be replaced by autonomy, where robots are not reprogrammed by humans to produce a new product, but learn to assemble a variant on their own. Siemens Corporate Technology has developed such a robot, which can analyze the product model from CAD and find the appropriate assembly solution. LG CNS, using a cloud-based smart factory service, collects data throughout the production process and can predict potential defects in a batch before it is produced [54].

One of the big challenges here is the use of AI in additive manufacturing (AM). The main challenges of AM are how the 3D printer head will affect the microstructure of the resulting material, and how to control the AM process to produce parts with the desired characteristics. The solution is to use a surrogate model* that performs pre-optimization, real-time on-site process control thanks to AI in sensors, portability of the AI model between different devices and/or raw material types (heterogeneous materials for AM) [54].

In general, programmable sensors and AI-based peripheral computing are of paramount importance in terms of improving AI models for future digital and custom manufacturing [54].

54 Wunner F. How AI-driven generative design disrupts traditional value chains / F. Wunner, T. Krüger, B. Gierse // Accenture, 2020. –URL: accenture.com/us-en/blogs/industry-digitization/how-ai-driven-generative-design-disrupts-traditional-value-chains.

55 From Sanjeev Srivastava's speech at the seminar "AI Driven Design Approach" // YouTube-канал Machine Learning Center at Georgia Tech, 2020. – URL: youtube.com/watch?v=eitWsEM2ljk.

* A surrogate model is a simplified model that simulates the behavior of an object or system.

** Design Space Exploration (DSE) is the process of finding the design solution or solutions that best meet the desired design requirements through a space of preliminary design points.

Let's list the research tasks for AI-driven engineering [55]:

1. Creating interactive DSE ** to help professionals who design, but do not have the technical competence to develop models.

2. Determining the characteristics of the design solution space, when you can quickly conclude which part of the design solution is good or bad or has specific properties.

3. Automatic generation of design solution constraints / rules: rules and constraints ensure that the logical and physical aspects of the solution meet the design requirements.

4. Automatic task formulation: requirements and information about the past are given, and the system must automatically formulate the target function, given its constraints.

5. Automatic surrogate model generation: automating this process will eliminate the need to know ML-specific tools.

6. Parametric display in different scales: the ability to automatically change the parameters of complex systems at different scales with binding.

7. Automatic data collection from the terms of reference (TOR): a complex process that requires not only NLP, but also the study of the relationship between different parts of the TOR itself and the functions described in the document

8. Understanding changes over time through version control: since complex projects have many versions, the ability to analyze entities and relationships between objects in a project not only in statics, but also in dynamics is an issue.

9. Transferability of solutions to other projects / platforms: o this task is usually easier in theory than in practice.

10. The problem of algorithm selection: the choice of algorithm must be justified by the task.

AI-centered manufacturing

AI-centered systems include large-scale monitoring, distributed control systems, advanced communication systems, and various levels of artificial intelligence on the periphery [54].

The Internet of Things and artificial intelligence are two separate innovations that, in combination, significantly impact different industries. While the Internet of Things (IoT) is a system of sensors, AI serves as the brain that controls this system. The AI in Internet of Things sensors detects data collection errors, independently identifies patterns, builds logic chains, and draws conclusions [56].

To enable the AI itself to work directly and efficiently with data from IoT sensors, it is advisable to use a priori knowledge of the subject area, concentrated in a digital twin. A digital twin is a software analogue of a physical device that simulates the internal processes, technical characteristics and behavior of a real object under interference and environmental conditions [57]. It is used for planning, demand modeling, control, optimization, efficiency improvement.

AI, together with digital twins, captures everything that happens in production, and through data analysis helps operators make better operational decisions. The combination of these technologies can predict possible breakdowns in equipment and determine their cause, offer options for keeping equipment up and running, minimizing downtime [58].

The use of AI in manufacturing is not limited to the production of specific products. Artificial intelligence can collect and analyze data about the enterprise as a whole by integrating data from individual subsystems [59].

AI is seen as a critical element that will provide the next step in the evolution of production systems. While the 2010s saw digitalization, including the spread of IoT platforms, in the 2020s, AI will take on the role of the main development tool. It will enable the transition from traditional high-volume production to flexible production systems capable of cost-effective production of small series of products [60].

AI will become a basic element in the architecture of modern custom manufacturing systems. This implies at least four basic elements: smart devices, smart interconnections, an AI layer, and smart services. The advantage of such systems will be improved production efficiency, easier preventive maintenance, extended smart supply chains [60].

56 Perspectives on IoT and AI: Experts Discuss Ethical Dilemmas // Connect-wit, 2020. – URL: connect-wit.ru/perspektivy-iot-i-ai-eksperty-obsudili-eticheskie-dilemmy.html. (in Russian)

57 Automation systems and integration — Digital twin framework for manufacturing —Part 1: Overview and general principles // ISO, 2021. — URL: iso.org/ru/standard/75066.html.

58 Beck R. Digital Twins and AI: Transforming Industrial Operations / R. Beck // AspenTech. – URL: reliableplant.com/Read/31897/digital-twins-ai.

