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Миссия журнала – развитие научных направлений по заявленной тематике в России и за рубежом, соответствующих приоритетным направлениям развития науки, технологий и техники в Российской Федерации, а также перечню критических технологий РФ.

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Abstract: the study considers and compares the research and development drivers in the USSR and modern Russia. It is shown that the competition for the global military and economic leadership shaped the need to develop advanced military and civil technologies in the USSR. The paper lists the USSR technology achievements in a number of key industries, and the educational technologies behind them. We identified significant differences between the Russian business practices and the socialist ones, and the negative impact of such differences on the research and technology advancement in Russia.

Keywords: research and technology advancement, digital economy.
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О ВЫГОДОПРИОБРЕТАТЕЛЯХ НАУЧНО-ТЕХНИЧЕСКОГО ПРОГРЕССА

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Аннотация: рассматриваются и сопоставляются движущие силы научно-технического прогресса в СССР и России. Показано, как конкуренция за достижение военного и экономического лидерства в мире определяла необходимость создания в СССР передовых военных и гражданских технологий. Приводятся научно-технические достижения СССР по ряду ключевых отраслей и прослеживается взаимосвязь с образовательными технологиями. Отмечаются существенные отличительные особенности российского коммерческого бизнеса по сравнению с принципами социалистического производства, пагубное влияние этих особенностей на развитие научно-технического прогресса в России.

Ключевые слова: научно-технический прогресс, цифровая экономика.
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On the Driving Forces of the Technological Progress and its Beneficiaries in the USSR

In the second half of the twentieth century, the main driving force of scientific and technological progress in the USSR was competition with the United States to achieve first military and then economic leadership in the world. Achieving military superiority or parity with the United States in creating new weapons systems required, first of all, advanced development of military nuclear, rocket-space and aviation industrial technologies. The need to create in the USSR such military serial technologies and serial weapons systems on their basis was dictated by the fact that in the early 50's the USA had developed and mass-produced thermonuclear bombs Mk-19 and Mk-24 with TNT equivalent of 10–15 Mt. Aircraft B-36, each of which could deliver two such bombs to a distance of up to 16,000 kilometers, were developed and serially produced in the United States. The B-36 bombers, each of which could deliver two such bombs to a distance of up to 16,000 kilometers, were developed and serially produced in the United States. By 1954 the United States had an arsenal of 305 Mk-17 and Mk-24 bombs and 385 B-36 aircraft, which all together were a real threat to the destruction of the USSR and most of its population [1] since at that time the USSR had no such weapons or means of their delivery.

This threat was countered by the postwar technological and industrial breakthrough of the USSR, which resulted in the creation of military, and later civilian, nuclear, rocket-space, and new aviation (jet aviation) industries. By the end of the 1950s, these new industries ensured the development and mass production of megaton-class thermonuclear charges [1], as well as their carriers, Tu-95 bombers, and R-7 ballistic missiles, which could deliver these charges up to 12,000 kilometers away [2]. As part of the new aviation industry, based on the Tu-95 and Tu-16 bombers were developed and mass-produced civilian long-range Tu-114 and long-range Tu-104. Until 1990 every fourth civilian long-haul aircraft in the world was produced in the USSR on average of 80 airliners annually [4]. In the nuclear industry, based on the diversification of military technologies, the development and construction of nuclear power plants, as well as nuclear power plants for the icebreaker fleet, were ensured. It is essential that within the framework of the implementation of these large-scale nuclear, rocket-space and aviation projects, the state, by consolidating the efforts of industrial and scientific enterprises, created new industries and modified existing ones and created millions of new well-paid jobs in these industries, in science and education as well. For example, in 1990 in the USSR the headcount of the nuclear industry was 1.1 million people [2], the headcount of the aviation industry was 1.5 million [4], and the headcount of the science and science services industry was 2 million 804 thousand [5]. On the whole, the number of industrial-production personnel in the RSFSR in 1990 was 23.1 million people. That is, the entire population of the USSR was the beneficiary of scientific and technological progress in both military and civilian industrial technologies, since this progress ensured, in particular, the prevention of a nuclear strike on the USSR and the destruction of most of its population, as well as the creation of millions of high-paying jobs for the country's population. Overall, the scientific and technological progress initiated by the USSR's competition with the United States ensured a twentyfold increase in industrial production in the RSFSR alone over the 35 years from 1945 to 1980 [3].

It is essential that scientific and technological progress in the USSR was fundamentally based on a "cult of knowledge", especially in the exact sciences, which the state, as a result of a targeted policy, managed to form and maintain in the public consciousness almost until 1991. The ability to solve complex scientific and technical problems based on fundamental knowledge opened to a member of society one of the ways to state and public recognition, material well-being, access to power structures, and, no less importantly, to large-scale technical creativity. The natural-science component of the mass educational system of the USSR, which provided training for the nuclear, aviation, and rocket-space industries, including applied research institutes and the Academy of Sciences, was aimed at acquiring these skills and knowledge.

On the Driving Forces of the Technological Progress and its Beneficiaries in Russia

Our business is to make money for shareholders [7]

However, after the collapse of the USSR in 1991, the new Russia abandoned the economic and political course of the USSR, including the competition with the United States to achieve military and economic leadership in the world, and, consequently, the driving force behind the scientific and technological progress of the USSR. The basis of Russia's economic policy and the driving force behind scientific and technological progress were the interests of the shareholders of commercial organizations, whose main goal, according to Article 50 of the Civil Code, is profit. Of course, the maximum and, of course, for a minimum amount of time, and with minimum risks. The most common forms of joint-stock companies and limited liability companies are also commercial. That is why in the interview "Poverty is not our concern" Peter Aven, President, Alfa-Bank (Argumenty i Facty newspaper) [7] to the reporter's question "Besides profit you are interested in something else?", answers: "In business – only it! We only do what is profitable for us – financial operations, oil, mobile communications, television, the Perekrestok retail chain . . . ". And then, in the same interview, he formulates one of the key tenets of Russian commercial business: "Our job is to make money for shareholders and customers within the limits of the law. We have no other duties" [7].

That is, in fact, according to the Civil Code of the Russian Federation, it is not the responsibility of this Russian business to develop new technologies for oil production, production of mobile communications and television equipment, because this requires long-term, large financial investments and, consequently, a decrease in the profits of shareholders, and is also associated with significant risks of returning the investments, that is, with the possibility of even greater losses for shareholders. That is, it is not profitable for the Russian commercial business, which is only interested in profit, to engage in the development or production of industrial products, or the technology of their development and production in Russia.

But it is profitable to purchase industrial products of large foreign companies and the provision of services on their basis [6]. For example, the provision based on foreign computing and communications equipment remote banking services, mobile communications services or television broadcasting.

The essence of the economic reforms carried out in Russia was the creation of such a commercial business, making money for shareholders based on the technology and equipment of foreign companies. Such domestic commercial business does not need both the science, education and industry, inherited from the USSR, which was aimed at creating and manufacturing industrial products and millions of high-paying jobs for the country's population, created in the industry, science and education of the USSR before 1991. It is for this reason, for example, that the number of workers in the aviation industry in Russia had decreased threefold by 2004 compared to 1990, and of the 96 mainline aircraft purchased by domestic carriers in 2002-2005, 76 were foreign-made [4]. Annual sales in the civilian segment of the industry became negligible – about $70 million. Sales in the military segment of the industry were almost entirely determined by export orders and did not exceed $2-$4 billion a year. For comparison, Boeing sales in 2006 were $61.5 billion [4].

Overall, the number of industrial personnel in the new Russia declined from 23.1 million in 1990 to 12.8 million in 2004, nearly halving it [3], even though, according to Vyacheslav Bobkov, director of the All-Russian Center for Living Standards, "salaries in Russia are so low that it is impossible to live on them" [7]. However, at the same time, the rich in Russia were buying yachts worth up to $10 million [7]. The rich are the beneficiaries of scientific and technological progress in new Russia, the driving force of which is profit. That is, the rich are the beneficiaries of private business profits, which are only its shareholders, but not the hired workers of this business, whose salaries are such that "it is impossible to live on them", i.e. "the poor". Among these "poor" employees are "normal honest toilers who have stable earnings" [7].

And this is a direct consequence of the Civil Code of the Russian Federation, which legally guaranteed and now guarantees the owner of the company the right to profit in any amount. At the same time, he bears no responsibility for the preservation of jobs, social support, and indexation of the wages of hired workers, as long as the wages are not lower than the minimum wage established by law. That is, the current Civil Code of the Russian Federation, in fact, legislatively states the supremacy of the owner-employer rights over the rights of employees, including the right to a decent life and human development. More precisely, it asserts the supremacy of the owner's interests in Russia, rather than the supremacy of the interests of society and the country's economy.

We pay taxes and don't owe anyone anything else [7]

This is the first key postulate of Russian commercial business, directly following from the current Civil Code of the Russian Federation. Since private business "pays taxes and owes nothing to anyone else", the fight against poverty in the new Russia is a matter for the state [7]. Therefore, even fifteen years from now, in 2020, the problem of poverty remains more than urgent in Russia. Indeed, according to the newspaper Moskovsky Komsomolets [8], in 2019 the number of people with incomes below the subsistence level rose to 20.9 million. The poverty rate rose to 14.3% compared to 13.9% in 2018. At the same time, the 20 richest people in our country – the shareholders, the beneficiaries of private business, for the last seven months together got rich by $36 billion, or 2.34 trillion rubles, it is quite natural, since the main purpose of this business, as well as 15 years ago in 2004. is to make money for shareholders [7]. Indeed, the owner of 84% of shares of PJSC Novolipetsk Steel is also one of these shareholders and 20 richest people in our country [9], whose Development Strategy until 2022 (hereinafter referred to as Strategy) declares that this company has the largest stake in Novolipetsk Metal Works. (hereinafter the Strategy) declares: "As part of Strategy 2022, we will continue our work to maximize returns to shareholders" [10]. The main tool to maximize profitability – increasing operational efficiency, which may well lead to a reduction in the number of jobs in the company and the income of employees. Especially since the Strategy only plans to "reduce the level of injuries" and "a high level of motivation and involvement" concerning personnel, i.e. hired employees [10], and in an interview with Vedomosti, NLMK's president talks about the intention, as part of his proposed Strategy and plan, to "close part of the production chain", which "is being discussed with trade unions and employees" [9]. That is, there are no guarantees even to maintain the existing number of employees and their remuneration level, which, according to IFRS reports, amounted to 58,300 in 2018. 58.3 thousand people and 60.8 thousand rubles, respectively. Another tool to maximize returns in the Strategy is to invest in growth projects, with the implementation of a "highly competitive dividend policy" [10], in other words, investing only in what has synergies with the core business [9] and does not lead to a reduction in shareholders' dividends, that is, "smart growth production" [9]. For example, in the production of steel for electric motors [9], but not in the production of electric motors themselves, let alone electric cars based on them, because this would require long-term financial investments with high risks and could lead to a reduction in shareholder income. In other words, the criterion for choosing the direction and pace of scientific and technological progress at NLMK, whose net profit in 2018 was $2.2 billion, is the growth of income for its shareholders, but not the growth of the country's economy and the income and employment levels of its population. That is, not the growth of Russian aircraft manufacturing, machine building, machine tools, automobile manufacturing, etc. That is why the "assets of the Russian metallurgy inherited from the USSR produce twice as much steel as is consumed within the country", and "in Russia, 60–70% of steel consumption is construction" and, according to NLMK President, "in the same segment . . . the main deferred demand" [9]. Therefore, it is quite natural that the president of NLMK is not a graduate of a technical university, but a graduate of the Finance Academy under the Government of Russia, a specialist in financial and management consulting, who "realized that steel production is a manageable system. And I became interested in the optimization of this system" [9]. Since the goal of optimization of this managed system, as follows from the Strategy, is to increase the profit of shareholders, growth projects should be based only on proven technical solutions with minimal risks, and the main criteria for selecting the optimal technical solution should be only financial. That is, in the new Russia for the last twenty-five years it is no longer the "cult of knowledge" in the field of exact sciences, but the "cult of knowledge" in the field of financial and management consulting opens the way for a member of society to state and public recognition, material well-being and entry into power structures. For example, in 2018, the average remuneration of NLMK Group Management Board members was 4 million 138 thousand rubles per month.

We only do what is profitable for us [7]

This is the second key tenet of Russian commercial business, which "benefits" anything that leads, according to the Russian Civil Code, to an increase in shareholder profits. It is "profitable" to increase operational efficiency, which is achieved, among other things, by reducing jobs and employee compensation levels. "Profitable" is the implementation of growth projects that do not reduce shareholder profits and maintain financial stability, i.e. the use in growth projects of only globally proven (i.e. foreign) technical and technological solutions with minimal risks.

"It is not profitable" to use domestic technical and technological solutions that have not been tested on the world market. "It is not profitable" to diversify oil, gas, steel, aluminium, etc. large Russian businesses to develop and mass-produce high-tech industrial products. Moreover, in fact, according to the Civil Code of the Russian Federation, any business based on the production of industrial products created by human hands, including microelectronics, loses to business based on products created by nature. Oil, gas, coal, iron and non-ferrous ores, timber, fish, drinking water are things that "grow by themselves". And can be sold with minimal risk on both the global and domestic markets. At the cost of extraction and preparation for sale, providing a high level of profit for shareholders. This is convincingly evidenced by the Bloomberg index, regarding the basis of the business of Russian billions.

This means that under the current Civil Code of the Russian Federation, Russia was, is and will be on the raw material needle and no economic methods, including both progressive taxation and regulation of interest rates, will change this situation. Neither will national projects that will build houses, highways, airports, create a strong information and communication infrastructure, etc. But they will not recreate industries similar to those that were in the USSR with millions of high-paying jobs. Such as the microelectronic and radio-electronic industries, for example. Even based on borrowed technology and equipment from foreign companies, commercial microelectronics is unprofitable for Russian shareholders since it requires billions of dollars in investments in production, technology and development of microelectronic products with high risks of failure on the global semiconductor market. For example, in 2009 the average cost of a semiconductor plant was from $1.6 to $3 billion and the cost of technology development was about $0.6 billion. Although the creation of both these and machine-building industries and jobs in Russia would provide a solution to the problem of poverty, the problem of getting the country's economy out of the "stagnant hole", and Russia's inclusion in the top five economies of the world. And, of course, a solution to the demographic problem, because young people would be provided with stable jobs and earnings. And not just targeted help from the state.

However, under the current Civil Code of the Russian Federation, the production of industrial products, and especially high-tech ones, such as microelectronics, is unprofitable for shareholders of commercial companies. That is, in other words, in these conditions Russian commercial business is not and cannot be a driving force for scientific and technological progress aimed at solving the problems of Russian society and the Russian economy. Indeed, for example, today Russian commercial business is the driving force behind the use of foreign, but not the creation of its own massively cheap digital technologies. But solely and only to increase the profits of business shareholders by increasing the rate of capital turnover, i.e. increasing the funds invested in the business and reducing the time of their return. Business desires to increase the rate of capital turnover that was and is the main driving force of scientific and technological progress, first in microelectronics and consumer electronics, and then in household appliances, including cars. This is the essence of the processes called the "new technological revolution" [18], and, in the terminology of UNCTAD, the phenomenon of "digital economy", for which, however, according to the authors of the Digital Economy Report 2019, there is not enough understanding [11].

Lack of Sufficient Understanding of the Digital Economy

This is explicitly declared in Section B What is the Digital Economy? Digital Economy Report 2019 (hereinafter – the Report), prepared within the framework of the UN Conference on Trade and Development (UNCTAD) [11]. It is also argued that the lack of a definition of the term is "a consequence of the novelty and lack of sufficient understanding and clarity of the phenomenon in question". In this regard, the Report introduces "a working definition of the term digital economy, which serves as the basis for the analysis carried out in this report" [11]. However, this analysis made in the Report has not resulted in understanding and clarity of the phenomenon in question. Indeed, in the "Conclusion" section, which is entitled "The Digital Economy for the Many, Not the Few," there are no specific political, economic, or technical recommendations to ensure that the benefits of digitalization are equitably distributed. The main content of this section is a general argument that digital technologies can both help and hinder the goal of sustainable development, depending on the policy decisions made. A few simple solutions are mentioned, but even fewer have been tried and tested. Moreover, it is stated that "there is a general lack of reliable factual and statistical evidence for (or against) a particular policy that would ensure that the potential benefits of digitalization are effectively distributed in the first place".

Nevertheless, despite the lack of sufficient understanding and clarity of the phenomenon addressed in the Report, as well as ways to ensure equitable distribution of the benefits of digitalization, the Report concludes by inviting the development community to "explore new ways to support countries that lag in their readiness to participate in and benefit from the digital economy", and to provide assistance aimed at "bridging the digital divide, strengthening the enabling environment for value creation in the digital economy" [11].

Moreover, in the face of this uncertainty, the Report recommends establishing an alliance of donor agencies and encouraging practices in donor support for the digital economy in **developing countries**, with a particular focus on **digital accessibility**. The governing and policymaking body of developing countries are recommended as: "the adoption and implementation of national strategies and programs for digital development", "the integration of donor support for the digital economy into local resource mobilization and allocation systems, including... **public financial management**".

In other words, the Report asks developing countries to fund, with their own and borrowed resources, costly experiments (e.g., "regulatory sandboxes") to understand what the digital economy is and how to ensure that the benefits of participation in it are equitably distributed.

According to UNCTAD (2017a), the elements of the emerging digital economy that can be financed include robotics, artificial intelligence, the Internet of Things, cloud computing, big data and 3D printers, as well as digital platforms, including e-commerce. For this particular case of the digital economy as a collection of the elements listed in UNCTAD (2017a), we can identify the relevant beneficiaries and the benefit-sharing system they have created, in which Russia has no place.

The U.S. semiconductor industry is the most significant beneficiary of the U.S. Internet of Things project

Over the past 20 years, the key factor in the growth of profitability and production of semiconductors was the reduction in the cost per transistor by switching to lower design standards. By now the model of development of the leading U.S. semiconductor industry, which is based on reducing the cost of a transistor by switching to lower design standards, has practically exhausted itself [12].

The concept of a new model of development of the U.S. semiconductor industry as a catalyst for the growth of the entire national economy was formulated in 2015 in the U.S. Senate's decision to accelerate the development and implementation of the Internet of Things. The initiators and most active participants in the discussion of this problem were representatives of INTEL and Samsung, as well as the U.S. Semiconductor Industry Association. The Internet of Things bill was approved by the Senate in 2017 and sent to the House of Representatives for consideration. The preamble to this law predicts that more than 50 billion devices will be connected to the Internet by 2020, which could generate trillions of dollars in turnover in new economic activity around the world [6].

The basis of this new economic activity will be the production by U.S. companies of hundreds of billions of semiconductors and tens of billions of digital control systems for these devices. It is these companies that will be among the main beneficiaries of the trillions of dollars, that is, the main beneficiaries of the U.S. Internet of Things.

Russia does not possess the technology and does not have the facilities capable of producing such quantities of semiconductors and digital control systems based on them. Products that fall into both the consumer and industrial categories of the U.S. Internet of Things, Russia merely imports or assembles from imported components. So do servers, computing and communications equipment, and mobile devices needed for cloud computing and artificial intelligence, big data, robotics, digital platforms and e-commerce. That is, the beneficiaries of these elements of the emerging digital economy in Russia will primarily be the semiconductor and radio-electronic companies in the United States, but not Russian companies and the state.

Mass-Market Cheap Short-Lived Services based on Mass-Market Cheap Digital Technologies

The formation of this model of service provision is directly linked to the creation in the late 1980s and early 1990s of separate segments of the Internet (the Network hereinafter) and digital technology for the transmission of text messages (e-mail). The cost of text messaging services was determined by the cost of data transmission equipment, including computing and communication equipment of the Network. In turn, the cost of this equipment was determined by the cost of semiconductors, based on which it is made. That is, the cheapening of the cost of semiconductors following the strategy of "double reduction" eventually led to a reduction in the cost of transmission of text and then graphics and video messages on the Network. According to Dr Peering. net, the cost of transmitting a 1 Mbyte message on the Web fell by an average of 61% per year from 1998 to 2010, from more than $1,000 to a few cents. The obvious consequence of this was the intensive cheapening of digital technologies and services based on them. At the same time, the profitability of this non-material "information consumer goods" turned out to be much higher than that of semiconductor. First of all, because of the huge number of services rendered daily (many hundreds of millions of messages transmitted), and also because for an intangible service there are no development and production costs, and its lifetime is determined by the time of message passage in the Network. The high profitability of these services is evidenced by the economic performance of Facebook, Google, Amazon and Apple, which specialize in delivering information and mass-market goods to the consumer. Indeed, the combined value of "The Four" is $2.8 trillion. Facebook and Google invested $29 billion in development in 2017, and Apple held $250 billion in overseas accounts that year, while Facebook capitalized $448 billion in 2018 and Intel only $165 billion. Every day, 1.2 billion users spend an average of 50 minutes on Facebook. A Facebook conversion is one in six minutes on the Internet and one in five minutes on mobile [16]. The strategic task of both this company and the whole "Four" is to increase the number of appeals, both by offering new services, and by increasing the number of its user community, or at least by maintaining this number. The prerequisite for solving this problem is to know how to analyze large amounts of data from users, and based on this analysis to form new types of services that will increase both the number of hits and the number of users. In other words, the companies of the "Four", or rather the shareholders of these companies, are the main beneficiaries of scientific and technological progress in the field of mass cheap digital technology, and such elements of the digital economy as big data and artificial intelligence, which are for the "Four" the key tools to increase the profitability of non-material "information consumer goods". These are tools of soft enslavement of people by the abundance of offered convenient and attractive services, depriving them at the end of essential skills and abilities for an independent and independent life from these companies. Such as, for example, the ability to memorize and analyze large volumes of data, building long chains of inferences, present the results of the analysis in writing, read and understand complex texts, etc. A person deprived of such skills and abilities is an ideal consumer of all the new services provided by each of the “Four” companies because he trusts them almost unconditionally and is enslaved by them.