59 Prahladrao S. The Future of Manufacturing to be AI Driven / S. Prahladrao // ARC Advisory Group. – URL: arcweb.com/industry-best-practices/future-manufacturing-be-ai-driven.

60 Artificial Intelligence-Driven Customized Manufacturing Factory: Key Technologies, Applications, and Challenges / J. Wan, X. Li, H. Dai [et al.] // arXiv, 2020. – URL: arxiv.org/pdf/2108.03383.pdf.

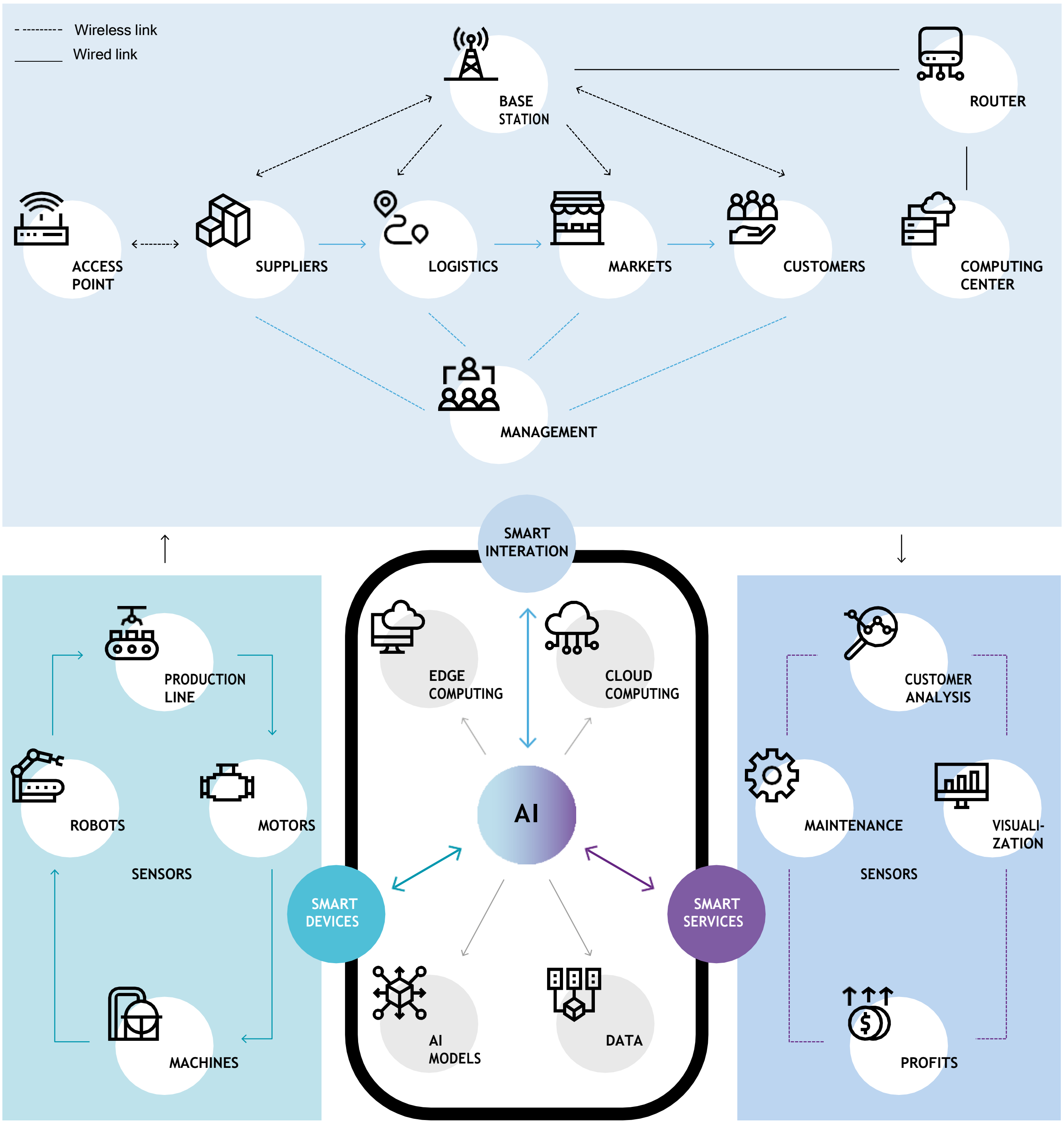

Fig. 11.
AI-based custom manufacturing architecture

Source: IEEE [60]

Industrial metaverse

A key strength of the metaverse is the ability to provide a holistic immersive experience in a virtual environment through ubiquitous and persistent connectivity. The industrial metaworld can contain digital twins of real objects, 3D models based on IoT data, and interactive platforms for data management and analysis.

Options for the use of the industrial metaverse [61].

- Increase brand awareness through virtual factory tours and interactive virtual events;
- virtual presentations of products and services;
- payments using blockchain, cryptocurrency and NFT technologies;
- collaborative research and development to design, model and test products and services;
- getting feedback from digital customers to improve the customer experience in the real world;
- industrial metaverse as a basis for companies to achieve carbon balance.

BMW has created a 3D virtual twin of the Regensburg factory for employees to work together from all over the world in real time. AB InBev has developed a comprehensive digital model of its breweries and supply chains. AB InBev is currently experimenting with "digital people" to simulate how real employees react to new work processes.

Adapting new technologies will require companies not only to purchase new equipment, but also to overcome the "digital mental gap" - the acceptance of influence from the virtual environment: ecosystem participants and potential customers.

61 Burian J. Is the 'Industrial Metaverse' the Next Big Thing? / J. Burian // Industry Week, 2022. — URL: industryweek.com/technology-and-iiot/emerging-technologies/article/21234184/is-the-industrial-metaverse-the-next-big-thing.

62 Bi Z. M. Safety assurance mechanisms of collaborative robotic systems in manufacturing / Z. M. Bi, C. Luo, Z. Miao [et al.] // ScienceDirect, 2021. –URL: sciencedirect.com/science/article/abs/pii/S0736584520302337.

63 Malik A. A. Digital twins for collaborative robots: A case study in human-robot interaction / A. A. Malik, A. Brem // ScienceDirect,2021. – URL: sciencedirect.com/science/article/abs/pii/S0736584520303021.

64 Human-robot collaboration: 3 Case Studies // Wevolver, 2020. – URL: wevolver.com/article/humanrobot.collaboration.3.case.studies.

Human-machine interaction (HRC)

Collaborative robots (cobots) are one of the mandatory components of Industry 5.0, a concept based on human-robot collaboration. Cobots can do no harm to humans or surrounding objects thanks to numerous sensors that monitor any movement around them [62]. Equipping a company with cobots gives a significant competitive advantage to business owners, including those working with "small batches" and "custom-made". The use of digital twins in man-machine systems will simplify design, integration, operations and reconfiguration of the system throughout its lifecycle [63].

Automotive manufacturers Dürr Systems AG and Ford are using KUKA's LBR iiwa collaborative robots for the labor-intensive and traumatic stage of installing the headlights and driver assistance system. The cobots have also been able to improve the quality and speed of assembly, which has reduced the cost of the car [64].

AI methods in industry

Traditional analytical methods, such as regression analysis, clustering, decision tree ensemble and other forms of logical inference, are actively used in various industries (Fig. 12). AI has great potential for application in various sectors, but it is not yet widespread, in part because of the relative immaturity of the technology and the organizational problems associated with deployment of these technologies [52].

Industry	Reinforcement l earning	Feedforward neural network	Recurrent neural networks	Convolutional neural network	Generative adversarial network	Tree-based ensemble learning	Dimensionality reduction	Classifiers	Clustering	Regression analysis	Statistical inference	Monte Carlo methods	Markov chain	Other optimization methods
Aerospace and defense	2	2	2	1	0	3	1	2	2	4	3	2	0	2
Pharmaceuticals and medical products	1	3	3	1	1	4	1	4	4	5	3	2	0	1
Oil and gas	2	3	1	2	0	4	1	2	1	4	3	2	1	1
Chemicals	1	2	2	1	0	3	1	2	2	3	3	2	0	1
High Tech	2	3	3	1	0	4	1	4	2	4	1	0	0	1
Basic materials	2	3	1	2	0	4	0	3	1	4	4	2	0	2
Automotive and assembly	2	4	2	3	0	5	1	4	3	5	3	1	1	1
Advanced electronics / semiconductors	2	3	2	2	0	5	1	4	3	6	3	1	0	2

Fig. 12.
Relevance of AI technologies for different industries (where 1 is low relevance, 6 - high relevance)

Source: McKinsey

AI will change the space industry

The next stage of space exploration involves the use of Industry 5.0 technologies. Researchers distinguish two technological bases for the development of Industry 5.0 [65]:

1. human-machine interaction: intelligent automation, smart factories;
2. bioeconomics: bio- and nanotechnology, biologization.

Industry 5.0 Concept Technologies [66]:

— human-machine interaction will open up the possibility of combining the strengths of humans and robots during manned missions, as well as implementing human telepresence technology in space (robot-avatar);
— biotechnology and smart materials: self-healing materials for spacecraft and spacesuit shells, lightweight materials that allow heavier cargoes to be transported to distant space, smart materials for temperature control;
— digital twins and simulations to create hundreds (or thousands) of possible space mission scenarios that take into account the many factors that affect the process of conducting activities in space;
— artificial intelligence, capable of making independent decisions and adaptable to new conditions, will increase the efficiency of automatic missions (autonomy of planetoids to work underground or in caves, coordination of satellite constellations among themselves, pre-processing of data);
— big data and soft computing will allow predicting the approach of space debris and other objects to the spacecraft, which will help avoid the Kessler effect * when the number of objects in orbit increases [67].

* The Kessler Syndrome, a hypothetical development in Earth orbit where the space debris resulting from multiple launches of artificial satellites renders near space completely unusable for practical purposes (source: Kessler D. J. Collision Frequencyof Artificial Satellites: The Creation of a Debris Belt / D. J. Kessler, B. G. Cour-Palais // Journal of Geophysical Research. – 1978. – № 83–A6. – 2637–2646 p.).

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PART 3

RUSSIA NEEDS REENGINEERING. REENGINEERING NEEDS ARTIFICIAL INTELLIGENCE

Due to the reduction of imports of hardware for artificial intelligence, there is a threat of a break in production chains. The solution to this problem will be the launch of reengineering programs (reverse engineering) of hardware and software.