As noted in the book *The Four* by New York University Business School professor Scott Galloway [16], the intense cheapening of digital technologies and the high profitability of replacing employees with these technologies have led to the accelerated destruction of jobs and the devastation of related sectors of the economy. For the first time since the Great Depression, thirty-year-old Americans are living worse than their parents did at the same age [16]. The Four companies are creating high-paying jobs, but in tiny numbers, that is, substantially less than they are destroying. They are building an America of 3 million masters and 350 million serfs [16]. That is, the payment for the use of convenient and attractive services of The Four is the destruction of jobs and lowering the standard of living of the American population, which is not the beneficiary of scientific and technological progress in the mass cheap digital technology and technologies of big data and artificial intelligence.

An example of plans for the accelerated destruction of jobs and the enslavement of users in Russia is the planned reduction of half of the 330,000 employees of Sberbank by 2025. Of course, by actively transferring bank services to the digital sphere [7], as well as building personal work with each client and increasing the loyalty of its users, that is their entrenchment based on big data technology and artificial intelligence.

In five years, 80% of decisions will be made by artificial intelligence. The Supervisory Board of Sberbank approved the transformation of this credit institution, which will go far beyond banking services. The consequence of this transformation will be the closure of physical branches and thereby reducing the number of employees [7]. That is, in fact, as a result of this transformation based on PJSC Sberbank will be created a company similar to the “Four”, which will create high-paying jobs, but in a tiny amount, that is significantly less than destroys and build Russia, which will have 1.4 million owners and 140 million serfs. Of course, the main beneficiaries of the planned transformation of Sberbank will be its shareholders, 45% of whom are foreigners.

However, the world is already ruled by a new economy of non-material “information consumerism”, in which the winner takes all. The leader of this new economy is the “Four” – Amazon, Google, Facebook and Apple, whose entire economic power is aimed at destroying competition. “The Four” either absorbs competitors or strangles them, repeating the functions of the competing product, that is, in the foreseeable future, it is likely that the transformed Sberbank, and the Russian companies Yandex and Ozon, many times inferior in financial power to the “Four”, will either be bought by it or destroyed.

This casts great doubt on G. Gref’s assertion that the creation of a digital economy is extremely necessary for our country’s economy because it is a global trend [17]. Especially since twenty-five years of blindly and thoughtlessly following various global trends have ultimately led to the need to solve the problems of taking the country’s economy out of the “serious stagnation hole”, defeating poverty and making Russia one of the world’s top five economies.

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SIMULATION OF COAGULABLE MIXTURES DYNAMICS IN INCOMPRESSIBLE LIQUID CONSIDERING CLOT CLUSTER FORMATION

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Abstract: one of the key problems associated with COVID-19 is blood circulation impairment, particularly caused by thrombosis. The impairment significantly reduces the blood flow and restricts oxygen delivery to the entire body. The paper covers the simulation model for the coagulable mixture dynamics in an incompressible liquid considering clot cluster formation. Simulation models for the thrombosis and coagulation processes in the human cardiovascular system will help efficiently manage these phenomena. The study proposes a simulation model of the coagulation processes in disperse systems, i.e., the thrombosis process. The paper presents the numerical solution results and the visualization of the analytical solution. The key thrombosis properties such as impurity concentration distribution in the liquid, and the pressure field distribution, were estimated. The simulation model can become a foundation for developing a multi-tier clot formation system in the cardiovascular system: from the microscopic level to the macroscopic structures. Besides, the model can estimate the efficiency of anticoagulants administered to COVID-19 positive patients at emergency care departments.

Keywords: simulation, thrombosis, hydrodynamics, disperse systems, crystal systems.
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О МАТЕМАТИЧЕСКОМ МОДЕЛИРОВАНИИ ДИНАМИКИ КОАГУЛИРУЮЩИХ СМЕСЕЙ В НЕСЖИМАЕМОЙ ЖИДКОСТИ С УЧЕТОМ ЯВЛЕНИЯ ФОРМИРОВАНИЯ КЛАСТЕРОВ-ТРОМБОВ

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Аннотация: одной из ключевых проблем, на решение которой направлены ресурсы общества по преодолению заболевания, вызванного новым коронавирусом COVID-19, является проблема нарушения кровотока, связанная, в частности, с процессом тромбообразования. Это явление существенно ограничивает кровоток, снижая доставку кислорода в целом по всему организму. В статье рассмотрены результаты создания математической модели динамики коагулирующих смесей в несжимаемой жидкости с учетом явления формирования кластеров-тромбов. Создание математических моделей процессов коагуляции и тромбообразования в сердечно-сосудистой системе человека обеспечит разработку эффективного управления этими явлениями. В статье описана математическая модель для процессов коагуляции в дисперсных системах — тромбообразования. Представлены результаты численного решения задачи и визуализация аналитического решения задачи, включая такие важнейшие параметры для тромбообразования, как распределение концентрации примеси в жидкости и распределение поля давления. Указанная модель может служить основой для построения иерархической системы образования тромбов в сердечно-сосудистой системе от микроскопического уровня до макроскопических структур. В том числе модель позволит сделать выводы об эффективности использования антикоагулянтов при поступлении пациентов в отделения неотложной помощи и при положительном результате теста на COVID-19.

Ключевые слова: математическое моделирование, тромбообразование, гидродинамика, дисперсные системы, кристаллические структуры.

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Introduction

One of the key problems to which society's resources are directed in addressing the disease caused by the new coronavirus COVID-19 is the problem of impaired blood flow, associated in particular with the process of thrombosis. This phenomenon significantly limits blood flow, reducing oxygen delivery throughout the whole organism. A mathematical study of coagulation and clot fragmentation processes in the human cardiovascular system will provide the development of effective management of these phenomena. It is important to develop a model of the flow of multiphase dispersed media in the human cardiovascular system, as well as in capillaries and porous media (in a more general problem statement), taking into account the time-varying flow region. This class of problems is characterized by the complex geometry of the flow manifold, the time-varying structure of the considered region, the combination of hydrodynamics and coagulation kinetics problems of the formed cluster-thrombi. The description of the dynamics of such processes is based on a combination of problems for the Smoluchowski-Boltzmann equation of the kinetic theory of coagulation in a spatially heterogeneous branched spatial structure of the porous medium type and hydrodynamics described by the Navier-Stokes equations. It should be taken into account that the density of distribution of the mixture components changing in time and space due to their mutual reactions changes the flow field of the medium, i.e., the diffusion coefficients that determine the fluctuations of the hydrodynamic field of transport velocities change. In the simplest approximation of the description of thrombosis, the model should include the Navier-Stokes equations for a viscous incompressible fluid with viscosity coefficients depending on the distribution density of the coagulating components carried in it, considered as an impurity. It is assumed that the admixture influences the hydrodynamic field as a set of microscopic scattering centers similar to Brownian particles in the well-known classical Smoluchowski-Fokker-Planck-Langevin-Kolmogorov models [1].

However, it should be emphasized at once that the mentioned models of Brownian motion should be considered for many different stochastic influences with averaging of results (canonical ensemble in molecular dynamics), which is a very resource-intensive task. Therefore, in this paper, we will limit ourselves to a heuristic model aimed at highlighting the essential relationships, which, naturally, will require further detail and microphysical justification.

An empirical investigation in physical and biological environments is limited due to high demands on time resources, patient safety, and small spatial scales. An equally important component for the medical staff is the need for high-quality visualization of the development of clot formation. There is a gap between specialized software aimed at solving scientific research and software for the end-user. This often does not allow mass implementation of developments in practical medicine. Creation of software for modeling and visualization of complex structures, including blood flow in vessels and coagulation (including thrombus formation) in humans on high-performance computing systems will form the basis for modeling processes occurring in physical and biological environments, having practical application in industry and medicine.

Models of Disperse Systems and Coagulation

Multicomponent medium-mixtures are widespread and used in many areas of human activity. Models of multicomponent media are considered for gas-dynamic mixtures in [2]. Conditions are formulated, under which the model of multi-velocity interacting continuums follows a model of turbulent mixing. The equations describing generation, dissipation and diffusion of turbulence for each component are proposed. For mixtures of isothermal and polytropic gases, analytical solutions on the structure of rarefaction and shock waves are given.

In the problems of describing thrombosis, it is important to take into account the processes of coagulation (merging or, in other words, inelastic collision) of mixture components in the hydrodynamic flow, which can serve as a source of formation of spatiotemporal structures in the medium flow field similar to the Belousov–Zhabotinsky reactions [3–7]. The first model of the Belousov-Zhabotinsky reaction was obtained in 1967 by Zhabotinsky and Korzukhin based on the selection of empirical relations correctly describing oscillations in the system, see [8]. The paper [8] is further considered in the "brusselator-type" models in the works of Prigozhine I. R. [9].

The inelastic collision of elements of complex systems affects a great deal in our daily lives, an example of this is the phenomenon of blood coagulation (coagulation) during cuts (lack of blood coagulation is lethal, as is its excessive intensity leading to the formation of blood clots with subsequent blockage of blood vessels!), the curdling of the milk and the formation of sour milk are also coagulation; polymerization processes, i.e. the very intense coagulation of particles, underlie the production of polymeric threads used in the manufacture of modern materials. Similar phenomena can be observed in the establishment of communications in the telephone network, in the transmission of messages over the Internet.

In many physical processes, mixtures can arise in systems in which they did not initially exist, in particular, due to the instability and breakdown of contact boundaries under dynamic loads. In other cases, dynamic loads can lead to the opposite effect: separation of the components of the pre-created mixture.

One of the main mechanisms of the evolution of dispersed systems is the mechanism of coagulation (fusion) of system particles. It should be emphasized that usually research works are devoted to the study of the behavior of already prepared mixtures and do not touch the issues of their formation.

Coagulation (merging) of particles is one of the main causes of the evolution of spatially heterogeneous disperse systems, which are understood as a mechanical mixture of medium (gaseous or liquid) with particles of the dispersed phase (solid or liquid), and the properties of phases significantly depend on the transfer of substance between different points of coordinate space. It is important to emphasize the presence of dispersion of transfer rates for particles in different states; otherwise, by replacing the system of spatial and temporal coordinates, the description is reduced to a model similar to the spatially homogeneous case. It should be emphasized that the presence of spatial inhomogeneity significantly complicates the investigation of mathematical models of coagulation. In particular, it is caused by a new effect (as compared to spatially homogeneous problems), namely by the emergence of non-differentiated features of solution on spatial and temporal variables. These features, in turn, generate spatial and temporal zones in which the conservation relation for the Smoluchowski collision operator turns into the dissipation relation (these regions can be interpreted as zones of intense precipitation formation not interacting with the dispersed phase).

Mathematical issues of the correctness of problems of the kinetic theory of coagulation are very complicated and most of the results refer, as a rule, to the theory of spatially homogeneous systems or close to them. Spatially inhomogeneous problems, especially those related to the free transfer of particles carried out through a one-parameter shift group on a spatial variable, are the most difficult from the mathematical point of view.

The Mathematical Model

Let in a viscous medium $\mathbb{R}_3 = \{x = (x_1,x_2,x_3)\}$ filled with particles of different masses $\mu \in \mathbb{R}^+$ with the distribution of concentration $f(\mu,x,t)$, moving under the action of a hydrodynamic field of the external medium, there is a process of coagulation during pair collisions of particles with intensity $\Phi(\mu, \mu_1,x,t) \geq 0$, or particle impacts at the $\Psi(\mu,\mu_1,x,t) \geq 0$ rate, where μ and μ_1 the are masses of interacting particles. (Below we will omit possible dependence of collision and fragmentation rates on the spatial and temporal coordinates x,t for simplicity. Still, the dependence on the masses is essential.) In this case, the dependence on the masses is essential. For the transfer rate of particles, for example, for homogeneous spheres with masses μ, falling in a viscous medium under the action of gravitation according to Stokes's law, a power dependence is valid:

$$\mathrm{V}(\mu)\sim\mu^{2/3}.$$

If in this case, the particles move in a locally uniform hydrodynamic flow of the external medium with velocity $V(,x,t) = (v_1,v_2,v_3) \in \mathbb{R}_3$ and experience Brownian wandering with the diffusion coefficient $\mathrm{D}(\mu,x,t)$, then the accepted mathematical model of the above process is the kinetic Smoluchowski equation for continuous masses [10–12]:

$$\frac{\partial f(\mu,x,t)}{\partial t} + \mathrm{div}_x[\mathrm{V}(\mu,x,t)f(\mu,x,t)] - \mathrm{div}_x[\mathrm{D}(\mu,x,t)\nabla_x f(\mu,x,t)] = S(f) + q(\mu,x,t),$$
$$x,\mu \geq 0, \quad t > 0, \tag{1}$$

where $S(f)$ is the particle collision operator, which acts on the unknown function (concentration) f by the variable μ, usually without affecting its spatial and temporal arguments x,t, $q(\mu,x,t) \geq 0$ is the given intensity of the particle sources:

$$S(f) = S_c(f) + S_b(f).$$

For the Smoluchowski model of coagulating systems consisting of particles with a continuous mass spectrum, the operator of inelastic collisions $S_c(f)$ local on x,t has the following form [1]:

$$S_c(f) = \frac{1}{2}\int_0^{\mu} \Phi(\mu - \mu_1,\mu_1)f(\mu - \mu_1,x,t)f(\mu_1,x,t)\,d\mu_1 - f(\mu,x,t)\int_0^{\infty} \Phi(\mu,\mu_1)f(\mu_1,x,t)\,d\mu_1. \tag{2}$$

The spontaneous particle fragmentation operator $S_b(f)$ with a spectrum $\Psi(\mu,\mu_1)$ of the distribution of decay products on the values of masses $\mu \geq 0$ formed from a fissile particle with a mass $\mu_1 \geq \mu$ provided that this process is Markovian) is given by the expression [13]:

$$S_b(f)(\mu,x,t) = \int_0^{\infty} \Psi(\mu,\mu_1)f(\mu + \mu_1,x,t)\,d\mu_1 - \frac{1}{2}f(\mu,x,t)\int_0^{\mu} \Psi(\mu - \mu_1,\mu_1)d\mu_1. \tag{3}$$

The $S_c(f)$ and $S_b(f)$ operators look similar for the spectra of $f^{(\omega)}$ particles with discrete masses $\omega \in \mathbb{N}$ [14]:

$$S_c^{(\omega)}(f^{(.)}) = \frac{1}{2}\sum_{\omega'=1}^{\omega-1} \Phi(\omega - \omega',\omega')f^{(\omega-\omega')}f^{(\omega')} - f^{(\omega)}\sum_{\omega'=1}^{\infty} \Phi(\omega,\omega')f^{(\omega')}, \quad \omega \in \mathbb{N} \tag{4}$$

$$S_b^{(\omega)}(f) = \sum_{\omega'=1}^{\infty} \Psi(\omega,\omega')f^{(\omega+\omega')} - \frac{1}{2}f^{(\omega)}\sum_{\omega'=1}^{\omega-1} \Psi(\omega - \omega',\omega'). \quad \omega \in \mathbb{N}. \tag{5}$$

Expressions in the above operators written with the minus sign set the "death" of particles in the spectrum, while the remaining non-negative terms set their "birth". The heuristic method of writing them is based on the local law of conservation of mass. (For the Smoluchowski collision operator these are balance relations of birth and death of particles in the process of their paired instantaneous interaction.) The mathematical justification of the coagulation model is very time-consuming, refer to [14].

In their physical content, the above models of interaction of particles in the external medium flow correspond to the Boltzmann approach in the kinetic theory of gases [15].

When considering the mathematical model, we will impose the following assumptions of physical nature:

- of particles is large enough that we can apply the particle number mass distribution function
- the particles of the system form a locally chaotic set.

The above class of Boltzmann-type models for locally interacting particles (in pairwise collisions) is joined by models with nonlocal interactions, which include, first of all, the plasma theory equations (Vlasova A.A.) [16]. In particular, the Vlasov-type kinetic equation was proposed in [17] to simulate the growth of crystal structures in the volume of a supercooled melt.

The state of such a system at each time moment t is described by the probability density of the distribution of particles *f(m,t)* by the masses *m*. At the initial moment, the state of the system is given by the probability density of distribution f_0. New particles can enter our system due to a source, which acts with intensity *q(m,t)*. In practice, the source can be, for example, inhomogeneity of the medium. That is, if we place ions of some substance in our system, the melt immediately condenses on them and new particles are formed. The function Φ is the intensity of particle collisions.

The coagulation equation of the Vlasov type [18–19] in the space of masses $m \geq 0$ has the form:,

$$\frac{\partial f(m,t)}{\partial t} + \frac{\partial \dot{m} f(m,t)}{\partial m} = -\frac{1}{2} f(m,t) \int_0^\infty \Phi(m,y) f(y,t) dy + q(m,t), \ \ t > 0, \tag{6}$$

where

$$\dot{m} = \frac{1}{2} \int_0^\infty \Phi(m,y) f(y,t) y dy.$$

The hypotheses, based on which equation (6) is written down, assume that in the process of interaction there is a paired interaction of particles, i.e. the particle field is quite rarefied, which corresponds to the initial stage of crystallization (thrombosis).

This equation for the dynamics of the spectrum in the space of values of continuous masses of interacting particles is directly related to the problems of creating and operating nuclear reactor facilities with heavy liquid metal coolant (HLMC) lead-bismuth or lead, one of the key problems of operation of which is the problem of freezing-defrosting of HLMC in the primary circuit. During freezing, heating and cooling of liquid metal coolant in a solid state, significant mechanical impacts on structures may occur due to inconsistency of movements of coolant volumes with movements of structures and commensurability of mechanical properties of coolant in a solid state with properties of structural materials.

Modeling of multiple mergers is a significantly more complex model of coagulation and is based on the kinetic approach. But even such simplified models demonstrate the extreme complexity of the problem related to the dissipative phenomena investigated in the simplest models of "brusselator" type by Prigozhine I.R. [9].

The specific feature of the models considered in this work is their substantially large (unbounded) dimensionality on the mass spectrum of the interacting particles, which may be the source of a new class of phenomena – spontaneous structure formation in the coagulating system, similar to the process of formation of shock fronts in gas dynamics [20–22].

In essence, the above mathematical models are analogous to the processes of thrombosis in the blood system due to the coagulation of clots formed in blood. In particular, the same processes were investigated for the phenomenon of crystal growth by a mathematical model of crystallization in the volume of supercooled melt based on the kinetic approach [23]. Equation (1) belongs to the "reaction-diffusion" type family [24–25] with a continuum of components. It is known that the formation of periodic space-time structures is possible for three-component families [9].

In multicomponent systems of coagulating mixtures with a stationary source, similar phenomena have been predicted, see [26].

Equation (1) for $t = 0$ in the spatial domain $G \subseteq \mathbb{R}_3$ is supplemented with initial data:

$$f(\mu,x,0) = f^{(0)}(\mu,x), \quad \mu,x \in \Pi_0 = \mathbb{R}_1^+ \times G. \tag{7}$$

Additional conditions at the boundary ∂G of the region G are discussed below.

Within the framework of the simplified model under consideration, as a first approximation, let us assume that the transport of particles obeys a system of Navier-Stokes equations for a viscous incompressible fluid with a flow velocity field $\mathrm{V}(x,t) = \{\mathrm{V}^{(i)}\} \in \mathbb{R}_N, \ x \in \mathbb{R}_N, \quad t > 0$ and pressure $p(x,t)$:

$$\frac{\partial}{\partial t}\mathrm{V}^{(i)} + \sum_{j=1}^{N} \mathrm{V}^{(j)} \frac{\partial}{\partial x_j}\mathrm{V}^{(i)} + \rho^{-1}\frac{\partial}{\partial x_i}\rho^{-1}p = \rho^{-1}R^{(i)} + \mathrm{div}_x[v(\mathrm{n},T)\nabla_x \mathrm{V}^{(i)}], \quad x \in G, \ t > 0, \\ i = 1,2,\ldots,N, \tag{8}$$

$$\mathrm{div}_x \mathrm{V} = 0, \tag{9}$$

$$\mathrm{n}(\mu,x,t) = \int_0^\infty f(\mu,x,t) d\mu, v(\mathrm{n}) \geq 0. \tag{10}$$

It is assumed that in the region G the fluid has constant density $\rho > 0$, $\nu = \eta\rho^{-1}$ is the kinematic viscosity of the fluid, η is the dynamic viscosity. In the general case, given the law of conservation of energy, equations of motion (1) should be considered in conjunction with the fluid temperature dynamics $T(x,t)$, on which the kinematic viscosity depends [27–28].

Here $R^{(i)} = R^{(i)}(x,t)$ are the density components of the field of external forces applied to the mixture (note that for potential forces, their influence leads only to the additive addition of the potential of forces to the value of pressure in the problem without their action, while the velocity field $\mathrm{V}(x,t)$ remains unchanged). It is assumed that the constituent parts of the mixture are captured by the medium flow, instantly acquiring its local velocity $\mathrm{V}(x,t)$, affecting the dynamics of the fluid composing the mixture through its integral local concentration $\mathrm{n}(\mu,x,t)$. This hypothesis of the influence of the mixture concentration on the flow field assumes that the mixture components are scattering centers, which through their local Brownian wandering change the mean value of the isotropic viscosity coefficient of the medium $v(\mathrm{n},T)$. When building more detailed models of the mixture dynamics, one should take into account the possibility of changing the flow field in time $G(t)$ [29].