Reverse engineering is the study of some device or program and its documentation in order to understand how it works and (most often) reproduce the device, program or other object with similar functions, but without copying as such [68].

The development of AI technologies has opened up new opportunities for reverse engineering. News about the application of reverse engineering systems have become a regular part of the information background in AI. In June 2020, there was a striking event: DeepMind introduced an AI system with software reengineering capabilities. Having access only to the inputs and outputs of the selected application, the system, dubbed IReEn, can repeatedly improve a copy of the target application until it becomes functionally equivalent to the original [69]. Examples like these indicate that artificial intelligence has created new opportunities in the high-tech market for players with limitations on the use of original products and those who need to recover solutions whose descriptions are partially lost.

At the same time, reengineering technologies create new risks for the market and society as a whole. Not only will it be necessary to revise intellectual property law: the development of such solutions may completely change attitudes and the public view of copying as a phenomenon [70].

Another useful quality of AI in the tasks of reengineering material objects is the ability to significantly simplify the equipment requirements needed to fully determine their characteristics. This is achieved by creating incomplete digital twins of the object based on basic facts, which are easy to measure with the existing equipment (in particular, mass-dimensional characteristics). The remaining elements of the twin (e.g., in the form of equations with specific coefficients reflecting nontrivial properties of the product) are reconstructed by means of automatic machine learning technologies on the basis of indirect experimental data. In this case, in some cases, not only the hidden properties of the object can be recovered, but also elements of the technology of its creation.

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Hardware

Sanctions have particularly affected the supply of highly specialized chips, so re-engineering of semiconductor product creation technologies becomes one of the most important conditions for the development of the Russian AI market. The lack of solutions here may lead to the fact that the predictions of another "winter of AI" will come true primarily for the domestic rather than the global market. Reengineering tasks cover not only the areas of chip design and production, but also the area of their key link, semiconductors. Artificial intelligence can become a useful technology for reengineering and import substitution only when it itself is provided with domestic semiconductor products.

Our country has its own projects of universal (CPU, DSP, GPU) and highly specialized (FPGA, ASIC) microprocessors, as well as tensor processors. Russian companies develop their designs, but it is difficult to produce these microprocessors in Russia due to lack of equipment, particularly lithographs.

Russia itself can produce processors based on standards of at least 65 nm (at the Mikron factory), which were considered advanced in 2004 [71]. But effective AI systems require solutions on microprocessors 16 nm and below. TSMC can already make chips in 5 nm topology [71], and plans to reach 3 nm [72].

Today, only one company, ASML of the Netherlands, produces equipment for 7 nm and smaller processors manufacturing. To achieve a resolution of up to 10 nm, the technology (EUV lithography) is much more complex and expensive than for chips with a topology above 10 nm [72].

The Russian Federation has a track record of developing an optical system and its elements for photolithography facilities at 13.5 nm (IPM RAS), a radiation source (ISAN RAS), and ultra-precise positioning systems for photolithographers (Amfora Laboratory). However, EUV lithography technology also requires extremely high-power lasers and extremely smooth mirrors, which makes it very expensive. The production of EUV scanners for photolithography by ASML pays off only with the production of chips in large quantities, which can be sold only in the global market.

But there is another way. For example, maskless lithography. This requires the efforts of many teams: the creators of MOEMS (micro-optical electromechanical systems), developers of the radiation source and coordinate tables, manufacturers of control electronics, including a specialized controller. There are such projects in Russia. For example, the IPM RAS coordinates a project in the field of maskless lithography. According to open data, the lithograph to be created will be 10 times cheaper than the EUV lithograph, and a prototype can be obtained in five to six years [73].

In any case, creating one's own lithographic industry is a complex and long-term task. As for the short-term perspective of hardware, the domestic AI industry faces great challenges and limitations to further development.

Software

Since Python, Lisp, R, Prolog and C++, some of the most popular AI programming languages, are not owned by certain companies, there is no risk of terminating their support in Russia, which cannot be said about Java and MATLAB, which are owned by American companies.

The big problem is frameworks, because the most popular of them (TensorFlow, Keras, PyTorch and Caffe2) belong to Google and Meta Platforms. Russia has its own Platform-GNS and PuzzleLib, as well as cloud platform IACPaaS, AI model creation platforms SMILE and DataMall. Nevertheless, rebuilding existing projects for Russian frameworks will require time and effort [73].

73 From a lecture by O. A. Telminov (NIIME) at the seminar of the Association "AI in Industry" // YouTube, 2022. — URL: youtu.be/26vqoN- it7g?t=8842. (in Russian)

PART 4

ST. PETERSBURG'S LEADERSHIP AMBITIONS IN THE AI MARKET

St. Petersburg is one of the largest centers of development and application of artificial intelligence technologies in the Russian Federation. Over the last five years, there has been an increase in publication activity in the field of AI and related technologies in St. Petersburg. It has its own clearly defined competence profile (its own strategic competences) in the field of AI, a unique ecosystem has been formed, including the leading universities and scientific organizations of the city, partners from the real sector and the city authorities.

The current AI agenda in Russia, and in St. Petersburg in particular, is defined by strong teams and centers that will develop and improve existing developments and directions [41].

Despite the fact that Moscow has a high centralization of financial and managerial flows, and the number of universities involved in AI research in St. Petersburg is small, they are very competitive.

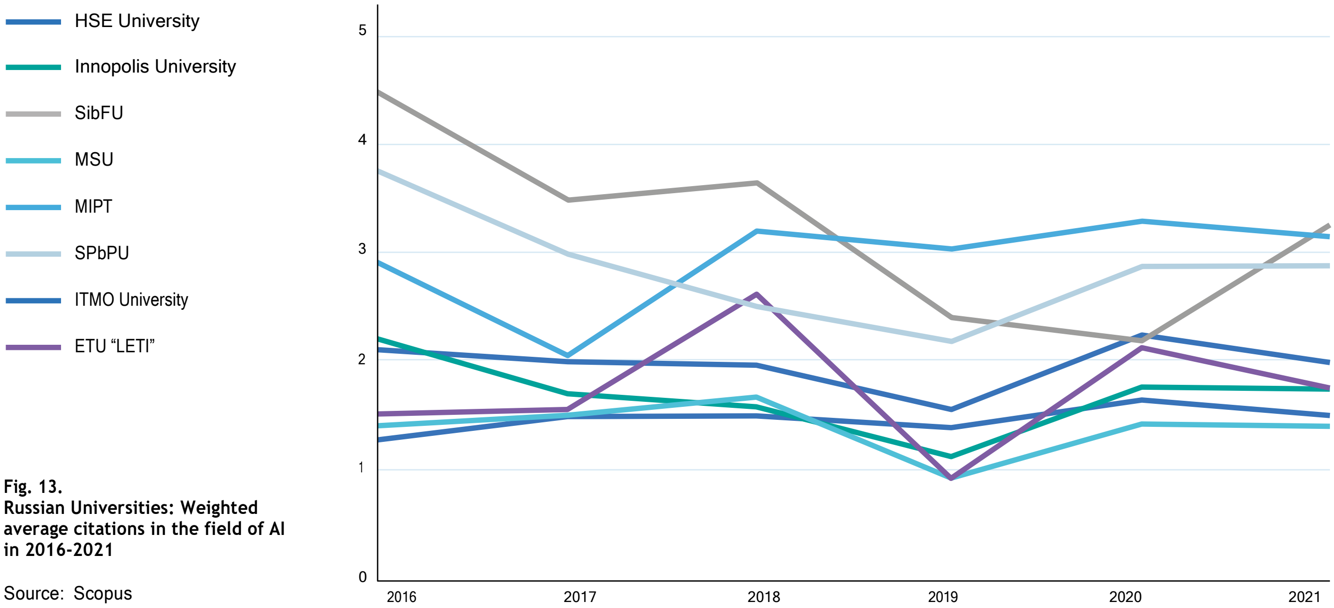


Fig. 13.
Russian Universities: Weighted average citations in the field of AI in 2016-2021

Source: Scopus

There is a strong mathematical school in St. Petersburg, which is also reflected in the number of publications on AI in the section "Mathematical Sciences" (Fig. 14). In Russia as a whole, according to the Scopus database, the publications on this topic are mainly in mathematical sciences (37.8%), computer sciences (33.8%) and engineering sciences (10.4%).

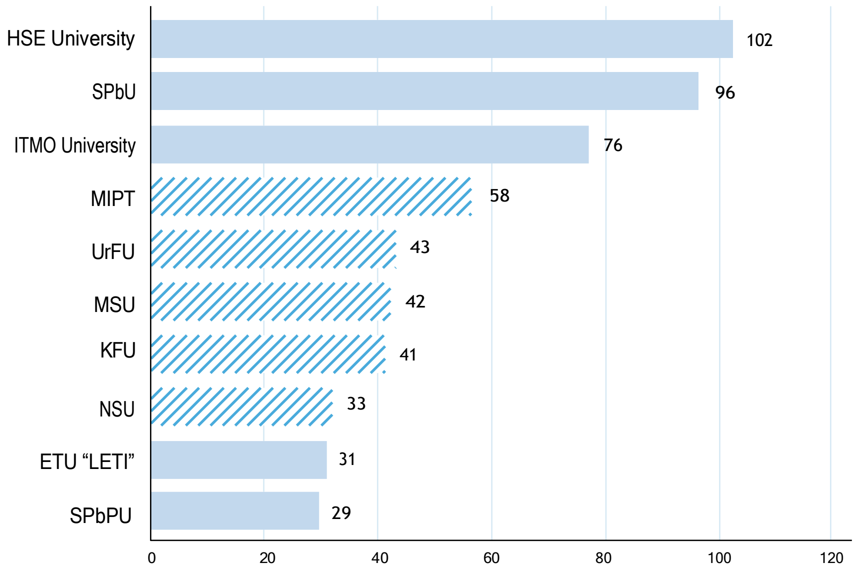


Fig. 14.
Top 10 Universities in Russia for AI in the Mathematical Sciences from 2015 to 2022

Source: Scopus

There is a small group of AI researchers in St. Petersburg who are developing their own research schools. This is one of the competitive advantages of the city, where generators of new ideas work in engineering universities. Among St. Petersburg's research organizations in the field of AI, we can single out HSE University, SPbSU, ITMO University, ETU "LETI" and SPbPU..