Including the effects of inertia effects for particles with positive mass μ, which change the configuration of the flow field with an explicit dependence $\mathrm{V}(\mu,x,t)$ the same applies to viscosity coefficients), should be taken into account. Moreover, the presence of extended sizes of coagulating particles in the flow can lead to a complex phenomenon – the meshing effect, see [13], when "an inertialess non-Brownian particle, generally speaking, should bypass a large particle... However, streamlined particles have finite sizes. And since at a distance of the order of particle radius from surface of a large particle the normal component of velocity ... is finite, at convective transport "meshing" of a small particle with a large particle is possible" [13]. There is also an effect of inertial deposition. "Since the hydrodynamic field of a large particle is inhomogeneous, movement of small particles in this field is always influenced by their inertia. The influence of inertia is manifested in the reduction of curvature of particle trajectories in some areas of flow as compared with the curvature of medium flow lines. There are two different modes of motion of particles under the influence of inertia in a heterogeneous field of the medium: subcritical when the trajectories of particles and the medium current lines do not coincide, but their behavior is similar, and supercritical when the influence of inertia is so great that the trajectories of particles cross the surface of large particles. In the first case, particle inertia either enhances or reduces the effect of other coagulation mechanisms, such as the entanglement effect. In supercritical mode, there is a new mechanism of coagulation acting independently – inertial deposition" [13]. Given the extreme complexity of accounting for such effects, we will limit ourselves to consideration of the above-mentioned simplified model, in which we can analyze the influence of joint factors: processes of coagulation, fragmentation of point particles and their interaction in the external weakly perturbed hydrodynamic field of incompressible liquid with viscosity coefficient, depending on the integral concentration of the mixture.

In particular, this paper assumes that the flow region G is constant in time and that adhesion conditions or no-flow conditions for the velocity field $\mathrm{V}(x,t)$ are set at its boundary, the values of concentrations and temperatures, or their incoming fluxes along the normal to the boundary of the region are also set.

Let us dwell on the phenomenon of internal friction in a viscous incompressible fluid [27, 28, 30, 31], which for large-scale flows can affect the thermal and electrical phenomena at large values of viscosity ν, changing the characteristics of the flow, and in some cases – lead to phase transitions, electrical breakdowns, etc. This may entail the overestimation of operating modes in reservoir management. Similar problems are associated with hemodynamics control, in particular, with thermoelectric processes during flow in porous media, typical for warm-blooded organisms, as well as with optimization problems of controlled swimming in a viscous incompressible fluid.

It follows from the law of conservation of energy that dissipative processes due to internal friction determine the equation for the temperature field of a viscous incompressible fluid [28, 30]:

$$\frac{\partial}{\partial t}T(x,t) + \sum_i \mathrm{V}^{(i)}\frac{\partial}{\partial x_i}T(x,t) = \chi\Delta T(x,t) + \frac{\varepsilon}{c_p}, t > 0, x \in G, \tag{11}$$

where $\chi = \kappa\rho^{-1}c_p^{-1}$ is the coefficient of thermal conductivity of the medium, c_p is the heat capacity. The last term in the right part of Equation (11) describes the total warming of the medium, caused by the internal friction of the liquid. Type of dissipative internal heat source is determined by the following expression:.

$$\varepsilon = \frac{1}{2}\nu \sum_{i,j} (\frac{\partial}{\partial x_i} \mathrm{V}^{(j)} + \frac{\partial}{\partial x_j} \mathrm{V}^{(i)})^2.$$

Direct calculations show a significant influence of this heat source for liquids with large viscosity coefficients ν, which is a direct analog of the Joule-Lenz law in electric circuits. There is experimental evidence [32] of the influence of such viscous heat generation in oil bearings. Note that the same nature has the effect of throttling the viscous fluid flow in a porous medium. In particular, in [33] there is a table of heat release values of petroleum products, water and methyl alcohol during throttling motion at a given pressure drop. The same heat release effects take place during the initiation of volumetric explosions when a porous catalyst is introduced into viscous fluids [34], described by functional solutions of systems of conservation laws [14].

Visualization and Numerical Solutions

An example of visualization of the exact solution of the equations of three-dimensional hydrodynamics in a porous medium consisting of a filamentary grid of vertical obstacles ∂G, which are located with a period $\lambda > 0$orthogonal to the plane $x_3 = 0$, is shown below. It is assumed that the sticking conditions in the obstacles are fulfilled $\mathrm{V}|_{\partial G} = 0$. The family of exact solutions of these equations, including the temperature $T(x,t)$ and admixture $n(x,t)$ fields determined by constant parameters $\alpha,\beta,\chi,\lambda,\mu,\nu$, has the following form:

$$\mathrm{V} = \begin{pmatrix} \exp(\mu x_3) \sin \lambda x_2 \\ \exp(-\mu x_3) \sin \lambda x_1 \\ 0 \end{pmatrix} \exp\left(\left(\mu^2 - \lambda^2\right) \nu t\right);$$

$$p = \exp\left(2\nu \left(\mu^2 - \lambda^2\right) t\right) \cos(\lambda x_1) \cos(\lambda x_2);$$

$$n = \exp\left(\left(\mu^2 - \lambda^2\right) \chi t\right) \left(\exp(-\mu x_3) \cos(\lambda x_1) - \exp(\mu x_3) \cos(\lambda x_2)\right) + \\ + \exp\left(\mu^2 \chi t\right) \left[\alpha \exp(-\mu x_3) + \beta \exp(-\mu x_3)\right].$$

The temperature field $T(x,t)$ in the absence of internal heat generation is similar to the impurity field $n(x,t)$.

Below are graphs of different cross-sections of the flow and impurity fields. (Visualization of the fields was made by Dubovik A.O., Institute for System Research, Russian Academy of Sciences.)

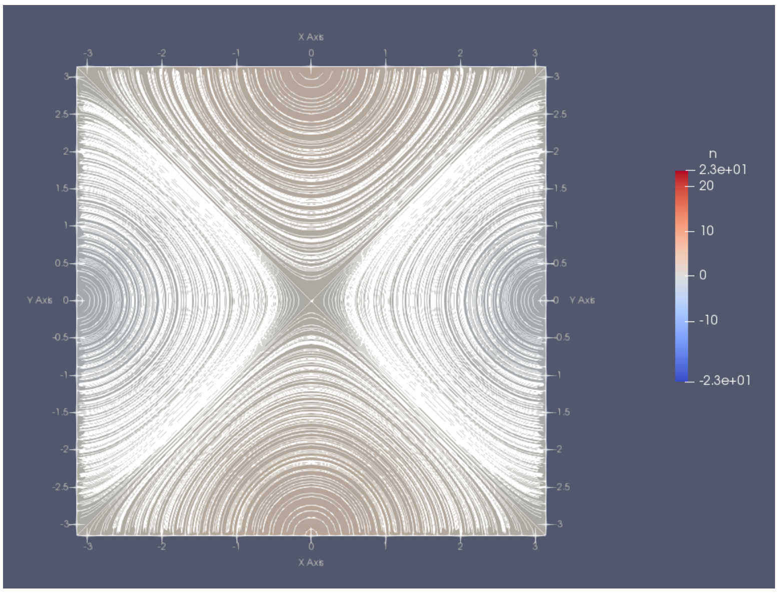

Figure 1. *Spatial distribution of impurity concentrations $n(x,t)$, cross section $x_3 = 0$*

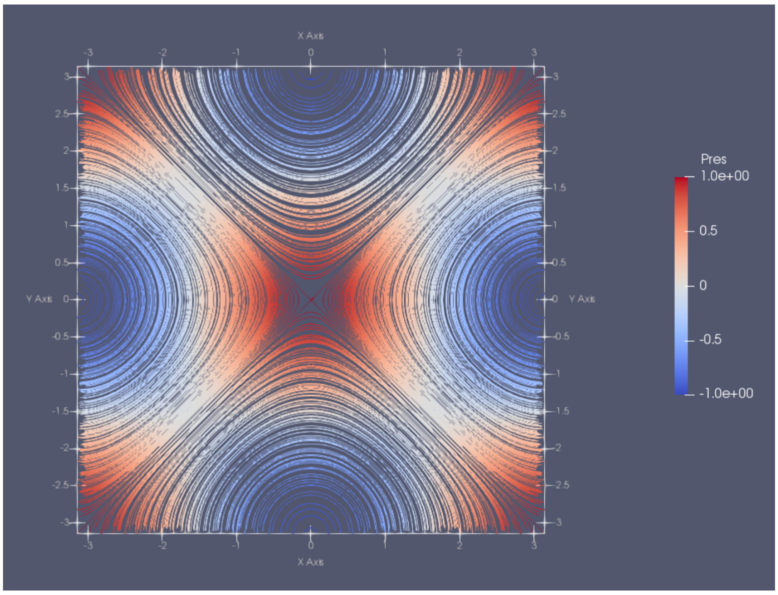

Figure 2. *Spatial distribution of the pressure field* $p(x,t)$*, cross section* $x_3 = 0$

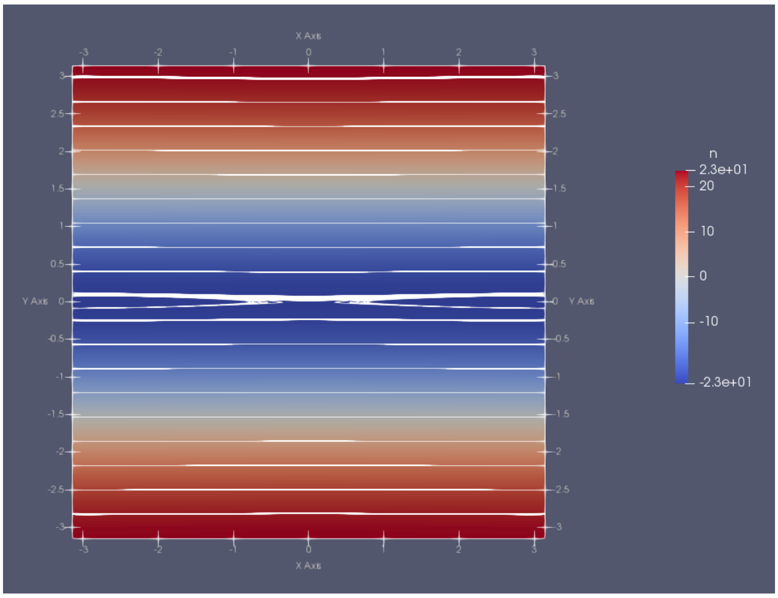

Figure 3. *Spatial distribution of the impurity concentration field* $n(x,t)$*, cross section* $x_3 > 0$

The following example of stationary hydrodynamics concerning the coagulation process indicates the possibility of the appearance of macroscopic structure in a one-dimensional flow of the coagulating substance:

$$\begin{aligned} &\mathrm{V}(\mu)\frac{\partial f(\mu,x)}{\partial x} = \frac{1}{2}\int\limits_0^{\mu} f(\mu-\mu_1,x)f(\mu_1,x)\,d\mu_1 - f(\mu,x)\int\limits_0^{\infty} f(\mu_1,x)\,d\mu_1, \qquad x \geq 0, \\ &f(\mu,0) = f_0(\mu), \end{aligned} \tag{12}$$

where the values of spatial transport velocity $\mathrm{V}(\mu) > 0$ are assumed to be a given function of the mass of the particles coagulating in the flow $\mu \geq 0$. At the inlet $x = 0$ of a one-dimensional flow channel located along the axis $x \geq 0$, a given stationary incoming particle flow $\mathrm{J}_0(\mu) = \mathrm{V}(\mu)f_0(\mu) \geq 0$. is supplied. Assuming the new unknown value of the flow $\mathrm{J}(\mu,x) = \mathrm{V}(\mu)f(\mu,x)$, for J we obtain the Cauchy problem

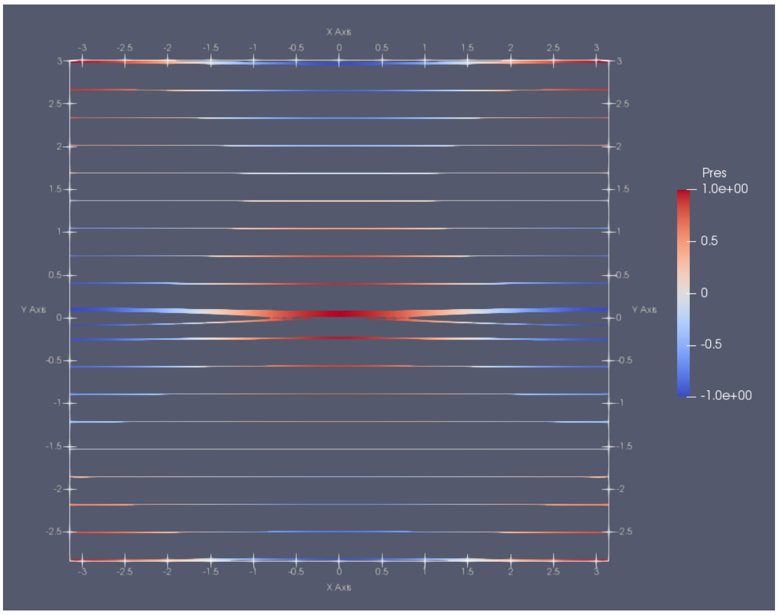

Figure 4. *Spatial distribution of the pressure field* $p(x,t)$*, cross section* $x_3 > 0$

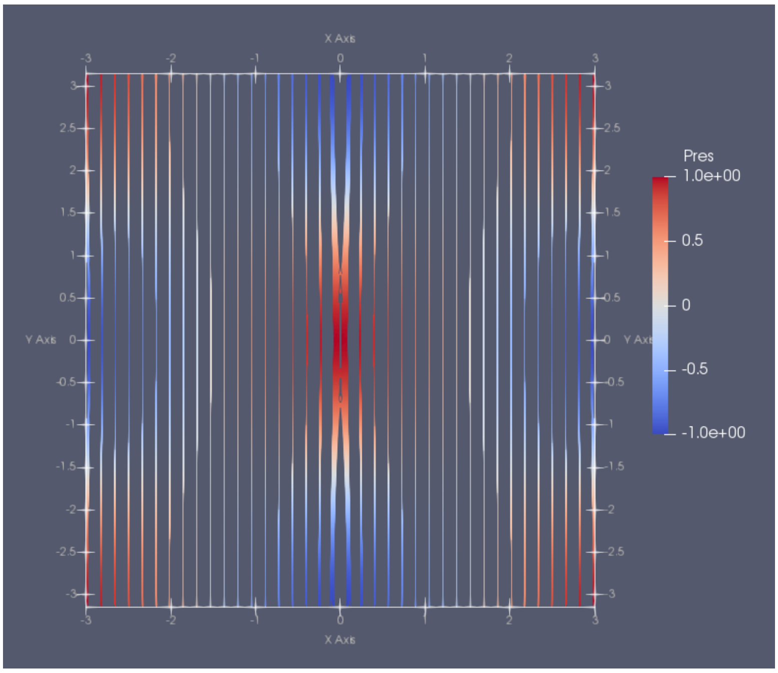

Figure 5. *Spatial distribution of the pressure field* $p(x,t)$*, cross section* $x_3 < 0$

for the Smoluchowski equation:

$$\begin{aligned} &\frac{\partial \mathrm{J}(\mu,x)}{\partial x} = \frac{1}{2}\int_0^{\mu} \Phi(\mu-\mu_1,\mu_1)\mathrm{J}(\mu-\mu_1,x)\mathrm{J}(\mu_1,x)\,d\mu_1 - \mathrm{J}(\mu,x)\int_0^{\infty}\Phi(\mu,\mu_1)\mathrm{J}(\mu_1,x)\,d\mu_1, \\ &x \geq 0,\ \ \mu \geq 0, \\ &\mathrm{J}(\mu,0) = \mathrm{J}_0(\mu), \quad \Phi(\mu,\mu_1) \equiv \mathrm{V}^{-1}(\mu)\mathrm{V}^{-1}(\mu_1). \end{aligned} \tag{13}$$

Assuming

$$\mathrm{V}(\mu) \equiv \mu^{-1} \tag{14}$$

at $\mu > 0$, we obtain a classical example of solutions with dissipative structure [23, 24]. In this case, macroscopic precipitation for values of spatial coordinates is released from the coagulation flow:

$$x \geq x_c = \frac{1}{\int\limits_0^\infty \mu^2 J_0(\mu) d\mu > 0}.$$

It should be emphasized that the integral mass flux value of coagulating particles $\int\limits_0^\infty \mu_1 J(\mu_1, x)\, d\mu_1$ is a constant value equal $\int\limits_0^\infty \mu_1 J_0(\mu_1) d\mu_1$ at $0 \leq x \leq x_c$, and at $x \geq x_c$, this value monotonically decreases, tending to zero at $x \to +\infty$, due to precipitation along the flow channel of macroscopic sediment not interacting with microparticles in the flow [10].

Additional hypotheses and studies are required to describe the flow characteristics of the released macrostructure and its effect on the flow structure [35, 23].

For visual analysis of the solution of equations (12, 13) when condition (14) for particle transport velocities in one-dimensional flow (14) is satisfied, let us consider an example with the following particle distribution at the channel inlet $x = 0$:

$$f_0(\mu) = \exp(-\mu), \quad \mu \geq 0.$$

Solving these equations, taking into account the requirement of adjacency of the solution to the initial function, we have:

$$J(\mu, x) = \begin{cases} \mu^{-2} x^{-1/2} I_1(2\mu x^{-1/2}) \exp[-\mu(1+x)], & \mu \geq 0, \quad 0 \leq x \leq x_c = 1, \\ \mu^{-2} x^{-1/2} I_1(2\mu x^{-1/2}) \exp[-2\mu x^{-1/2}], & \mu \geq 0, \quad x > x_c, \end{cases}$$

where I_1 is the Bessel function of the imaginary argument. The position of the critical point x_c, to the right of which the mass release of sediment along the flow of coagulating particles begins, is determined by equality $x_c = 1$. The corresponding equations for the integral mass flow of the coagulating substance along the channel $Ox = \{x \geq 0\}$ are as follows:

$$\bar{J}_{micro}(x) \equiv \int\limits_0^\infty \mu_1 J(\mu_1, x)\, d\mu_1 = \begin{cases} 1, & 0 \leq x \leq x_c = 1, \\ x^{-1/2}, & x > x_c. \end{cases} \tag{15}$$

,

Accordingly, under the law of mass conservation, the flux of matter in the form of a deposit $\bar{J}_{macro}(x)$ (macrostructure-polymer) released along the channel Ox and does not interact with the flow of coagulating particles (microphase of matter) is determined by the following equations:

$$\bar{J}_{macro}(x) = \begin{cases} 0, & 0 \leq x \leq x_c = 1, \\ 1 - x^{-1/2}, & x > x_c. \end{cases} \tag{16}$$

Equations (15), (16) were tested by direct modeling method for the mentioned process and satisfactory agreement of Monte Carlo results with analytical solution and calculations according to the difference scheme was obtained, see Fig. 6.

Conclusion

The specified model can serve as a basis for the construction of a hierarchical system of thrombus formation in the cardiovascular system from the microscopic level to macroscopic structures. In particular, in [36] the specialists of Mount Sinai Medical Complex in New York emphasize: "The use of agents that reduce blood clotting – anticoagulants – can increase the chances of COVID-19 patients for survival". The researchers analyzed records of 2,773 patients with COVID-19 admitted to hospitals between March 14 and April 11, 2020. They paid particular attention to the survival rates of patients who received anticoagulants. The researchers also took into account certain risk factors, including age, ethnicity, chronic disease, etc. Anticoagulants were given to 28% of patients. They were given a dose higher than the prophylactic dose: high concentrations of drugs are used when blood clots are detected or suspected to have formed. The

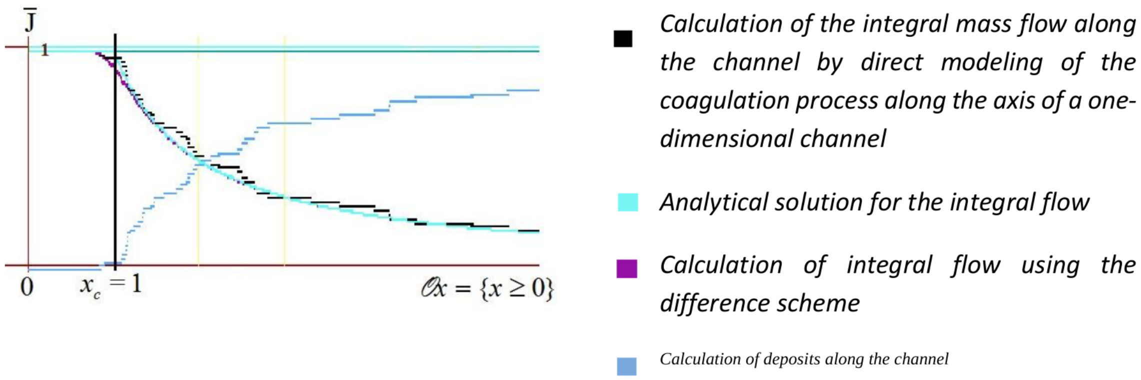

Figure 6. *Integral values of the amount of precipitation from the flow of coagulating particles along the flow channel* Ox

use of anticoagulants was associated with improved survival in COVID-19 patients both in and out of the ICU. Among the patients who died, those who received anticoagulants survived 21 days. Those who were not receiving anticoagulants lasted 14. Taking anticoagulants was associated with increased survival among ventilated patients: 62.7% of patients who did not receive the drugs died in the group, and half as many patients who did, 29.1%. All patients were given blood tests on admission to the hospital, which also showed various inflammatory markers. Analysis of these records showed that the patients who received anticoagulants had higher inflammatory markers than the others. This may indicate that patients in the more severe condition may have received anticoagulants at an early stage. However, patients who received anticoagulants were more likely to have bleeding of various types, from intracerebral to gastric, hemorrhage in the eyes and blood in the urine, which was 3%. In the group that did not receive anticoagulants, bleeding and hemorrhage occurred in 1.9%. This study demonstrates that anticoagulants taken orally, subcutaneously, or intravenously can play an important role in the care of patients with COVID-19 and can prevent possible fatal outcomes associated with coronavirus, including heart attack, stroke, and pulmonary embolism. The use of anticoagulants should be considered when patients are admitted to emergency departments and when they test positive for COVID-19.

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INVESTIGATION OF SYSTEMS WEAKENED BY KINKED CRACKS

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Abstract: structural strength of aircraft is a key aspect of flight safety. Hidden defects in the material significantly affect its strength under various loads. The crack growth rate and direction, and the crack growth threshold load (stress intensity factor) affect the strength of the damaged material. This study investigates a 3D elastic structure weakened by a system of flat cracks and a kinked crack. The numerical method used was the boundary element method, specifically, the displacement discontinuity method. The code was developed with C++. The results were compared against the available analytic results. The behavior of cracks under bending and a range of loading conditions was studied.