According to the SCImago Institutions Rankings, which determine the effectiveness of universities' research, innovation results and impact on society as measured by their visibility on the Internet, the top leaders are SPbU, SPbPU, HSE University and ITMO University (Fig. 15). The same universities lead among universities specializing in "computer science" (Fig. 16).

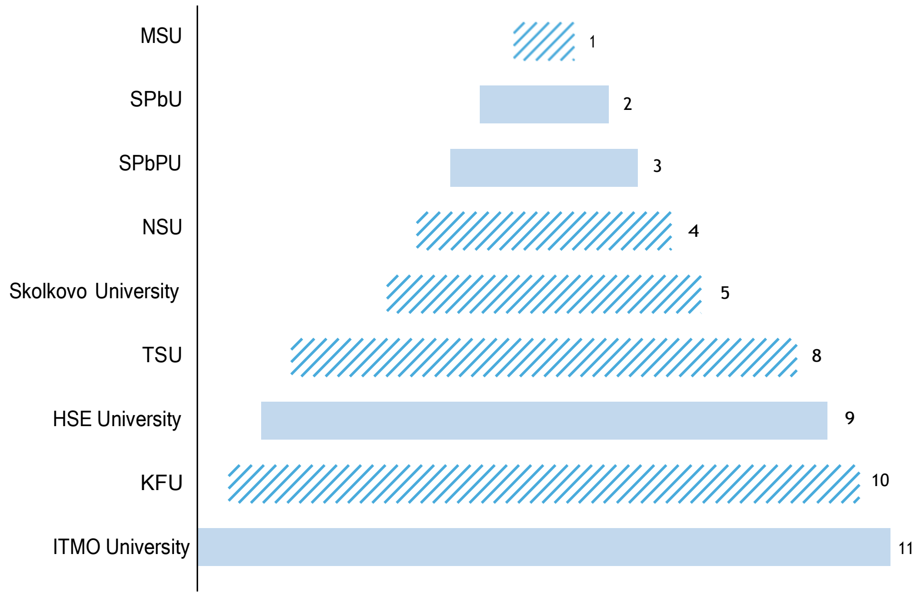


Fig. 15.
Ranking of universities among scientific organizations in Russia in the section "Mathematical Sciences," 2021

Source: SCImago

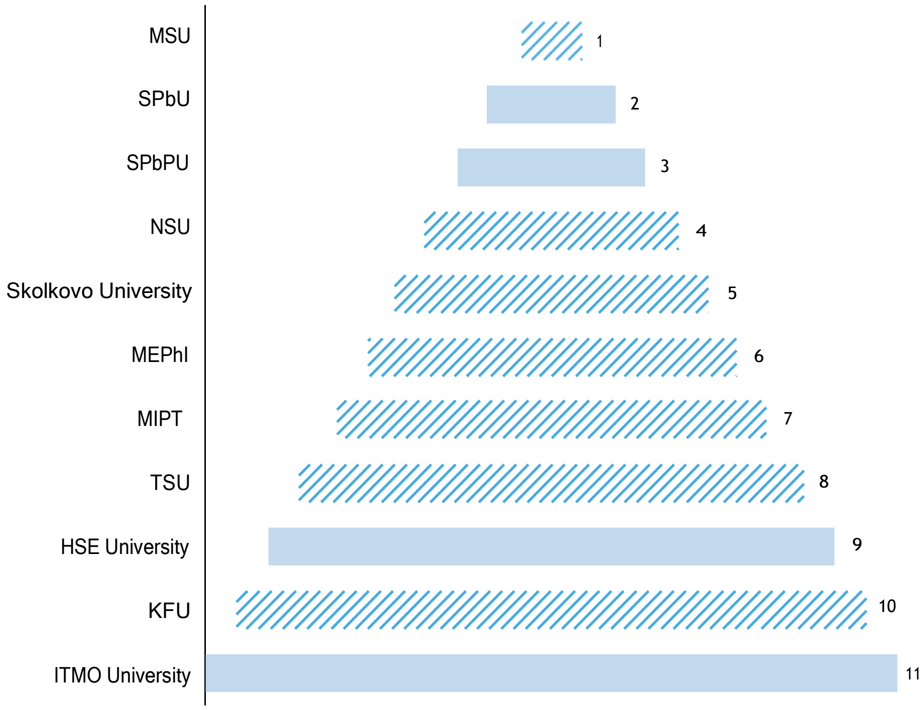


Fig. 16.
Ranking of universities (top 10) among scientific organizations in Russia in the section "Computer Science," 2021

Source: SCImago

The publication activity in the field of artificial intelligence in St. Petersburg is noted among a limited number of research organizations. The first places are occupied by universities.