Keywords: 3D space, elastic medium, crack, stress intensity factor, boundary element method, displacement discontinuity method.

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ИЗУЧЕНИЕ СИСТЕМ, ОСЛАБЛЕННЫХ ТРЕЩИНАМИ С ИЗЛОМОМ

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Аннотация: прочность летательных аппаратов любых типов — важнейший вопрос безопасности полетов. Наличие скрытых дефектов в материале существенно влияет на прочность при различных нагрузках. Важными характеристиками прочности материалов с дефектами являются скорость и направление роста трещины, а также величина критической нагрузки (коэффициента интенсивности напряжений), при которой начинается рост трещины. В данной работе исследуется трехмерная упругая среда, ослабленная системой плоских трещин и одной трещиной с изгибом. В качестве численного метода был выбран метод граничных элементов, а именно метод разрывных перемещений. Код реализован на C++. Было проведено сравнение с известными аналитическими результатами. Изучено поведение трещин при изгибе при различных нагрузках.

Ключевые слова: трёхмерное пространство, упругая среда, трещина, коэффициент интенсивности напряжений, метод граничных элементов, метод разрывных смещений.

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Introduction

Structures can experience planned and random external loads that affect their safety [1]. The study of the strength of aircraft structures is a complex process, which can be considered from different perspectives. The study of strength under different types of loads is presented in [2, 5], and the strength under high-temperature loads is discussed in [3]. There have also been studies in which the spatial failure of the membrane has been investigated [6]. The problem of asteroid destruction during their interaction with impact or explosive missiles is also relevant [4]. Data on the presence of micro defects inside asteroids help us to understand where the heterogeneities are located. This allows us to predict where the impactor should be directed to blow up the asteroid, getting the maximum effect at minimum cost. The development of such missions requires predictive numerical modeling, which relies heavily on the science of strength of materials and structures, particularly linear fracture mechanics. The foundations of this theory were developed in [7, 8]. The primary cause of fracture is the presence of defects in the material in the form of so-called cracks, which are simulated by the displacement field jump on a certain part of the surface. For an elastic medium, this leads to the appearance of features at the crack boundary. When approaching the crack boundary, the stresses tend to infinity, i.e. the concentration of stresses occurs in a sufficiently small vicinity of the boundary. Since the existence of infinite stresses in real materials is impossible, a region of irreversible plastic deformations occurs near the crack edges. Nevertheless, in cases where the size of this field is small compared to the size of the crack itself, the applicability of the crack growth criteria is based on the analysis of the elastic solution obtained [9–14]. Linear fracture mechanics has developed rapidly and is currently one of the main tools for assessing the strength of materials with defects. A sufficiently complete picture of the results obtained in this field is given by the reviews [14–18].

We use the three fundamental solutions of the theory of elasticity about the discontinuity of the three components of the displacement vector on the surface of the boundary element as the basic functions of the solution decomposition. The general solution of the entire problem is represented as a sum with indefinite coefficients, i.e., as a finite series of analytically defined basis functions. The coefficients of the series are determined by the collocation method on the boundary (the boundary conditions are fulfilled only in the centers of boundary elements). This approach makes it possible to avoid calculating singular integrals that arise when using direct methods of boundary integral equations.

The advantage of the boundary element method is that only the fracture surface, modeling the fracture of the elastic medium, is broken into finite elements. This reduces the scale of the problem at the stage of its solution. Three independent analytical solutions are used for each element, in each of which one of the three displacement vector components suffers a discontinuity in the element. The solution to a particular boundary value problem is sought as a series with uncertain coefficients over the entire set of elements. Each element solution contributes to the displacement field and the stress field with a weight, which is the corresponding uncertain coefficient of the series. Fulfilling the specific boundary conditions leads to a system of linear equations after numerically determining the expansion coefficients. We have an analytical representation of the solution as a finite series within the domain. In terms of memory, we only need to save the found expansion coefficients, which will then allow us to find any desired characteristics at any point in the solution domain. This is important in terms of the ease of practical use of the resulting solution. Another important advantage of the proposed method is the possibility to solve any boundary value problem (stress problem, displacement problem, any mixed problem).

The disadvantage of the method is its weak mathematical reliability; therefore, a large amount of work is required to verify the reliability of the results. For this purpose, a comparison was made with the available analytical solutions of spatial problems, as well as with the known results of numerical solutions of fracture mechanics problems obtained by other numerical methods. The program codes have been implemented by the authors in C++. The main characteristic of linear fracture mechanics is the stress intensity coefficient at the crack edge (Fig. 1), which in the case of tensile strain in the direction normal to the crack plane is defined as

$$K_I = \lim_{s \to 0} \sqrt{2\pi s} \ \cdot \sigma_{zz}(s),$$

in the case of shear deformation in the crack plane along the normal to its edge is defined

$$K_{II} = \lim_{s \to 0} \sqrt{2\pi s} \ \cdot \sigma_{nz}(s),$$

and in the case of antiplane deformation (shear in the crack plane tangential to the edge) is determined.

$$K_{III} = \lim_{s \to 0} \sqrt{2\pi s} \ \cdot \sigma_{\tau z}(s).$$

This problem was solved numerically in the three-dimensional formulation for different radii. The comparison results allow us to speak about sufficient efficiency and satisfactory accuracy of the proposed method [22].

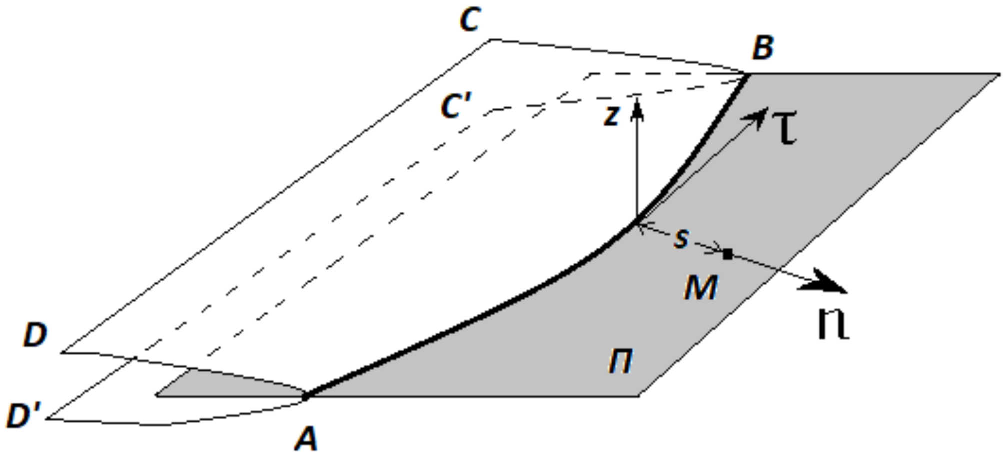


Figure 1. *Determination of the stress intensity coefficients for the cases of different types of deformations*

The written program was tested by comparing it with known analytical solutions [15–16], [19–21]. The comparison showed good qualitative and quantitative agreement with the available results of other authors. For example, a comparison was made with the solution for an axisymmetric crack in the form of a disk, which is under the action of internal pressure. In the cylindrical coordinate system r,φ,z (the crack corresponds to the disk $z= 0{,}0 \le r \le R$) and in the given problem we have boundary conditions: $z= 0{,}0 \le r \le R, \sigma_{zz}= -p, \sigma_{rz}= 0$. In the analytical solution for a circular crack the value K_I is equal to:

$$K_I = \frac{2}{\sqrt{\pi R}} \int\limits_0^R \frac{r \sigma_{zz}(r) dr}{\sqrt{R^2 - r^2}}.$$

Circular fracture with fracture (fracture angle $30°$) is under internal pressure $p = 0.1$

Of some practical interest are cracks, the surface of which has a fracture (the angle between the planes of individual segments of the crack is different from zero). Such a geometric configuration can arise at the merger of two separate plane cracks. In linear elasticity theory, the presence of any jumps in the boundary conditions leads to peculiarities in the solution. Since the crack model itself (the discontinuity surface of the displacement field) carries a peculiarity of the solution, it is interesting to investigate the effect of a possible kink in its surface on the change in the stress distribution in the vicinity of the crack edge.

We consider an elastic medium weakened by a fracture crack. The crack is active, that is, it is loaded with internal pressure P, as shown in Fig. 2. Geometrically, the surface of the crack is two semicircles of the same radius, the planes of which are located at a given angle to each other. It is necessary to investigate in which direction the crack is most likely to grow.

The value of the J-integral of Cherepanov-Rice is taken as the main characteristic responsible for the possible crack growth. This integral is a combination of the squares of the stress intensity coefficients (Cherepanov and Rice) [11–13]:

$$J = \frac{1-\nu}{2\mu}\left(K_I^2 + K_{II}^2\right) + \frac{1}{2\mu} K_{III}^2.$$

Since in the geometric configuration under consideration the two halves of the crack are equal, the edge of that half of the crack, which is located in the plane xy(Fig. 2), has been studied. In the calculations, dimensionless quantities have been used: the length unit is the radius of half-circle of each half of the crack; stresses and pressure have been referred to the value 2μ, Poisson's ratio has been chosen to equal $\nu = 0.25$. The internal pressure is assumed to be $p = P/2\mu = 0.1$. Such an unrealistically large pressure has been chosen to make it possible to visualize the crack opening. The angle between the planes of two

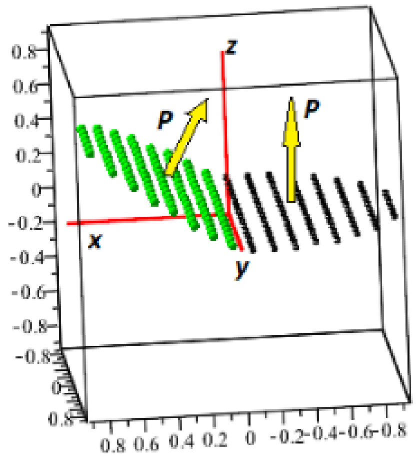


Figure 2. *Crack with fracture under internal pressure, directed along the normal to the banks of the crack*

planar semicircular segments of the crack is called a fracture angle. For comparison, the calculations for two fracture angles with values 30° and 60°.

Fig. 3 shows graphs of the value J vs. the angle. The angle is counted along the arc of the circular edge of the crack and varies within $[-\pi/2,\pi/2]$. The zero value of the angle corresponds to the point $x = -1, y = 0, z = 0$ (Fig. 2), the value of the angle $\pi/2-$ corresponds to a point with coordinates $x = 0, y = 1, z = 0$, the angle $-\pi/2$ corresponds to a point with coordinates $x = 0, y = -1, z = 0$. The last two points are on the fracture line, which is part of the axis y(Fig. 2). Fig. 3a shows the curve J for the break angle 30°, Fig. 2b shows the curve for the break angle 60°.

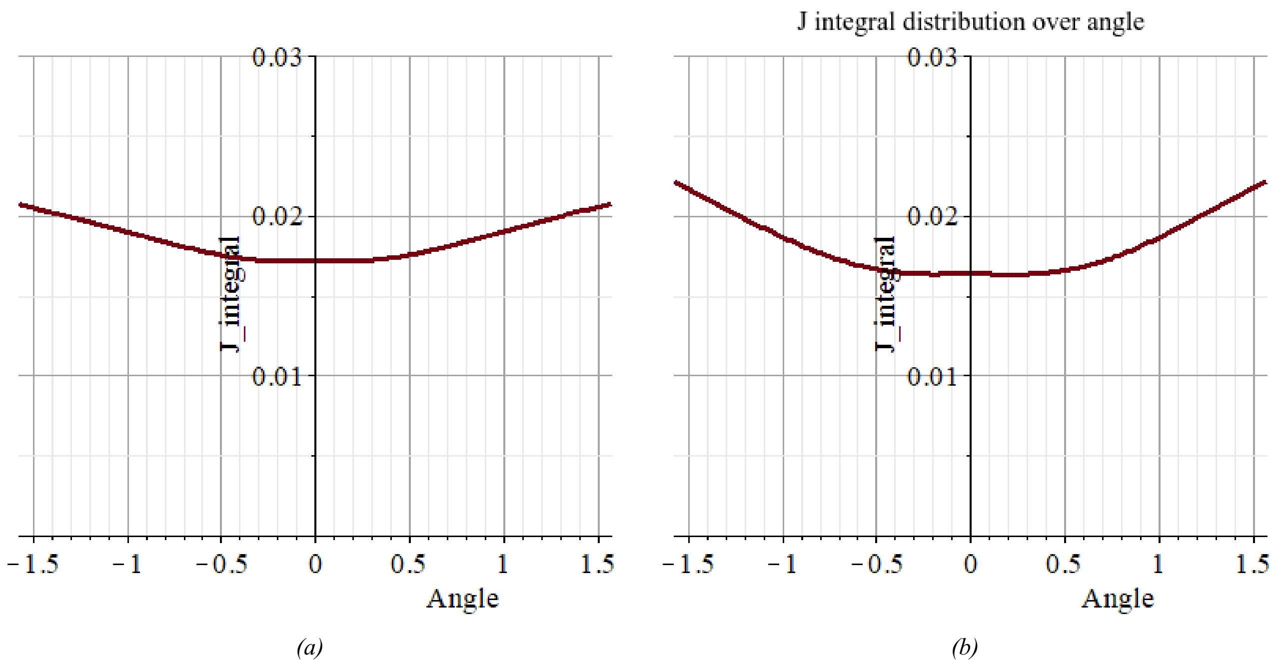
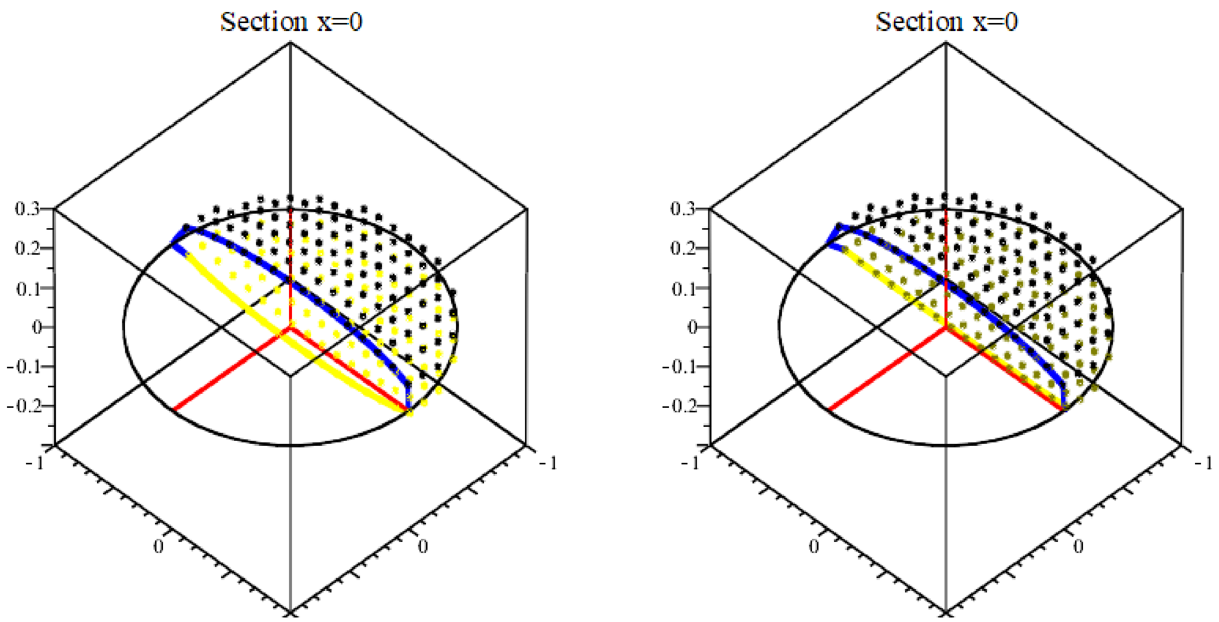


Figure 3. *J-integral on the interval* $\left(-\frac{\pi}{2};\frac{\pi}{2}\right)$*, a is for the break angle* 30°*, b is for the break angle* 60°

As follows from the dependencies in Fig. 3 a and b dependences, the maximum values J for both angles are reached at the points lying on the fracture line, i.e., on the axis y. This means that possible crack growth will develop in the directions of the fracture line. As the fracture angle increased, the maximum J-integral increased and the minimum decreased. The effect of the fracture angle on the qualitative appearance of the J-integral distribution curve is insignificant.

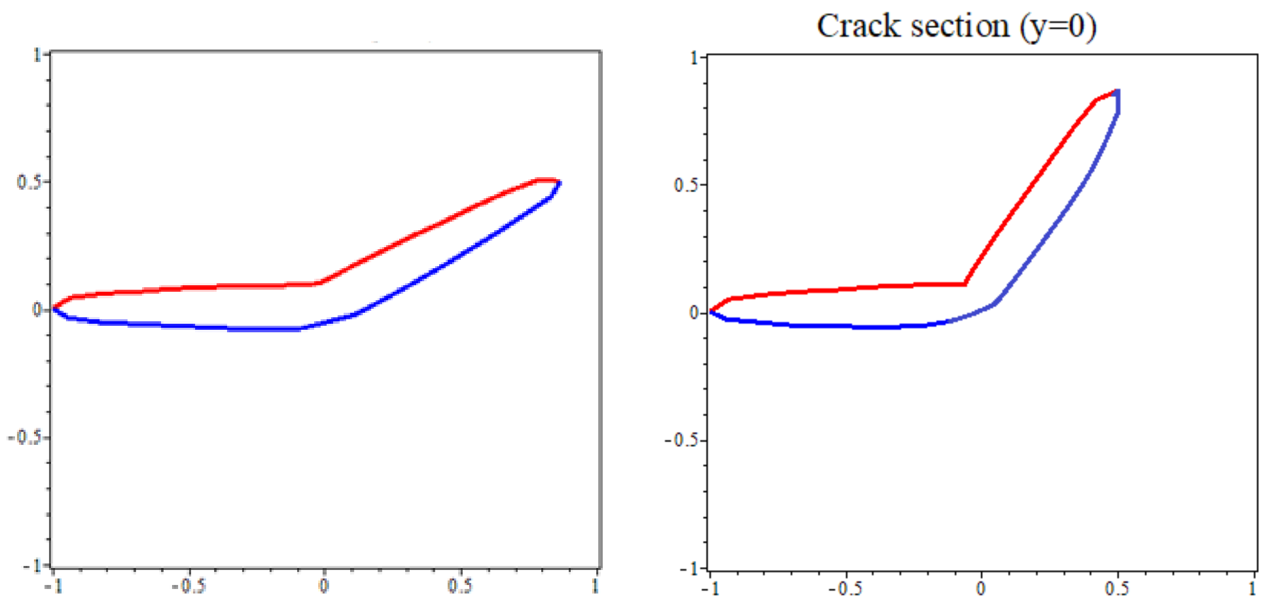
Fig. 4 shows the crack opening in the fracture section $x = 0$. The opening is understood as the value of the difference of displacements corresponding to the upper and lower banks of the crack. Fig. 4a and 4b show the three-dimensional opening of half of the crack (points of different colors correspond to the upper and lower banks) for the 30° and 60° fracture angles. The solid curve shows the position of the points in the fracture section. As can be seen, the effect of the fracture angle on the opening is also insignificant.

Fig. 5 shows the opening of the entire crack in the section $y = 0$ (Fig. 5a corresponds to the fracture angle 30°, Fig. 5b to the fracture angle 60°). The above results allow us to conclude that the crack opening is mainly determined by pressure and weakly depends on the fracture angle.



(a) *(b)*

Figure 4. *Crack opening in space (a is the fracture angle* 30°*, b is the fracture angle* 60°*). The solid curve corresponds to the points of the section* $x = 0$



(a) *(b)*

Figure 5. *Crack opening in the section* $y = 0$ *(a is the fracture angle* 30°*, b is the fracture angle* 60°*)*

The graphs (Figs. 4–5) show that the maximum opening is achieved in the fracture section $x = 0$. This corresponds to the results of the location of the maximum values of the J-integral and the directions of possible crack growth along the axis y.

It is known that in the vicinity of the crack boundary the stresses have a feature $\sigma \sim !/\sqrt{s}$, where $s-$ is the distance to the crack edge. To control the stresses, their calculation was made in the cylindrical coordinate system r,φ,z for angles $\varphi \in [\pi/2, 3\pi/2]$, corresponding to the boundary of the semicircle $z = 0$, $x^2 + y^2 = R^2$, $x \leq 0$. The value of radius was taken as the value of $R = 1.01$. This corresponds to the value of the distance s o the boundary equal to $s = 0.01$.

The graphs of stress distribution along the crack edge, depending on the angular coordinate ϕ in the polar coordinate system, are shown in Fig. 6 (a corresponds to the fracture angle 30°, b to the fracture angle 60°).

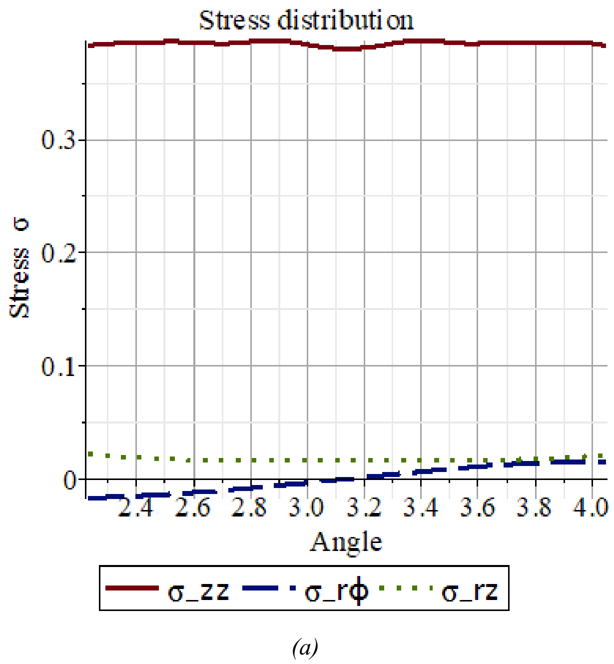


Figure 6. *Stress $\sigma_{zz}, \sigma_{r\varphi}, \sigma_{rz}$ vs. angular coordinate φ along the crack boundary in the cylindrical coordinate system (r,φ,z), $r = 1.01$, $\pi/2 \leq \varphi \leq 3\pi/2$, $z = 0$ (a is the fracture angle 30°, b is the fracture angle 60°)*

It can be seen (Fig. 6) that the stresses σ_{zz} do not depend on the fracture angle. The stresses differ greatly at σ_{rz}. That is, these calculations show that the growth of the J-integral when approaching the fracture is mainly provided by the growth of the stress σ_{rz}. Thus, the crack will grow in the direction of the fracture line if the fracture criterion is met.

To check the influence of the crack loading method, calculations have been made in which the crack sides are free from loads, with the elastic space subjected to tension by stresses acting at infinity along the axis z. That is, an elastic medium weakened by a fracture crack is considered. The angle of the fracture is known and is equal to 30 $\circ$. At infinity, a tensile load $\sigma = 0.1$, perpendicular to the plane of one of the fracture parts, is applied, as shown in Fig. 7.

Fig. 8 shows plots of the stress intensity coefficients K_I, K_{II}, K_{III} respectively. The intensity coefficients were calculated by the displacement method using asymptotic formulas:

$$u_z = \frac{K_I}{\mu}\sqrt{\frac{r}{2\pi}} sin\frac{\theta}{2}\left(2 - 2\vartheta - cos^2\frac{\theta}{2}\right)$$

$$u_x = \frac{K_{II}}{\mu}\sqrt{\frac{r}{2\pi}} sin\frac{\theta}{2}\left(2 - 2\vartheta + cos^2\frac{\theta}{2}\right)$$

$$u_y = \frac{K_{III}}{\mu}\sqrt{\frac{r}{2\pi}} sin\frac{\theta}{2} \ .$$

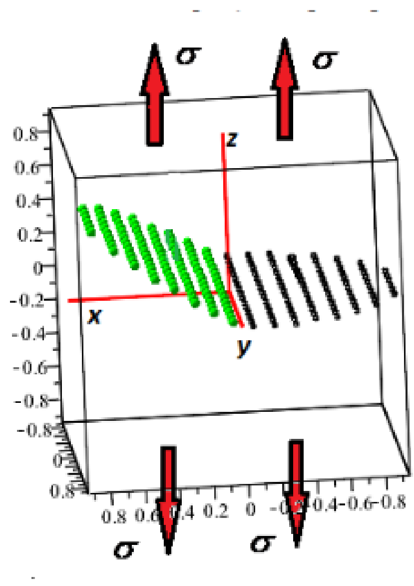
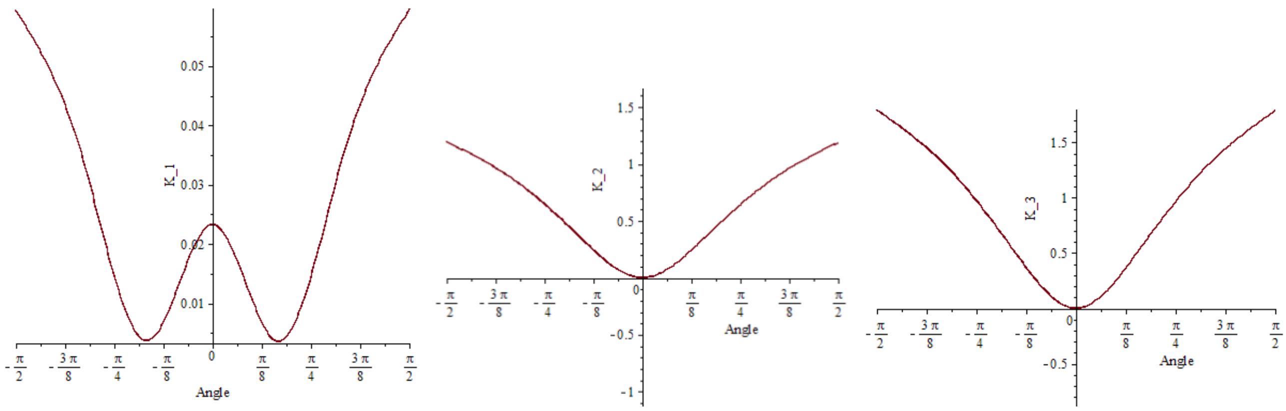


Figure 7. *Crack with fracture* 30°, *the load is applied in the direction of the OZ axis*

The graphs show the distribution of the corresponding coefficients on the interval $(-\pi/2,\pi/2)$. The zero angle corresponds to the fracture boundary point $x=-1, y=0, z=0$, the angles $(-\pi/2,\pi/2)$ correspond to the fracture points of the boundary.



(a) *(b)* *(c)*

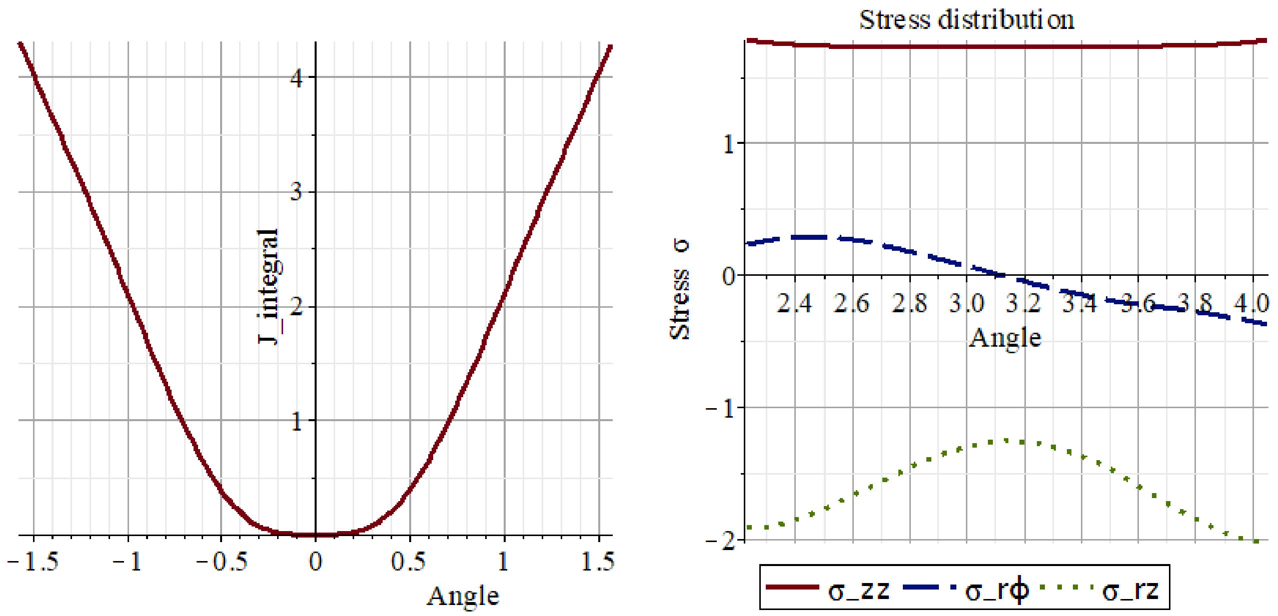
Figure 8. *Distribution of intensity coefficients: a –* K_I*, b –* K_{II} *, c –* K_{III}

J-integral and the stress distribution along the boundary of the crack segment perpendicular to the axis of z in the cylindrical coordinate system are presented in Figs. 9 a, b, respectively. As in the previous cases, the value of the distance to the crack edge was used $s=0.01$.

The above calculations show a very strong dependence of the problem on the nature of the load.

Conclusions

1. Fracture cracks always start to grow along the fracture line, regardless of the type of load.
2. If the fracture crack is under pressure, its opening and stress distribution weakly depend on the fracture angle (they are slightly larger with a larger fracture angle).
3. The stresses are very much dependent on the nature of the crack load. If the fracture crack is passive and the load is applied at infinity, the stresses in the vicinity of the crack are very different.
4. The crack under load applied at infinity is less stable. This follows from a comparison of the value of the combination of stress intensity coefficients for a crack under pressure and a crack in space subjected to tension at infinity.



(a) *(b)*

Figure 9. *a – J-integral, b – stress distribution*

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THE APPLICATION OF MACHINE LEARNING AND NEURAL NETWORKS TO AUTOMATED TEXT AND VISUAL ASSIGNMENT VERIFICATION USED AS ASSISTANCE TO EDUCATORS

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Abstract: the digitalization of education in Russia and worldwide enables a more extensive introduction of advanced teaching methods through a partial switch from offline to online teaching. The existing and coming e-learning platforms feature not only digital lecture videos and e-textbooks but some automated assessment/grading tools. There is a need to expand the coverage of such tools to avoid the extreme burden of online teaching as the educator has to allocate significant time for assessing the increased amount of high school/university student assignments. Also, distant learning diminishes the effect of the educator personal presence since the teacher and the student are separated by their computer screens. Smart educator assistants and automated assessment tools based on machine learning and neural networks can significantly alleviate the problem. This study offers some strategies for automated assessment of graphic assignments and checks for plagiarism. Possible AI-based implementations of such features are presented.

Keywords: e-learning platform, checking for plagiarism, distant learning, automated assessment, smart educator assistant.

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ИСПОЛЬЗОВАНИЕ МАШИННОГО ОБУЧЕНИЯ И НЕЙРОННЫХ СЕТЕЙ ДЛЯ АВТОМАТИЧЕСКОЙ ВЕРИФИКАЦИИ ЗАДАНИЙ В ТЕКСТОВОМ И ГРАФИЧЕСКОМ ПРЕДСТАВЛЕНИИ И ПОМОЩИ ПРЕПОДАВАТЕЛЮ

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Аннотация: процесс цифровизации образования, активно проводимый в нашей стране и по всему миру, позволил более широко применить в учебном процессе современные приемы преподавания, перенося часть педагогической нагрузки с очного формата на дистанционный. Проектируемые и используемые цифровые образовательные платформы уже сейчас включают в себя не только оцифрованный лекционный видеоматериал и электронные формы учебников, но и элементы автоматизации проверки выполненных учащимися заданий. Расширение области применения автоматической проверки решенных учащимися задач и выполненных упражнений является объективной необходимостью, в противном случае при дистанционных формах образовательного процесса резко возрастает нагрузка на педагога, который должен выделять значительное время на проверку увеличившегося самостоятельной работы школьников и студентов. Кроме того, при дистанционном преподавании снижается эффект личного присутствия педагога, когда учитель и ученики разделены экранами компьютеров. Существенной помощью может стать использование интеллектуальных помощников преподавателя и автоматизированных систем проверки, построенных методами машинного обучения и технологии нейронных сетей. В настоящей статье рассмотрены подходы к решению поставленных задач по автоматической проверке графических заданий и выявлению заимствований в текстовом виде. Показаны возможные варианты реализации этих функций с использованием технологий искусственного интеллекта.

Ключевые слова: цифровая образовательная платформа, поиск заимствований, дистанционное образование, автоматическая проверка, интеллектуальный помощник преподавателя.

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We began to talk about a fully automatic learning process without the participation of a human teacher back in the 1970s when the first intelligent learning systems appeared [1, 2, 3], but the actual successes in this direction today do not allow us to fully replace traditional training in the format of a full-time school, university and classroom. Currently, there is a gradual transition of education to the digital form, which allows for wide accessibility and high efficiency of the educational process [4].

Digitalization of education has made it possible to move some of the learning processes from a face-to-face classroom format to a remote one, which has opened up the possibility of automating some of the functions of the human teacher, allowing to maintain the quality of learning and to fully use all the possibilities of the digital educational platform. Such functions, for example, include checking graphical assignments, estimating the probability of borrowing the solution of an assignment, including textual ones (anti-plagiarism), and the function of helping students find answers to common questions arising during the solution of assignments. Even though these functions are not traditional features of “intelligent learning systems” [5], for their effective implementation the use of artificial intelligence technologies is justified. The article considers the requirements for these functions and describes possible implementations of these functions using artificial intelligence technologies.

The automation of task checking is a typical task of a digital educational platform, which is especially in demand in programming education. Further in the paper, we will consider automatic checking of graphic tasks. We will call “graphic task” the task, the result of which is estimated from the image. The task of checking graphic tasks occurs, for example, in such disciplines as engineering and computer graphics [6]. In the case of computer graphics, the task checking can not be limited to a pixel-by-pixel comparison with the original and should allow counting the tasks with insignificant admissible deviations.

A graphical task is considered to be correctly solved if the image synthesized by the student’s program is close to what was required by the conditions of the task. One of the predefined functions can be chosen as a measure of closeness of the provided and expected solution, for example, a pixel-by-pixel comparison or an intelligent comparison with a reference. In this case, the teacher is not required to create a specialized software tool to check the tasks or to describe the results of the task in any formal language.

The verification function can be implemented both by classical methods of comparison with the reference and using modern intelligent methods, for example, based on the application of ANN [7]. In the case of the application of intelligent methods for setting the function of checking the result, it is enough to provide the system with one or more images containing valid answers. As the result of the comparison determines the probability of proximity of the provided image to the expected one, in case of low probability the task is transferred to the final manual check by a human teacher. In practice, an intelligent system for checking graphical assignments can be composed of an embedder, which translates images into vectors of low dimensionality, and a KNN classifier, working in the space of these vectors (figure 1).

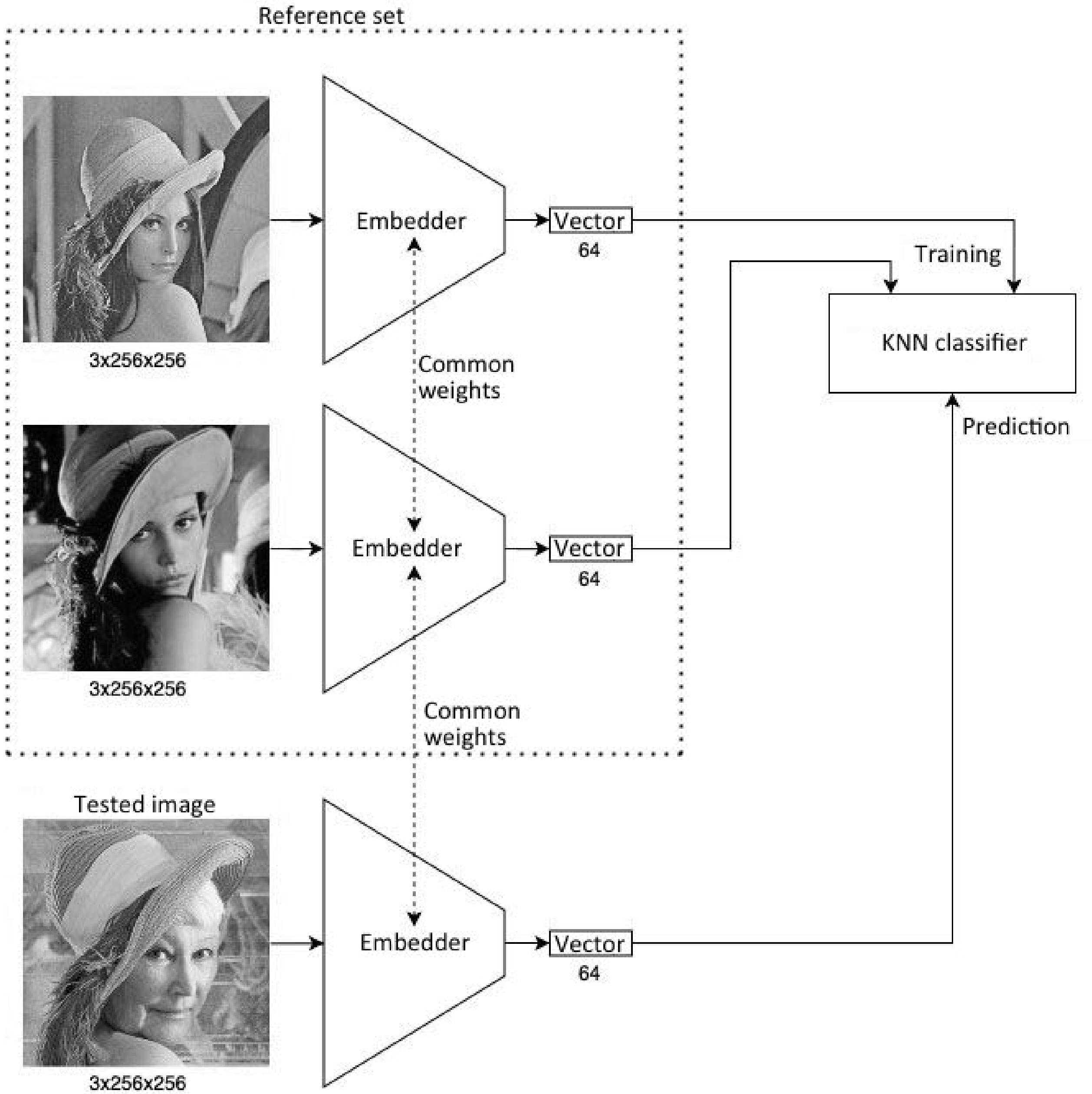

Figure 1. *Image comparator architecture with an embedder and a KNN classifier*

The embedder can be represented by an ANN, which can be trained on any available volumetric data set. During training the embedder is augmented by an extender to a full ANN of the following form: the embedder takes as input an image and outputs a low-dimensional vector, the extender takes as input this vector and outputs an image. During training, such an extender augmented ANN optimizes the pixel-by-pixel distance between the input and output images (Figure 2).

Thus, the Embedder is trained to encode high-dimensional spatial features embedded in the image into a low-dimensional vector. In this case, similar-looking images will be converted to vectors that are close in the Euclidean metric. It is noteworthy that it is not necessary to train the Embedder on new images to test the new type of problems, a single initially high-quality training on a sufficiently large set of pictures

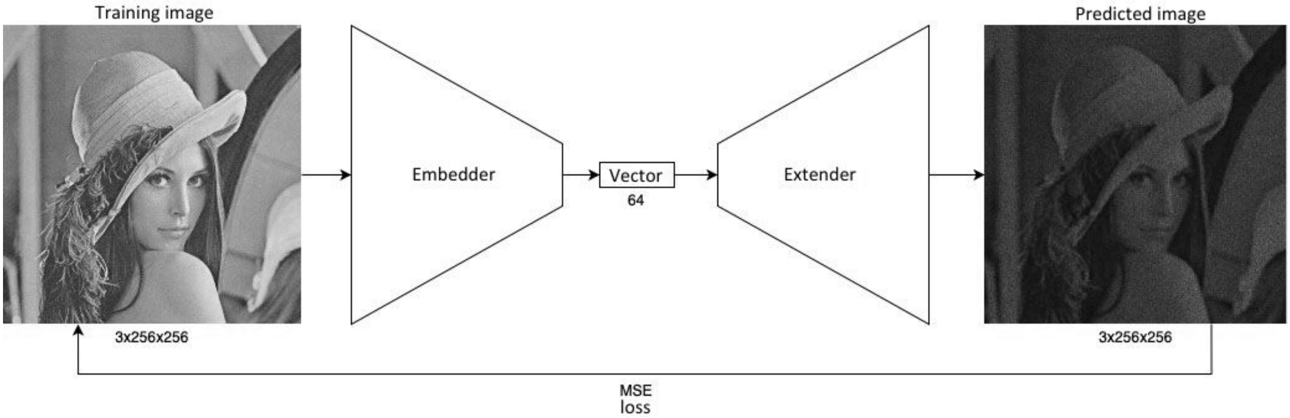

Figure 2. *Embedder training chart*

is enough.

For all the universality of intelligent methods in practice, the developers of verification systems resort to combining intelligent and heuristic methods, for example, to exclude the possibility of successful completion of the task when providing a blank, filled with one tone or containing a special “mask” (rather than the task solution) image.

In addition to graphical solutions, automatic verification can also be implemented in a wide range of tasks. For example, an obvious application is the automatic verification of solutions to programming problems, where it is sufficient to test the solution on a finite set of input data. And here artificial intelligence, oddly enough, can also be successfully applied, for example, to determine the so-called hardcode. Other cases, such as the automation of essay verification, without training and competent implementation of heavyweight neural network language models, are not feasible at all.

An equally urgent task in a remote environment is tracking and preventing the borrowing of solutions.

When working in the classroom, the problem of borrowing is solved by the teacher’s communication with the student in the process of solving the task, which allows you to assess his level of understanding of the program provided and the degree of his “independence” in the preparation of the solution.

In the case of distance learning, there is no such possibility, so the teacher has to look through all solutions of tasks and analyze the possibility of borrowing them to maintain the quality of learning. The number of such tasks for each student can number in the dozens during the course. Let’s consider this problem in the example of the task in the programming course.

The task of tracing borrowings is closest to the existing concept of “anti-plagiarism”, that is, we are talking about the fact that, for example, when solving a programming problem, one student’s solution was fully or partially used by one or more other students. A distinctive feature of educational programming tasks is that, firstly, the solution of simple (typical) tasks can be repeated with exact values of parameters by several students, and, secondly, the main part of the program can be a “template” of the program which is not changed by the student. Thus, only a small fragment of the program remains for the evaluation of borrowing. In this regard, there is no unambiguous solution to the problem of plagiarism assessment in this case, and it is only possible to indicate that several submitted solutions are similar, which is a signal to the teacher, who, drawing attention to the anomaly, will take action to prevent further copying of solutions, if it is confirmed.

Several techniques can be used to implement this function: style analysis, program structure analysis, problem-solving analysis, and heuristic analysis.

Analysis of style, in our case source code [8], is a kind of handwriting expertise. The limitation of this method’s application is those novice developers either have not yet formed the style, or it repeats the industry standard, or the code can be automatically formatted by the development environment used. Signs of time can also include extensive copying fragments of solutions from programming sites or popular forums.