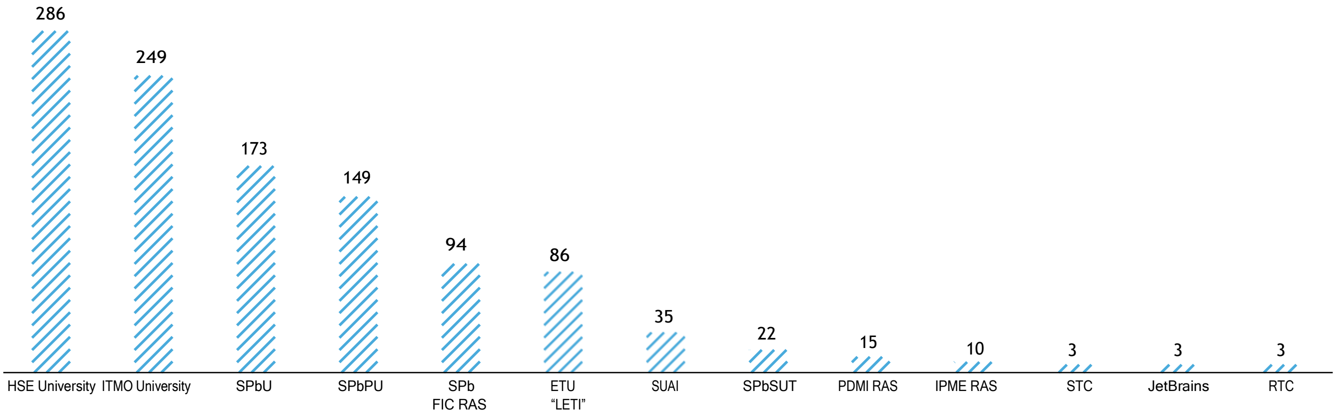


Fig. 17.
Number of publications on AI among St. Petersburg research organizations in 2015-2022 (Scopus)

Source: Scopus

According to the AI map, there are 34 AI companies in St. Petersburg, which is five times less than in the capital (187 companies). Among large IT companies in St. Petersburg there are Yandex (as a division of Yandex.Cloud, Yandex Self-Driving Group, Yandex.Toloka), as well as JetBrains and VKontakte.

Two national-level research centers in the field of artificial intelligence, established at ITMO University and pursuing complementary goals, are successfully operating in the city. Together they form the city's largest human capital hub in the research and development of applied AI systems, bringing together more than 300 specialists.

The National Center for Cognitive Development (NTI Competence Center) was created in 2018 with the end-to-end technology "Machine Learning and Cognitive Technologies. It is focused on the development of enhanced intelligence technologies in terms of creating industry-specific decision support systems in various subject areas and interacts with industrial partners in the open market (including industry, energy, retail, financial sector, healthcare, etc.).

On the contrary, the research center "Strong AI in Industry", which opened in 2021 as part of the federal project "Artificial Intelligence", builds its activities on the fronts of AI technologies, providing reproduction of the creative activity of industry specialists (designers, technologists, etc.). Collaboration with industrial partners is realized through a single customer institute, the Association "Artificial Intelligence in Industry," which manages the orders of individual partners and the resources attracted to them.

Together, both centers form a sustainable model that provides a full cycle of creation and implementation of promising technologies of applied AI in various tasks (not limited to industry and existing partners). At the same time, the open structure of organization and management of the centers allows the legitimate involvement of teams of researchers and developers from other universities and scientific organizations (both St. Petersburg and Russia) on a collaborative basis. This provides an opportunity to further expand the presence of St. Petersburg on the AI technology market and increase the professional recognition of the Northern Capital.

With the support of the Association "Artificial Intelligence in Industry", financing of research projects is organized, mentoring and support of six youth research laboratories created with the help of the grant of the Ministry of Education and Science of Russia, educational programs "School of Key Researchers in AI" are conducted. (for undergraduate and graduate students) and the "School of the Customer in AI" (for companies and government agencies). In addition, there is the original BlueSkyResearch competition, which supports exploratory research in the early stages of idea formation (funded by the St. Petersburg Innovation and Youth Initiatives Support Fund. The main goal of the competition is to test an interdisciplinary innovation mechanism for identifying promising research topics in frontier, high-risk areas, followed by the creation of solutions based on neural networks and/or machine learning [74].

74 Blue Sky Research Artificial Intelligence in Science Contest // Blue Sky Research, 2022. – URL: blueskyresearch.ru. (in Russian)

In the field of applied artificial intelligence, the city has competences in solutions for medicine and oil and gas sector. This is largely determined by the presence of large customers (primarily Gazprom Neft). Despite the fact that AI developers and customers are localized in St. Petersburg, data collection and practical application of created models often takes place in other regions of Russia.

Most of the key researchers of Artificial Intelligence in St. Petersburg are convinced: in order for the city to begin to form as an independent research center in the field of artificial intelligence, a number of conditions must be met.

1. Creating a platform for cooperation between the city government, universities, research centers and businesses in the form of the Center of Expertise in AI, which will be able to implement practical projects on a federal scale.
2. Development and unification (in terms of best practices) of training areas in Artificial Intelligence in universities. Although many universities have opened new training programs in AI in recent years, there is still a problem of attracting and retraining teachers, without which it is impossible to scale the training of specialists in these areas.
3. Public positioning of St. Petersburg as a mega-regional hub in the field of artificial intelligence, including by focusing on niche tasks for AI (primarily infrastructure), as well as by creating new jobs.