Methods of style analysis are implemented using ANN [8] and have proved to be good when analyzing large fragments of source code: the proximity of code styles of different students is evaluated and, if “suspicious proximity” is noticed, the task is sent to the teacher for checking. To implement such methods, it is necessary to form a set of code metrics, based on which the comparison will be performed. Examples of metrics are indentation type, statements and block elements, naming character and length of names of parameters, functions and classes, etc.

The ANN itself is an embedder already familiar with recognizing solutions to graphical problems (Figure 3). The difference lies in the training process. Embedder for the task of plagiarism detection in practice is better trained as a Siamese network, using, for example, triplet loss.

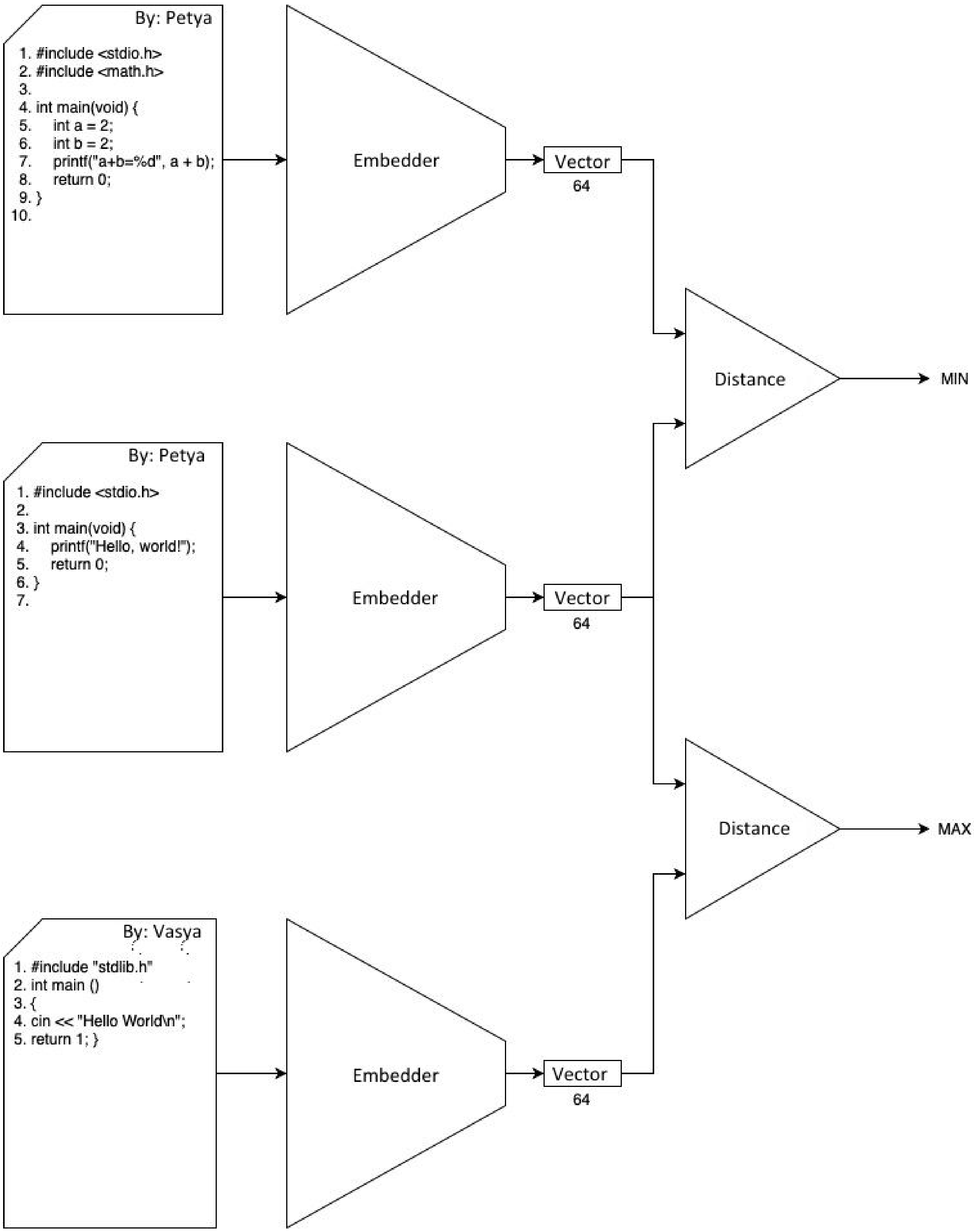

Figure 3. *The architecture of the system of source code comparison based on embedder*

Various open-source data sources can be used for learning, such as public repositories from GitHub. Examples of the same class in this approach are program codes belonging to the same author.

Program structure analysis can also be used for borrowing analysis. In this case, the program is analyzed and transformed into a representation that allows comparing the structures of two programs and their proximity [8]. Advanced intelligent implementations of such methods are resistant to the use of "obfuscation" – the addition of redundant language and algorithmic constructions to the code to reduce the "similarity" of two programs. For simple tasks, such methods will not show reliable results, because the structure of programs will be the same for all students.

The method of analyzing the problem-solving process is promising. In practice, even simple problems are not handed in on the first try. Thus, it is possible to analyze the evolution of the task to assess how the student progressed to the final solution. If the digital platform supports online editing of the assignment code, the analysis can be extended by using data on the student's work in the online editor. In this case, the problem-solution collects metrics about the nature of the code work, the specifics of entering language elements (parameter names, keywords), general typing parameters, etc. The application of ANN, in this case, will require the preparation of a large amount of data for training, which is a significant limitation for the application of this method at the stage of launching a new digital system.

Heuristic methods of analysis also go in combination with intelligent methods to rule out the simplest methods of borrowing, based on surrendering copies without change, etc.

Of course, any of the above methods can be bypassed by students, but the main function of checking is to prevent borrowing, not to catch them red-handed. Knowing that the assignment will be checked for borrowing, the student may decide to spend more time preparing an independent solution to avoid unintended consequences. The technology of generating unique assignments for each student can also be used to solve the borrowing problem, but this topic is the subject of a separate study.

In a distance learning environment, the issue arises of communicating answers to typical questions to students. In the classroom, such information spreads naturally in the course of the class, when the teacher answers one student's question and all the other students unwittingly listen to the answer. But in the case of distance learning, typical questions will come repeatedly. To relieve this burden the teacher may need an intellectual assistant. Below we will consider the dialog assistant (chat-bot).

The dialog assistant is the result of the development of information retrieval systems that provide answers to questions posed in the form of natural language statements. Although the very idea of dialog mode of communication with the student appeared in the '70s [3], this technology has become widespread only in the last 10 years due to the emergence of new technologies and computing tools for effective implementation of natural language analysis techniques.

The requirements for such systems may include support for students' vocabulary (abbreviations, slang, etc.), resistance to spelling and syntactic errors, collection of statistics on the questions for further analysis, the ability to redirect the question to the teacher if the assistant could not answer it.

Natural language analysis and dialog systems are high-tech intelligent solutions that require specialized knowledge, so it is important to provide the teacher with the ability to use such solutions at a high level, describing only the subject area in the form of typical questions and answers with reference material.

One solution in this area is the open-source library Rasa [5]. Based on this library, intelligent solutions can be built that do not require knowledge of specialized languages for describing dialog interfaces. Thus, the teacher can foresee the typical questions of students in advance and include them in the scripts of the dialog assistant's answer. Moreover, it becomes possible to transfer the control of the conversation to the teacher in case of the absence of the necessary answer to automatically "train" the dialog assistant to answer more students' questions later on.

Digital educational platforms at the current stage can be seen not as a substitute for the human teacher, but as a teacher's tool to automate resource-intensive activities. Automation frees up teacher's time to work with students who need extra attention and to continuously improve teaching methods. The usual human-teacher activities often turn out to be creative tasks that require either special knowledge to automate them or the use of intelligent technologies which take up all the complexity of automation.

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ESTIMATION OF THE Ki-67 PROLIFERATION MARKER EXPRESSION LEVEL WITH COMPUTER VISION TECHNOLOGY

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Abstract: lately, computer vision technologies have become common computer diagnostics tools. The study objective is the development of software tools to automatically detect cells with proliferation markers on medical images. We managed to qualitatively assess the number of cells with proliferation markers on a medical image sample. We closely cooperated with morphologists who identified the areas of interest on the image where the cells with proliferation markers were to be counted. Another enabler was extensive experience with developing computer vision systems for other applications. The medical images were tokenized by the morphologists. The images were slices where the proliferation marker cells were dyed. The organ under investigation was the tongue. We counted the immune-positive cells. It helped the morphologists to have some objective slice image metrics used to adjust the diagnosis and therapy plans.

Keywords: computer vision, Python, OpenCV, Ki-67 proliferation marker.

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ОПРЕДЕЛЕНИЕ УРОВНЯ ЭКСПРЕССИИ МАРКЕРА ПРОЛИФЕРАЦИИ Ki-67 С ПОМОЩЬЮ ТЕХНОЛОГИИ КОМПЬЮТЕРНОГО ЗРЕНИЯ

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Аннотация: в последнее время в качестве средств компьютерной диагностики широкую популярность приобретают элементы из области компьютерного зрения. Целью данной работы является разработка программных средств, позволяющих автоматически анализировать онкомаркированные клетки в образцах медицинских изображений. В процессе работы была решена такая задача, как выявление количества онкомаркированных клеток в образце медицинского изображения. Это стало возможно благодаря тесному взаимодействию с морфологами, обозначавшими интересующие их фрагменты снимка, где необходимо было произвести подсчет онкомаркированных клеток, и опыту программиста в решениях подобных задач других областей жизнедеятельности с помощью технологии компьютерного зрения. Медицинские изображения были размечены морфологами и представляли собой срез стекла, на котором были окрашены в определенный цвет онкомаркированные клетки специальным препаратом. Исследуемым органом стал язык. В результате был совершен подсчет иммунопозитивных клеток, что дает морфологам возможность наблюдать более объективную картину в изображении среза стекла образца, позволяющую скорректировать решение в отношении постановки диагноза и назначения необходимого лечения.

Ключевые слова: компьютерное зрение, Python, OpenCV, онкомаркер Ki-67.

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Introduction

Currently, there is a rapid growth in the development of computer-assisted diagnosis tools. Analytics itself has served medicine for more than 40 years, but only in the last decade its use in healthcare reached a new level: powerful tools, including those based on computer vision technology, machine learning, etc., emerged.

Computer vision is a technology for object detection and classification. As a field of science, it refers to the subject of image processing, and in its technical component it is used in video surveillance systems, industrial process control, object modeling, and recently such systems are very popular in the construction of augmented reality.

Software such systems are implemented using open-source computer vision algorithm libraries, such as Open computer vision (OpenCV) or Point Cloud Library (PCL).

The paper considers the possibilities of visual analysis of the marker, discusses the technical side of the implementation of determining its level of expression based on computer vision technology, and presents the main results of the analysis.

Ki-67 Proliferation Marker

The development of malignant tumors is based on cell proliferation, which leads to an increase in the number of atypical elements. To determine cell proliferation features of malignant tumors the most common marker of proliferation is the Ki-67 antigen, which is expressed practically in all phases of the mitotic cycle, except for the G_0 resting phase, and, accordingly, reflects the value of proliferative pool [1]. Ki-67 protein synthesis starts in the middle of the G_1 phase of mitosis and, gradually increasing, its level reaches a maximum in metaphase, then sharply decreasing in anaphase. Ki-67 antigen detected by appropriate monoclonal antibodies is a short-lived protein, it is destroyed within 1.5–2 hours. Therefore, antibodies to Ki-67 detect only dividing cells, because Ki-67 does not have enough time to accumulate and does not remain in resting cells.

The conventional mitotic activity estimation does not reflect the proliferative potential of the tumor, since mitosis itself takes several hours and preparation for it takes about 24 hours. A study of non-histone protein Ki-67 expressed in all cells coming out of G_0 and early G_1 phases of mitosis allows determining the latent proliferative potential of a tumor.

The proliferative activity directly correlates with the degree of histological malignancy, the degree of invasion, the presence of metastases. The physiological role of the Ki-67 antigen in cell life is still unclear. Nevertheless, its presence in all active phases of the mitotic cycle allows using this protein as a universal proliferation marker for the evaluation of malignant tumor growth activity. Tumor mass growth rate represents very important information for determining the tumor oncological status and aggressiveness. In such cases, its proliferative activity index is one of the decisive factors taken into account when choosing a treatment approach [2].

Artificial System for Assessing the Expression Level of the Ki-67 Marker

To build this artificial system for obtaining an objective assessment, it is necessary to solve the following problems:

1. Applying a mathematical method of selecting two types of spots: brown and blue, where cells are treated as spots of a certain color.
2. Calculation of the ratio of areas of spots of different colors in the image. A prerequisite is a classification concerning the ratio of the excess of one of the spot types.

Direct implementation of the system is performed programmatically in the Python programming language and with the help of the OpenCV computer vision library [3]. The structure of the software operations is shown in Fig. 1.

Let us consider the main steps of the proposed approach:

1. Stain highlighting.

After obtaining the primary image it is necessary to implement the procedure of spots extraction. For this purpose we use the Adaptive threshold from the OpenCV library [4]:

```
mask = cv2.adaptiveThreshold(cv2.cvtColor(img, cv2.COLOR_BGR2GRAY),255,\
```

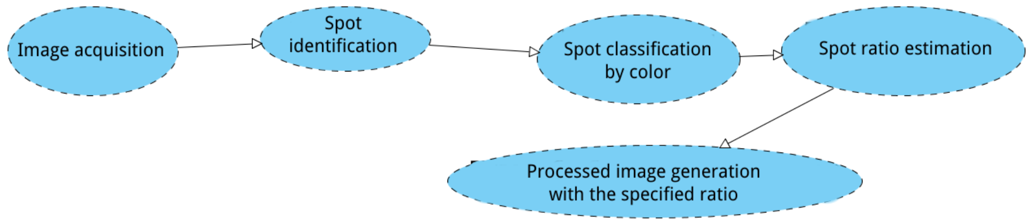


Figure 1. *Software flowchart*

cv2.ADAPTIVE_THRESH_GAUSSIAN_C, cv2.THRESH_BINARY,1931,3)

The next step is to clean the mask of too small pixel blobs. To do this, we blur the mask and apply the same adaptive threshold again. To compensate the small expansion of black spots during the cleaning procedure, the function of narrowing the black areas of the mask is applied. We also use the OpenCV library [5]:

```
mask = cv2.GaussianBlur(mask,(15,15),0)
mask = cv2.adaptiveThreshold(mask,255,\
cv2.ADAPTIVE_THRESH_GAUSSIAN_C, cv2.THRESH_BINARY,1931,3)\
kernel = np.ones((5,5),np.uint8)
mask = cv2.dilate(mask,kernel,iterations = 1)
return mask
```

A combination of these methods and functions results in a mask for cutting off the light background (highlighting spots):

```
mask = clear_mask(get_mask(img))
```

2. Classification of stains by color.

The next step is the operation of separation: which spots are brown and which are blue. To the brown pixels we will refer the pixels for which the following conditions are met:

1. Located inside the spot (mask == 0).
2. The intensity of blue is less than the intensity of red or both: blue is less than 120 and red less than 110, the intensity of green is less than the intensity of red.
3. To the blue pixels, we refer all the pixels of the spots that did not turn out to be brown.
4. Calculation of the percentage of stains.

The calculation of the number of brown and blue spots is based on the estimation of their total area. We find the ratios between the spots in percentages: ratios for both excess brown and excess blue spots, which differ only in what is in the denominator. But even though we count both images, the user sees one count: the minimum. The algorithm is as follows:

1. Find the ratio between them and the blue and brown cells.
2. Calculate which of the ratios is less.
3. A copy of the original image is created and a mask with selected spots on it is applied. A copy of the image is created, on which brown and blue pixels are applied.
4. The user is returned the percentage ratio and the processed final image.

Results

Based on the analysis of images, cells colored blue and brown were identified, their ratio was calculated, and the choice of processing one or more images was provided. When processing this program, the user receives a photo with selected cells and their percentage ratio. The graphical result is shown in Fig. 2.

Medical images of the Ki-67 tumor marker and the main results of the analysis – the excess of brown and blue cells obtained as a result of the program processing are presented in Table.

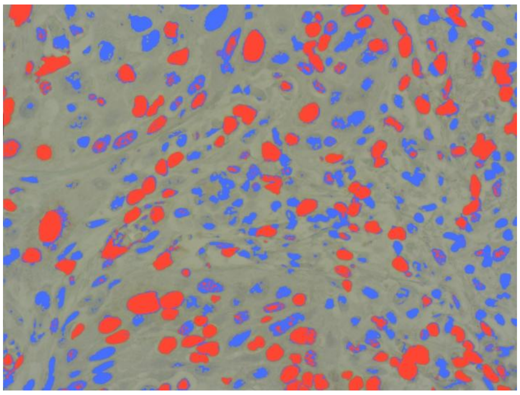
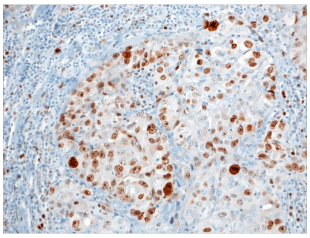
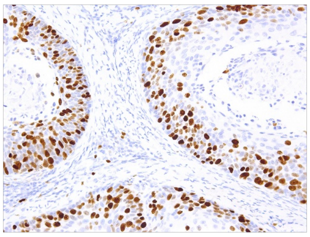
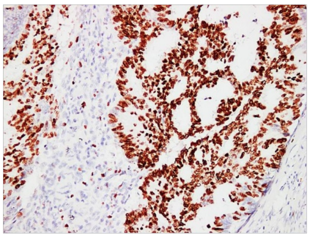
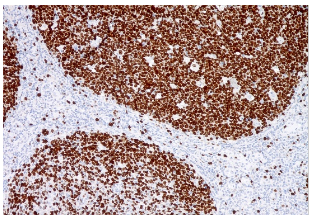
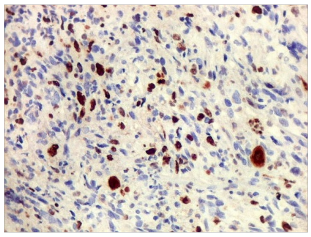


Figure 2. *An SW-generated image*

Table

# picture	Medical image	Excess
1		Brown cells 70 percent
2		Blue cells 30 percent
3		Brown cells 60 percent
4		Brown cells 96 percent
5		Blue cells 39 percent

The results of the analysis are shown for the areas of direct interest to the physician, not for the entire medical image.

Conclusion

The first part of the software implementation solved the problem of detecting cells stained blue and brown (immunopositive cells) in photos and counting their ratio. Taking into account the fact that the proliferative activity of human tumor cells correlates with the degree of their histological and biological malignancy, the calculation of the proliferation index using computer vision significantly increases the objectivity of the data. Further development of the current software product can increase the color range of spots, expand the data set processed by the program, to refine the cell counting, because the error is 5 % so far.

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B-COMPUTERS: SELF-EVOLUTION

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Abstract: the study demonstrates that the evolution of the B-computer can be unlimited as it can integrate a range of other digital devices. With this fact, we claimed that AI can be implemented with B-computers.

Keywords: B-computer, artificial intelligence (AI), PCB layout template, abstract computer (AC), B-circuit.

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B-КОМПЬЮТЕРЫ: САМОРАЗВИТИЕ

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Аннотация: показано, что B-компьютеры обладают неограниченным потенциалом развития, реализуемым на уровне разнообразных цифровых устройств, интегрируемых B-компьютером. На основании этого факта делается вывод о том, что решение задачи создания искусственного интеллекта в полной мере может быть осуществлено на базе B-компьютеров.

Ключевые слова: B-компьютер, искусственный интеллект (ИИ), шаблон заготовки, абстрактное вычислительное устройство (АВУ), B-схема.

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A Preliminary Informal Explanation

This paper refers to “A-computers” and “B-computers” (the letters “A” and “B” are Latin). By A-computers we mean computers and related devices such as all kinds of gadgets. In conjunction with A-computers are B-computers. The A-computers have a historical priority, they are primary, which is emphasized by the use of the letter “A” in their name. Concerning them, B-computers are secondary, which is also shaded by the use of the letter “B” in their name. A-computers and B-computers unite and at the same time contrast related principles of abstract schemes construction. Principle A, which serves to build A-computer circuits, states: *different information signals can be transmitted over the same line.* But, understandably, too many different information signals cannot be transmitted over the same row, because in this case there is a difficult problem of distinguishing signals, leading to unreliable calculations. This was the reason for J. von Neumann to formulate the thesis that the best system of notation suitable for computers is binary notation. And indeed in this case the calculations are as reliable as possible. The whole computer industry has been binary ever since. A-computer computing, while being as reliable as possible in the binary number system, is nevertheless not free from failures.

Principle A is contrasted with its dual principle B, which states that different information signals cannot be transmitted along the same row. As we can see, both principles, being the antithesis of each other, complement one another so that there is no third. Thus, under Principle B, there is a one-to-one mapping between the row and the information signal, and there is never any confusion of signals in the row. This ensures the reliability of calculations for any number of signals. Therefore Neumann's thesis does not apply to B-computers. Consequently, B-computers can be created for any number system without experiencing any difficulties in principle. One of the features of B-computers is the simplicity of the basis on which both B-computers themselves and the B-devices contained in them can be built. This structural basis consists of two elements: the row, which transmits information signals, and the element &, which controls the direction of the information signal. The basis can be represented by the notation: $\{\ |\ ,\ \&\ \}$; this set of structural elements satisfies the principle of maximum simplicity. Consequently, B-circuits of B-computers are as simple as possible in their design.

Every object is at some stage of development. The stage of development of an object is understood as its constructive state, as well as a set of functional interactions of the object with the environment, which we will call a set of functions of the object. By development, we mean the transition of an object from one stage of development to another. This implies both a possible constructive change of the object itself and a change in the set of functions associated with it. In connection with the concept of development, it is immediately necessary to characterize this development, whether the development will be regressive or progressive. As stated above, each stage of development is characterized by two components: the structural features of the object and its function set. It is quite natural to assume that the functional set of an object depends on its construction so that the set of functions characterizing a stage of development is a kind of function of its constructive perfection, which is reflected by the notation $\{f_1, f_2, \dots\} = \Psi(k)$, where k is the coefficient characterizing constructive development. Let us assume that it varies within the limits $0 \leq k < \infty$ (there is no limit to perfection). Thus the stage of development of an object is a pair $\langle k, \{f_1, f_2, \dots\}\rangle$, consisting of the coefficient of constructive development k and a set of functions $\{f_1, f_2, \dots\}$. This is a peculiar vector of development. Let us not, however, further deepen the vector analogy. Both regression and progress are characterized by the behavior of the pair $\langle k, \{f_1, f_2, \dots\}\rangle$. Both factors included in this pair may be determined by external influence, in which case we speak of induced development. But it may also be the case that the behavior of the pair $\langle k, \{f_1, f_2, \dots\}\rangle$ is determined by internal causes inherent in the object, with little or no external influence. Then we speak about *self-development.*

Closely related to the concept of self-development is the concept of *artificial intelligence* (AI), so popular recently. *Artificial intelligence is understood as an artificially created object, which has the ability to independent intellectual activity.* Thus, the first distinguishing feature of artificial intelligence is its artificial origin, i.e. it must be created by someone else capable of creative activity, such as a human creator or some other thinking being (MC) capable of creating creations. For this reason, a fly is not artificial intelligence, even though it shows signs of intelligence. It is not for the reason that neither man nor any other MS is its creator. On the other hand, a car that rolls around on the floor and is controlled by a boy with levers on a remote control is also not an AI, despite the apparent intelligence of its behavior. Its apparent intelligence is the result of the boy's intelligence, not the machine itself. Similarly, the famous Japanese robots are not examples of AI, because although they are artificially created, they do not have an intelligence of their own; they behave by obeying orders from computers embedded in them, which in turn contain programs written by humans. These programs determine the robots' behavior. Ultimately, the robot's behavior is determined by humans, just as in the case of a machine. All robots are controlled by A-computers, an attribute of which are programs created by humans. Therefore, the behavior of robots is entirely dependent on humans. Consequently, as long as they are controlled by A-computers, no "machine revolt" is possible. Simply because these machines have no intelligence of their own.

B-computers are another matter. B-computers have unlimited development potential. The presence of developmental potential allows the possibility of self-development and, eventually, its transformation into intelligence. This potential can be used by humans for their purposes, or it can be used by the computer itself for its development. By acquiring intelligence, the B-computer can enter into a competitive intellectual game with humans and even win it. Not necessarily, however, it must end in "war", a friendly symbiosis of man and machine is quite possible.

Synthesis of Fully Defined Devices on Blank Templates

Blanks are abstract boards on which semi-finished products for future device circuits are prepared in advance. The blanks meet the requirement of maximum simplicity. On the blanks, there are rows for transmitting information signals, as well as many elements &. There is nothing else. If all rows in the template are parallel, then in such a template it is not possible to vary the links. Variation of links is only possible in a billet where there are intersecting rows. If there are intersecting rows, then their connection, although possible, is not necessary. The presence of a connection will be represented by a bold dot in the crosshair, as shown in Fig. 1.

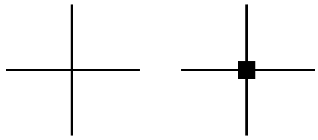

Figure 1. *No connection (left), connection (right)*

Thus, in abstract B-schemes, the connection operation is reduced to the simplest operation – a point.

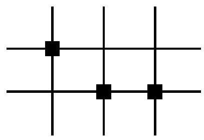

Figure 2. *An example of the connection option*

Figure 2 shows one possible way of connecting the five crossed rows. There are a total of 2^6 possible variants. This number evaluates the development potential (potential of possibilities) of this configuration of rows.

On the next page is an example of a typical template. On the left is a "raw" template with no connections; on the right is the same template, but with one of the possible connections selected. There are unimaginably many connection options (2^{728}), and each connection option corresponds to a different computing device. Not all of them are of any interest at the moment, but some certainly are. Such is the device resulting from the shown connection variants. This device is nothing other than a multiplier by three in the quadratic number system. They are denoted as: $\bar{x} \cdot 3|\bar{q}$, where $\bar{x}$ is the numberid written on the grid $Gr^0 = \ldots_{\bar{2}\,\bar{1}\,\bar{0}}$representing, in particular, natural numbers; $\bar{q}$ is the state of the multiplier $\bar{q} \in \{0,1,2\}$. As you can see, after selecting a connection option, "extra" rows may remain on the template. Not playing any role concerning the chosen connection variant, they can carry new information signals and be useful for other purposes. The number 2^{728} expresses the "hidden" potential for development, the potential for opportunities associated with this type of template. If we consider that there can also be unimaginably many types of blanks, we can imagine what is the potential for development associated with B-computers. The symbolic attributes present in Fig. 3, is necessary for us to understand the functioning of the device. The device itself, at its current stage of development, does not need it. Among the many modes of operation of the device, there are modes meaningful from our point of view. Therefore, it makes sense to equip some elements of the circuit with informational signals that we understand. Thus, symbols 0, 1, 2, 3 are provided with some rows of the device. Groups of four rows form input and output devices, groups of three rows - control signals. The group of elements & , with 0 on the first (left) place, forms the state $\bar{q} = 0$; similarly, the states $\bar{q} = 1$ and $\bar{q} = 2$.

The state $\bar{q} = 0$ will be called the initial state. The device performs multiplication by three by being put into the initial state $t = 0$. If it is put in other states for $t = 0$, it calculates other functions.

Let's look at an example of calculation with this device.

Example 1. Let us assume that $\bar{x} = \ldots 00322$ is in the quadratic number system. We follow the computation using the time sweep of the computation process.

The information in the sweep is read from right to left. In the same way, the numbers of the digits in the numeric digits grow from right to left. The first row shows the moments in which the device functions. These moments are non-negative integers. In the second row are the digits of the number applied to the input. In the bit 0 corresponding to the moment of $t = 0$, there is a digit $x_0 = 2$. Similarly, in all other

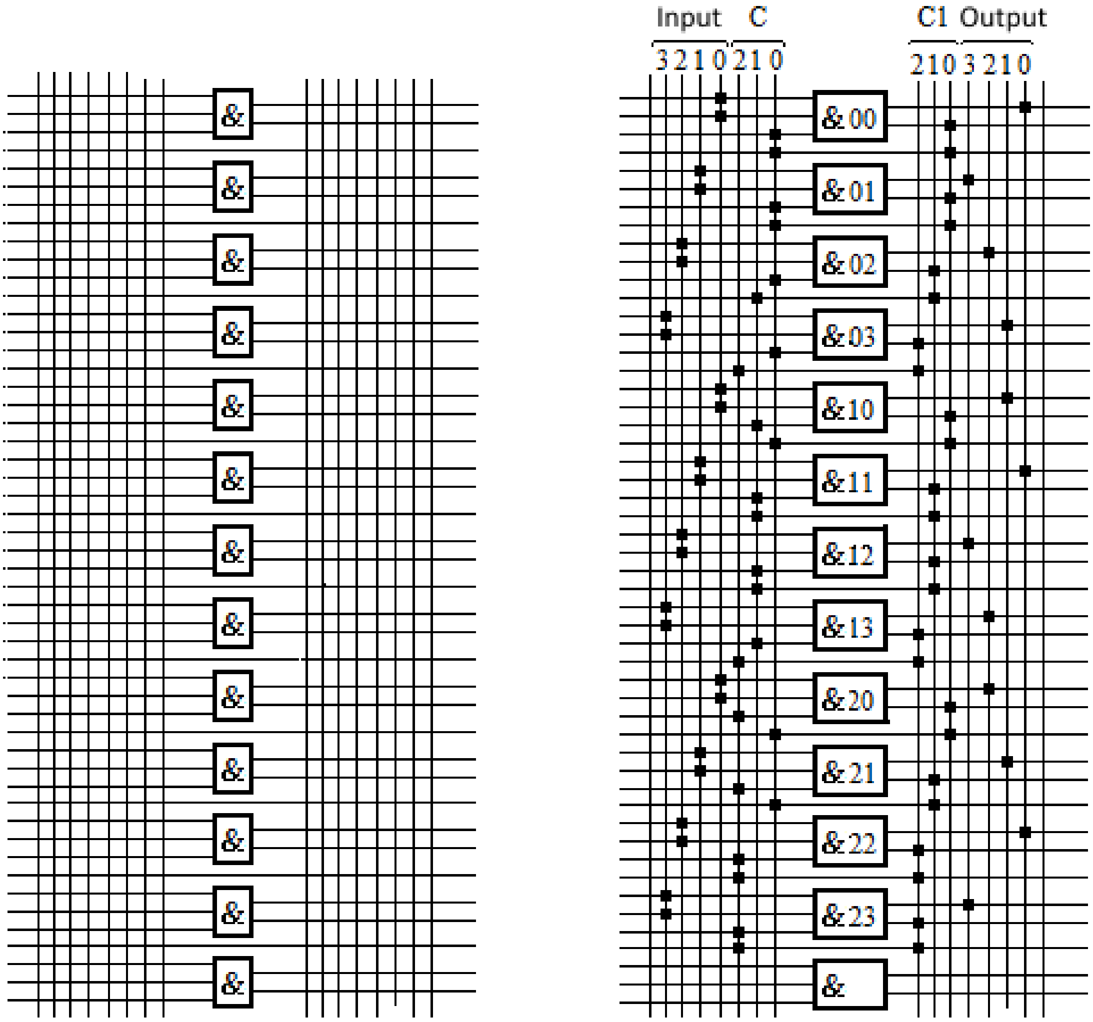

Figure 3. *Template without connections (left) and template with connections (right)*

6	5	4	3	2	1	0	t
...	0	0	0	3	2	2	x_t
&00	&00	&00	&20	&13	&12	&02	$\&qx_t$
...	0	0	2	2	3	2	y_t

bits. In the row, $\&qx_t$ there are elements of &, which are triggered at time t. The row y_t contains bitwise added digits of the result, and the correspondence between the moment t and the digit number is preserved, just as for the input. Note that the device is an abstraction, i.e., an ideal object in which everything is perfectly actuated, all elements & have the same delay; the output signal is output at the same time moment as the incoming input. In reality, the output signal is always output with some delay relative to the input signal. But computational engineers always try to reduce this delay as much as possible. Mathematicians take this process down, reducing the lag to zero. Clearly, this is an idealization, but it does not spoil the mathematical content of the computational process, rather it represents it.

The design of the device alone is not enough to make the principle of its operation clear. It is required to give the law of functioning of the device, which is provided by its functioning equations. They have the form:

$$\begin{cases} \bar{q}_{t+1} = \theta\bar{q}_t x_t = \rangle 3 \cdot x_t + \bar{q}_t \langle \,, \\ y_t \;\; = \sigma\bar{q}_t x_t = \langle 3 \cdot x + \bar{q} \rangle \;\;, \end{cases} \tag{1}$$

where $\bar{q} \in Q_3 = \{0, 1, 2\}$, $x,y \in Z_{(4)} = \{0, 1, 2, 3\}$ θ is the function of transitions, σ

is the function of outputs. In (1) we use the notations: $\langle\bar{\alpha}\rangle = \langle\ldots 00\alpha_{r}\ldots\alpha_1\alpha_0\rangle = \alpha_0$ and $\rangle\bar{\alpha}\langle = \rangle\ldots 00\alpha_{r}\ldots\alpha_1\alpha_0\langle = \ldots 00\alpha_{r}\ldots\alpha_1$.

Read the sweep: for $t = 0$ the device is in the initial state $\bar{q} = 0$, which is provided by the arrival of the control signal on row-0 of input-C. All four elements & of the initial state are ready to be triggered: &00, &01, &02,&03. But only one of them will actuate, namely, the one which corresponds to the digit received at the input, which is the digit $x_0 = 2$. That is why the element &02, which is marked in the sweep, is triggered. According to the device diagram, digit 2 appears on the output, and the control signal for the moment $t = 1$ is transmitted to elements & state 1, i.e. to the elements &10, &11, &12, &13. At the same moment, the digit $x_1 = 2$ is at the input; then it goes similarly to $t = 0$. As a result, the output will form the result, the number $\bar{y} = \ldots 002232$.

Let us write down the result of the device in the form: $\ldots 00322 \cdot 3|0 = \ldots 002232$.

Read: if we put the device in the initial state $\bar{q} = 0$ (marked by zero to the right of the vertical row) and input the number $\bar{x} = \ldots 00322$, then the device will output the result $\bar{y} = \ldots 2232$, which is the product of the number $\bar{x} = \ldots 00322$ by three: $\ldots 00322 \cdot 3 = \ldots 2232$. The result is checked by the school multiplication "column" (in the quadratic notation system).

Note that the result is output at $t = 2$, i.e., in 3 (not 4) clock cycles. This is explained by the fact that the highest two digits of the result are output by the device at the same time. This phenomenon is generalized when considering all B-devices, which leads to the conclusion that in B-devices the computation ends at the moment when the highest digit comes from the input. This is only true for B-devices. Similarly, we can parse the operation of any of the devices 2^{728} that can be created on the template pattern shown in Fig. 3. If we take into account that there are unimaginably many templates like the above and other much more complex ones, then, again, it is clear how great the potential for B-devices development is.

In the example above it was assumed that the mapping realized by the device is fully specified, i.e. either the equations of functioning of the device (1), or its table specification (was not given), or its B-scheme (was not given) are known. It was required to obtain its template B-scheme by making the necessary connections.

This is not the case in the next section, where the mapping is set in fragments.

Synthesis of devices from fragments of mappings

We will not describe the *algorithm for the synthesis of abstract computational devices (ACD) by fragments of mappings*, but only give an example of the result of its work. Hereinafter, instead of "synthesis algorithm" we will simply say "algorithm".

Let us denote ${}_pA_q$ by the symbol an abstract computational device (ACD) with anticipation for p steps and with a consequence of q steps, i.e. a device whose functioning is described by equations:

$$\begin{cases} \bar{q}_{t+1} = \theta\bar{q}_t x_{t+p}\ldots x_{t+1}x_t x_{t-1}\ldots x_{t-q}\,, \\ y_t \;\;= \sigma\bar{q}_t x_{t+p}\ldots x_{t+1}x_t x_{t-1}\ldots x_{t-q}\,, \end{cases} \quad (t \in Z = \{\ldots 2.1.0, -1, -2, \ldots\}) \tag{2}$$

where $x \in Z_k = \{0,1,\ldots,k-1\}$, $y \in Z_l = \{0,1,\ldots,l-1\}$ are the sets of digits in the k and l number systems, respectively; $k,l \geq 2$, natural numbers; $p,q \geq 0$. We denote by the symbol ${}_p\mathcal{A}_q$ the *set* of all ACDs with p step anticipation and a $q$step consequence: ${}_p\mathcal{A}_q = \{{}_pA_q\}$. The set of all ACDs is the set $\mathcal{A}=\bigcup\limits_p\bigcup\limits_q {}_p\mathcal{A}_q$. Abstract automata form the set ${}_0\mathcal{A}_0$.

A mapping fragment is the set of mappings of the type $\bar{x} \to \bar{y}$, where $\bar{x}$ is taken from the mapping definition domain and $\bar{y}$ is taken from the value domain. The number of mappings in the fragment can be any, except zero.

A mapping fragment is called representative if it allows the mapping to be found completely.

Let the numerical object $\bar{x} = 1300122203\underset{0}{1}$ expressed in the quaternary notation. It means all its digits belong to the set of digits $Z_{(4)} = \{0,1,2,3\}$. The digit numbers grow from right to left, starting from the zero digit marked with a zero from below. Let, similarly, an object $\bar{y} = 4403212103\underset{0}{4}$ be expressed in the pentatonic notation, $Z_{(5)} = \{0,1,2,3,4\}$ and let the mapping be such that there a mapping between the objects $\bar{x}$ and $\bar{y}$ which we will write on the digit grid:

10	9	8	7	6	5	4	3	2	1	0	t
1	3	0	0	1	2	2	2	0	3	1	x_t
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
4	4	0	3	2	1	2	1	0	3	4	y_t

(3)

The question is: whether there are ACDs from the class ${}_p\mathcal{A}_q$, $(p,q \geq 0)$ that implement the mapping of numerical objects $\bar{x} \to \bar{y}$?

The algorithm starts searching for an ACD from the class ${}_0\mathcal{A}_0$, i.e., first, it asks whether there exists an abstract automaton that implements the given mapping (recall that abstract automata fill the class ${}_0\mathcal{A}_0$) in the set of all ACDs.

Applying the algorithm, it turns out that there are two minimal automata A_1 and A_2 with two states, for which the mapping (3) takes place. These automata are defined by tables:

A_1:

q \ x	0	1
0	0, 0	0, 3
1	1, 4	1, 2
2	1, 1	0, 2
3	0, 4	0, 3

A_2:

q \ x	0	1
0	1, 3	0, 0
1	1, 4	0, 2
2	1, 1	0, 2
3	0, 4	1, 3

(4)

In the tables $x \in Z_{(4)} = \{0,1,2,3\}$, q is the state of the automaton, $\bar{q} \in Q = \{0, 1\}$, Q is the set of states of the automaton. At the intersection of row-x and column-q there is a pair (θ,σ), where $\theta = \theta(q,x)$ is the value of the transition function on the pair (q,x), and $\sigma = \sigma(q,x)$ is the value of the output function on the pair (q,x).

Thus, according to the algorithm, there are two automata mappings 1 and 2, realized, respectively, by automata A_1 and A_2, for each of which the given correspondence takes place $\bar{x} \to \bar{y}$.

Let us check that this is true. Pass the object $\bar{x}$ through automata A_1 and A_2 and make sure that in both cases the output is represented $\bar{y}$. Let us plot the time sweeps of the automata calculations as $\bar{x}$ passes through them.

Through A_1:

11	10	9	8	7	6	5	4	3	2	1	0	t
	1	3	0	0	1	2	2	2	0	3	1	x_t
1	0	0	0	1	1	0	1	0	0	1	0	q_t
	4	4	0	3	2	1	2	1	0	3	4	y_t

(5)

Through A_2:

11	10	9	8	7	6	5	4	3	2	1	0	t
	1	3	0	0	1	2	2	2	0	3	1	x_t
1	0	0	1	0	1	0	1	0	1	1	0	q_t
	4	4	0	3	2	1	2	1	0	3	4	y_t

(6)

The symbol t denotes the automaton time and simultaneously for rows x_t and y_t the digit number; the initial state of the automata in both cases is $q = 0$.

The results of automata are read in the lower rows of sweeps (5) and (6), in both cases they coincide and are equal to the object $\bar{y}$, as they should be.

The fact that the algorithm singled out two automata A_1 and A_2 in the class ${}_0\mathcal{A}_0$ means that the information contained in the mapping fragment $\bar{x} \to \bar{y}$ is insufficient for the unambiguous selection of the automaton. To uniquely find an automaton in the class ${}_0\mathcal{A}_0$, we add a mapping $\bar{x} \to \bar{y}$ in the 11th digit and pass to a new mapping:

11	10	9	8	7	6	5	4	3	2	1	0	t
0	1	3	0	0	1	2	2	2	0	3	1	x_t
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
3	4	4	0	3	2	1	2	1	0	3	4	y_t

(7)

Let us pass the object $\bar{x}_1 = 01300122203\underset{0}{1}$ through the automata A_1 and A2 and see what we get on their outputs. When passing $\bar{x}_1$ through A_1, the sweep (5) will be completed only by the 12th step:

12	11	10	...	...	1	0	t
	0	1			3	1	x_t
0	1	0			1	0	q_t
	3	4			3	4	y_t

(8)

As can be seen, in step 11, in full accordance with (7), the result is $y = 3$, i.e., the automaton A_1 implements the mapping $\bar{x}_1 \to \bar{y}_1$, where $\bar{y}_1 = 34403212103\underset{0}{4}$.

As $\bar{x}_1$ passes through A_2 we will have the same thing:

12	11	10	...	...	1	0	t
	0	1			3	1	x_t
0	1	0			1	0	q_t
	0	4			4	4	y_t

(9)

But this time for $t = 11$ the automaton A_2 generates a signal $y'_{11} = 0$ different from the required number 3:

$$\bar{x}_1 \xrightarrow{A_2} \bar{y}'_1 \neq \bar{y}_1 \tag{10}$$

The chart (10) states that automaton A_2 does not implement the mapping $\bar{x}_1 \to \bar{y}_1$ and thus there is only one automaton, A_1 (Fig. 4), which implements the mapping $\bar{x}_1 \to \bar{y}_1$, and thus, assuming that the mapping $\bar{x}_1 \to \bar{y}_1$ is representative, there is only one automaton mapping f1, for which $\bar{x}_1 \to \bar{y}_1$. Thus by a single mapping one can find the whole automaton mapping.

If at t=11 we required, say, a mapping of digits: $\begin{matrix}0\\\downarrow\\1\end{matrix}$, or $\begin{matrix}0\\\downarrow\\2\end{matrix}$, or $\begin{matrix}0\\\downarrow\\4\end{matrix}$ (as well as some more), we would not find any automaton implementing a mapping $\bar{x} \to \bar{y}$ with the specified mappings in the 11th bit. In that case, the algorithm would go on to the search of the ACDs in the classes ${}_1\mathcal{A}_0$, ${}_0\mathcal{A}_1$, etc.

The fact of constructing the automata A_1 by mapping $\bar{x}_1 \to \bar{y}_1$ can be interpreted as a learning process, with which the synthesis of A_1 by mapping $\bar{x}_1 \to \bar{y}_1$ bears a great resemblance.

Indeed, in the brain of a schoolboy when teaching him, say, the operation of addition, after he has performed a finite number of examples, something is formed that allows him to further solve any example on the performance of the operation of addition.

Here we have an analogy. The external constructor, which contains the algorithm for synthesizing from fragments of mappings, passes a *finite* number of correspondences (in the example we have considered one: $\bar{x}_1 \to \bar{y}_1$), and as a result forms a structure (automaton A_1), which allows finding *any* other correspondence of automaton mapping f_1.