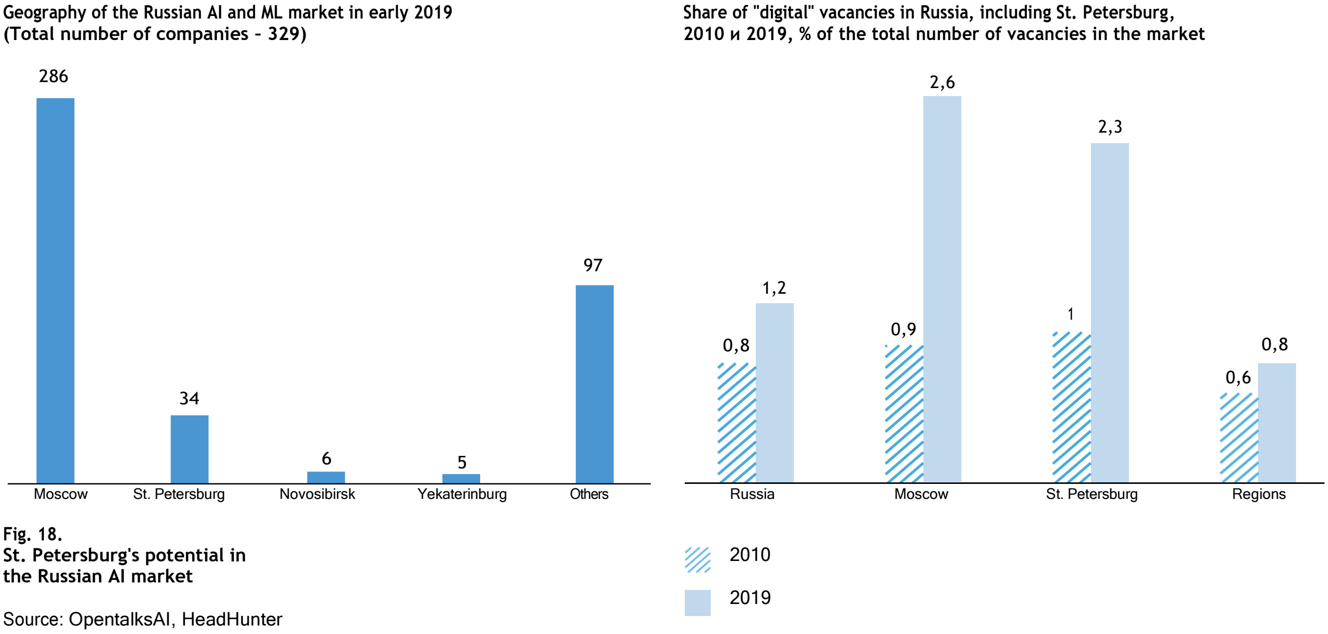


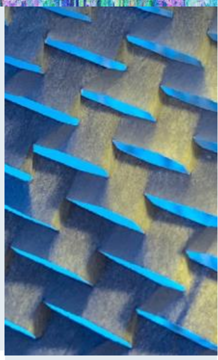
Fig. 18.
St. Petersburg's potential in the Russian AI market

Source: OpentalksAI, HeadHunter

It is these mechanisms that will be developed during the implementation of the program of the world-class scientific and educational center "Artificial Intelligence in Industry" in St. Petersburg, involving into its orbit more and more organizations from all over the country.

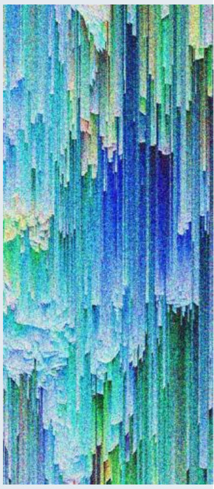
Conclusion

In the unstable geopolitical situation an acceptable strategy for the scientific sector of the Russian AI industry would be to increase and support cooperation with neutral platforms and highly ranked journals, develop an independent internal system of evaluation of AI research by experts working in the industry, develop interaction between the country's research teams, focus on tasks of public importance and super-tasks. It is extremely important that investments in artificial intelligence in the coming years have a sufficient volume and focus on technologies that provide a breakthrough in manufacturing, scientific and design developments and consumer services in Russia.



It is industry that is capable of becoming the main investor in the AI industry in the Russian Federation after the government. The oil and gas sector claims to be the most active industry interested in the development of the AI technology market, along with metallurgy and the chemical industry.

Due to the reduction of imports of hardware for artificial intelligence, it is necessary to launch reengineering programs for hardware and software. AI technologies open up new opportunities for reengineering, speeding up and simplifying the process of reverse engineering of devices.



St. Petersburg is one of the largest centers of development and application of artificial intelligence in Russia due to the presence of competitive technical universities, scientific organizations and companies that improve AI technologies. In the interests of further development it is necessary to create a platform for cooperation between the city authorities, universities, research teams and businesses in the form of a Center of Expertise in Artificial Intelligence, modernize and unify training areas in the field of AI in universities, concentrate efforts on niche tasks for Artificial Intelligence.

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