Of course, we are not claiming that the same thing happens in the brain; we are merely emphasizing an analogy. Moreover, we will not seek to model nature, not only out of ignorance of how it does it but also because the quantitative effect in achieving the same goal is most often achieved by paths different from those followed by nature.

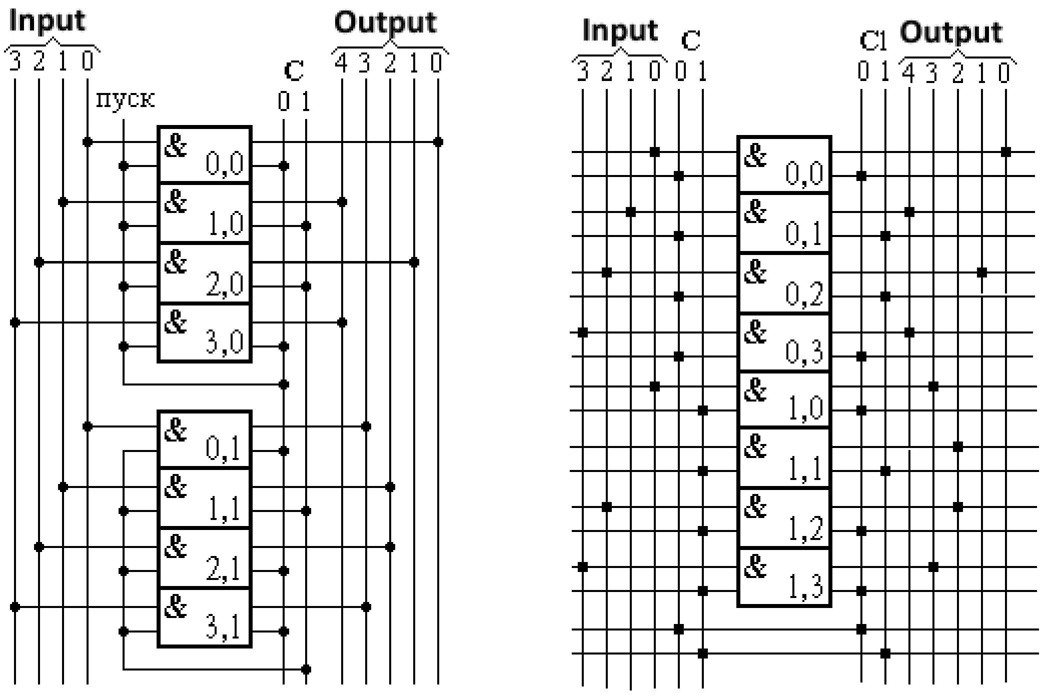

Figure 4. *The canonical B-scheme of automata A_1 (left) and its duplicate (right), made on the template*

A total of 2^{234} various connection options are possible on this type of template. One of them is shown.

The effect of reducing the role of programs in B-computers

Consider a typical fragment of a program code executed on an A-computer (see Fig. 5). The program contains blocks in which functions are calculated. The calculation is performed programmatically. After completing calculations in a block, control is transferred to the next block, in which the same happens. Note that each block calculation takes place programmatically.

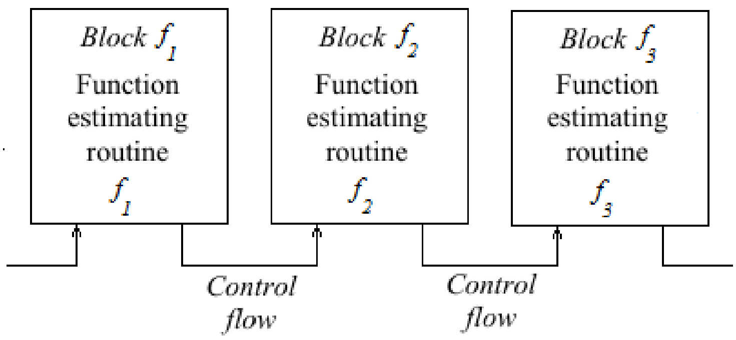

Figure 5. *The linear part of the A-computer program*

Let us compare this situation with a similar one in the B-computer. Let's picture the same part of the program, but done by a B-computer. The difference is that calculation in blocks is not done programmatically, but with the help of devices.

Let us immediately note that this part of the program will be executed by the B-computer faster

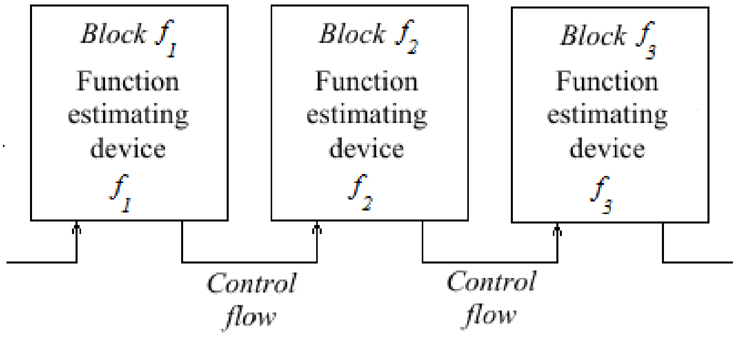

Figure 6. *The same linear part of the program, but executed by the B-computer*

than by the A-computer since the computation of the function by the device is faster than the program computation. But let us not only look at this fact but also at the fact that a large part of the program component has disappeared. This is exactly what we have called the diminishing role of programs in B-computers. In the long term, we can talk about almost completely leveling out the role of programs in B-computers. And what will remain? There will remain the part of programs which is connected with management functions, which is marked in the figures as "management transfer". But this, too, can be implemented in the future by hardware, using devices.

Conclusion

The above brief analysis quite convincingly shows that B-computers can increase their "iron mass" unlimitedly, but not at the expense of single-type boxes piled up within a certain volume, but at the expense of synthesis of various computing devices and their subsequent integration into the computer. The variety of computing devices integrated into the B-computer indicates the "sophistication" of the B-computer, its ability to solve various and complex computational problems. These examples show that synthesis of computing devices embedded into B-computer can be performed by the computer itself inside itself, as it comes down to putting points on templates of blanks – the simplest of all possible operations. The solution to the problem of creating artificial intelligence can be obtained by using B-computers since it is B-computers that make it possible to get rid of the influence of the human factor, which manifests itself through programs, whose influence in B-computers tends to level out.

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NON-STATIONARY STATES IN PHYSICS AND BIOPHYSICS

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Abstract: I. R. Prigogine emphasized the need to research unstable systems. However, for the last 40 years, this problem has not been studied well. Still, in the last 25 years, the statistical instability of biomechanical motion properties was proved as the Eskov–Zinchenko effect. Such unstable systems exist in the Earth's inorganic nature, too, as the human habitat climate/weather regulation systems. In 1948 W. Weather called such systems "3rd kind systems". They feature a special statistical instability peculiar to self-organizing systems. The study presents the key properties of such 3rd kind systems and some invariants that define these non-stationary systems. Significantly, the simulation is based on some quantum mechanics postulates. Particularly, these are the Heisenberg uncertainty principle, and the quantum entanglement principle.

Keywords: non-stationary state, 3rd kind systems, Eskov-Zinchenko effect, quantum entanglement.

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Compliance with ethical standards: all the studies that involved human participants comply with the appropriate institutional and/or national research ethics committee and have been performed following the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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ПРОБЛЕМА НЕСТАЦИОНАРНОСТИ В ФИЗИКЕ И БИОФИЗИКЕ

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Аннотация: необходимость изучения неустойчивых систем подчеркивал I. R. Prigogine, но за последние 40 лет эта проблема не рассматривается в науке. Однако за последние 25 лет была доказана статистическая неустойчивость параметров движения в биомеханике в виде эффекта Еськова–Зинченко. Подобные неустойчивые системы имеются и в неживой природе на Земле в виде систем регуляции климата и метеопараметров среды обитания человека. Эти системы в 1948 г. W. Weaver обозначил как системы третьего типа, они обладают особой статистической неустойчивостью, характерной для самоорганизующихся систем. В работе представлены основные свойства таких систем третьего типа и некоторые инварианты для их описания. Существенно, что их моделирование основано на ряде принципов квантовой механики. В частности, принципе неопределенности Гейзенберга и квантовой запутанности.

Ключевые слова: нестационарность, системы третьего типа, эффект Еськова–Зинченко, квантовая запутанность.

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Соблюдение этических стандартов: все процедуры, выполненные в исследовании с участием людей, соответствуют этическим стандартам институционального и/или национального комитета по исследовательской этике, Хельсинкской декларации 1964 года и ее последующим изменениям или сопоставимым нормам этики.

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Introduction

In 1989, I. R. Prigogine [1] for the first time in the history of science drew attention to the lack of proper attention in modern science to unstable systems. There is no developed theory for them, and there are no models to describe such systems. By now enough experimental data have already been accumulated that allow us to present some classification of such unstable systems and to build some theoretical models for their description.

Let us recall that W. Weaver [2] more than 70 years ago presented a special classification of all systems in nature. In our interpretation, we are talking about deterministic systems (*simplicity systems* – type 1), stochastic systems (*nonorganized complexity* – type 2) and systems of the third type (3TS) – *organized complexity*. The first two types of systems are the object of study of modern science, but nothing has been created for 3TS during these more than 70 years. W. Weaver primarily classified living systems as 3TS, but what special properties do such systems have and why can they not be the object of study in functional analysis and stochastics? These questions were not answered by W. Weaver or two Nobel laureates (I. R Prigogine [1, 3], M. Gell-Mann [4]).

To answer these questions we need to present special properties of 3TS and propose a formal apparatus for their description, which can be based on several principles of quantum mechanics [5-7]. Let us emphasize that we are not talking about dynamic chaos, but about a special type of unstable systems. These are systems with statistical instability of any parameters $x_i(t)$ that form the system state vector $x=x(t)=(x_1, x_2, \dots, x_m)^T$ in the m-dimensional phase space of states (PSS) [3-5]. The dynamics of 3TS-complexity behavior cannot be described within the framework of modern science.

The general problem of nonstationarity

There are a huge number of objects (systems) in the animate and inanimate nature that exhibit nonstationary behavior. For example, in 2009 the star KIC 8462852 (star Tabby) was discovered, which showed a particular irregularity both in luminosity and in the intervals (periods of oscillation) of this luminosity. In 2007, fast radio bursts (FRBs) were recorded, which also showed the absence of any periodicity in their characteristics. There are also many objects on the Earth, which show a particular instability. It is manifested in the absence of statistical stability of samples of the state vector of the system $x=x(t)=(x_1, x_2, \dots, x_m)^T$ in the PSS [3, 4, 6–8].

In 1989, I. R. Prigogine [1] emphasized (see Philosophy of instability) the necessity to study such unstable systems, but no progress in this field has been established over these 30 years. The very notion of ”instability” requires a clear mathematical definition, which as of today does not exist, or rather there is no classification of the types of instability. The generally accepted definition of the stationary mode (SM) for any dynamical system (in a deterministic approach), for the state vector of the dynamical system $x(t)$ in PSS as $dx/dt=0$ and $x_i=const,$ has very limited application in the study of 3TS [6–8]. It concerns systems that are described within the framework of functional analysis, and let us say at once that all living systems (STT, by the definition of W. Weaver [2]) are not dynamic systems (in the sense of determinism), i.e. for them $dx/dt\neq 0$ is continuous (and constant) [8].

In stochastics, there is a notion of statistical stability (invariance), when during multiple repetitions of a process in observation of many samples of the same variable $x_i(t)$ we will observe invariance of statistical distribution functions *f(x)*, their statistical characteristics (statistical mean $< x>$, statistical dispersion (D_x^*), spectral signal densities (SSD), autocorrelations *A(t)*, etc.) If *f(x)*, SSD, *A(t)* and other characteristics do not change from sample to sample, then in stochasticity we conclude that the system is invariant [3–5].

However, in living and inanimate nature some systems cannot be repeated not only at the end of the process (as samples of the final state of the system $x_i(t_k)$), but also as the initial parameters of the vector $x(t_0)$. In this case, any dynamical equation is unique because the next repetition of the dynamics of the process leads to other equations [3–5]. This means that there is no Cauchy problem, no causality, and no predictability of not only $x(t_k)$ but also of any samples of the final state $x(t_k)$ [6–8]. These are precisely the properties of living systems.

Such systems continuously show $dx/dt\neq0$, and their statistical functions *f(x)*, SSD, *A(t)*, and other characteristics cannot be repeated twice in a row arbitrarily [3–9]. These are statistically unstable systems with some self-organization. They cannot be described within the framework of functional analysis (determinism) or stochasticity. For them, it is necessary to create a new theory and new models. Such work requires, first of all, the development of new invariants for the estimation of stationary states (and a new understanding of such stationary modes: SMs) and the estimation of kinematics *x(t)* in PSS [3–5, 8]. Some authors [9–12] also note the instability in the brain neural networks, which is approaching the chaos of 3TS [3–5].

Statistical Parameter Instability in Biomechanics and Meteorology

Earlier [3–5] we noted that in biomechanics, any movement has a unique character [13]. This means that the matrix of pairwise comparisons of samples of tremorograms (TMG) or teppingrams (TPG) demonstrates an extremely small share of stochasticity (for TMG less than 5%), i.e., we observe statistical chaos for samples of TMG. Our further studies showed that a similar result (low stochasticity fraction) is observed for spectral signal densities (SSD) as TMG, or TPG, or human SSS parameters [14–15]. For example, in Table 1 we present a matrix of pairwise comparisons of SSD that were obtained by fast Fourier transform from 15 TMGs (from the same subject in his unchanged state) [3–5].

Table 1

Matrix of paired comparison of 15 SSD tremorograms of one GDS subject in repeated experiments ($k_1 = 25$), by Wilcoxon criterion

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		,00	**,95**	,01	,00	**,13**	**,77**	,00	,00	,00	,00	,02	**,68**	,00	**,58**
2	,00		,00	,00	,00	,00	,00	,00	,00	**,08**	**,90**	,00	,00	,00	,00
3	,95	,00		,01	,00	**,15**	**,56**	,00	,00	,01	,00	**,48**	**,38**	,00	**,60**
4	,01	,00	,01		,00	,00	**,07**	,00	,00	,00	,00	,00	,01	,00	,01
5	,00	,00	,00	,00		,00	,00	**,11**	**,74**	,00	,00	,00	,00	,00	,00
6	,13	,00	,15	,00	,00		**,17**	,00	,00	,02	,00	**,60**	**,13**	,00	**,29**
7	,77	,00	,56	,07	,00	,17		,00	,00	,01	,00	,01	**,66**	,00	**,75**
8	,00	,00	,00	,00	,11	,00	,00		,00	,00	,00	,00	,00	,00	,00
9	,00	,00	,00	,00	,74	,00	,00	,00		,00	,00	,00	,00	,00	,00
10	,00	,08	,01	,00	,00	,02	,01	,00	,00		,02	**,06**	,00	,00	,00
11	,00	,90	,00	,00	,00	,00	,00	,00	,00	,02		,00	,00	,00	,00
12	,02	,00	,48	,00	,00	,60	,01	,00	,00	,06	,00		**,12**	,00	**,17**
13	,68	,00	,38	,01	,00	,13	,66	,00	,00	,00	,00	,12		,00	**,54**
14	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00		,00
15	,58	,00	,60	,01	,00	,29	,75	,00	,00	,00	,00	,17	,54	,00	

Several hundred such matrices were constructed for the TMG and TPG samples themselves of their SSD and *A(t)* for more than 100 subjects, and in all cases, we had a stochasticity fraction of less than 25%. This means that the number of k_1 SSD pairs that have a Wilcoxon criterion of $p\geq0.05$ is small. There is no statistical robustness of samples not only of TMG or TPG, but also of their SSD, *A(t)*, and other statistical characteristics. Any sample in biomechanics will be unique (statistically unique). The statistics will then have a historical character (no predictions). Characteristically, this is now designated as the Eskov-Zinchenko effect (EZE) and this EZE is extended to many other body parameters [7, 8, 13].

We emphasize that 3TS include not only living systems but also many climate parameters and meteorological parameters [3, 4]. As an example, we present Table 2 for air temperature (for 15 years, samples for January). This table presents the results of statistical comparison of pairs of samples of air temperature parameters *T* for 15 January in the Khanty-Mansi Autonomous Okrug – Ugra (for 15 years). The number of temperature sample pairs *k*, for which the Wilcoxon criterion $p \geq 0.05$ (i.e., the two temperature samples being compared may have one common general population) is small: k_2=30.

Table 2

Matrix of pairwise comparison of samples of temperature T for January 1991–2009, Wilcoxon criterion was used (significance level $p < 0.05$, number of coincidences $k_2 = 30$)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
1991		,00	,00	,00	,00	,00	,00	,00	,00	,00	**,62**	,00	,00	,00	,00
1992	,00		,03	,01	**,38**	**,50**	,00	**,98**	**,22**	**,15**	,00	,00	,00	**,80**	**,97**
1993	,00	,03		,00	,05	,00	**,37**	,02	,00	,00	,00	,00	,00	,00	,00
1994	,00	,01	,00		**,11**	,01	,00	,00	**,20**	**,06**	,04	,00	,00	,00	,00
1995	,00	,38	,05	,11		**,71**	,01	**,66**	**,12**	**,59**	,00	,00	,00	**,76**	**,63**
1996	,00	,50	,00	,01	,71		,00	**,37**	**,98**	**,62**	,01	,00	,00	**,51**	**,32**
1997	,00	,00	,37	,00	,01	,00		,01	,00	,00	,00	,00	,00	,00	,00
1998	,00	,98	,02	,00	,66	,37	,01		**,23**	,05	,00	,00	,00	**,56**	**,67**
1999	,00	,22	,00	,20	,12	,98	,00	,23		**,94**	,00	,00	,00	**,40**	**,08**
2000	,00	,15	,00	,06	,59	,62	,00	,05	,94		,00	,00	,00	,01	,05
2001	,62	,00	,00	,04	,00	,01	,00	,00	,00	,00		,00	,00	,00	,00
2002	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00		,00	,00	,00
2003	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00		,00	,00
2004	,00	,80	,00	,00	,76	,51	,00	,56	,40	,01	,00	,00	,00		**,97**
2005	,00	,97	,00	,00	,63	,32	,00	,67	,08	,05	,00	,00	,00	0,97	

Comparing characteristic tables 1 and 2 (from biomechanics and meteorology), we can make a general conclusion about the absence of statistically stable samples of tremorograms and temperatures of the human environment. In other words, we prove N.A. Bernstein's hypothesis of "repetition without repetition" not only in living nature but also in nonliving nature. For these two different systems, we have EZE, i.e. there is no statistical stability of samples xi of the process under study [3–5, 14–15]. The creation of new models and new invariants should change the situation in biophysics and cybernetics (when studying 3TS).

We now denote all such systems as homeostatic systems (HS), i.e. they exhibit statistical chaos (the stochastic fraction for TMG is less than 5%, and for T – less than 30%). How then can such processes be compared, how can the system's invariance and its real change be determined, if all statistical functions f(x), SSD, A(t), and other statistical characteristics change continuously and chaotically even in a supposedly stationary regime? For all such HS there is EZE, and then it is necessary to create new invariants and new methods of modeling stationary modes (SM) [3, 4].

New Invariants for Homeostatic Systems

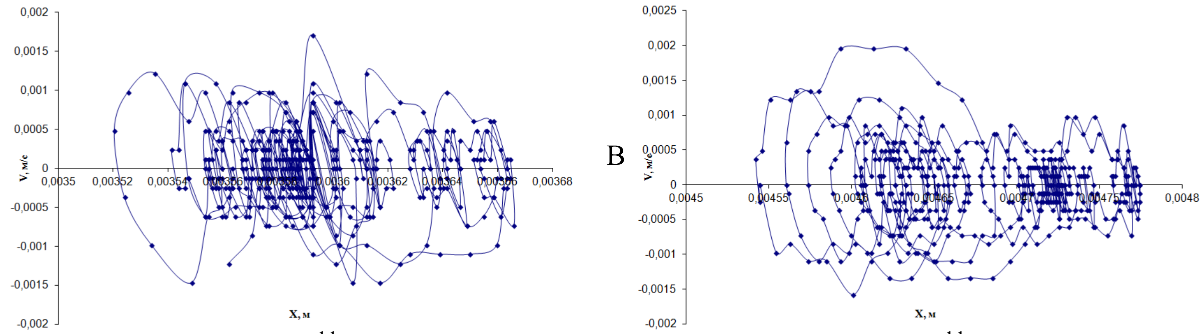
We emphasize again that modern stochastics cannot describe supposedly unchanging systems, but their statistical functions, SSD, *A(t)* will change continuously and chaotically from sample to sample. Note that if we have different objects of research, for example, we record TMG in 15 different subjects, we also get a matrix of pairwise comparison of TMG samples similar to Table 1. In this case, we can speak about the loss of homogeneity of samples. In the case of temperature we can take 15 different samples for January of a certain year, but from different geographical territories and get a table similar to Table 2.

The presence of small k_1 (low stochasticity) indicates a loss of homogeneity of the group. In other words, we can never get a homogeneous group of subjects in biomechanics or parameters in meteorology. How to work with such samples? What are stationary modes for such systems (3TS – HS) and what invariants should be taken to prove the existence of SM in such 3TS – HS? Answers to these questions follow from the analogues of quantum mechanics in the description of 3TS-*complexity* [4–6].

Let us recall that the Heisenberg uncertainty principle imposes constraints on the phase coordinates x_1 – the displacement (of a quantum particle, for example) and $x_2 = dx_1/dt$ – the speed of this displacement. It follows from the Heisenberg inequality that $\Delta x_i \cdot \Delta P \geq h/(4\pi)$, where $P = x_2 \cdot m$. If (at low velocities) the mass m of the particle is constant, we have the Heisenberg equation only for the phase coordinates: $\Delta x_1 \cdot \Delta x_2 \geq h/(4\pi m) = Z^k{}_{min}$.

In the case of biomechanics, we can introduce an analogue of the Heisenberg principle in the form: $Z_{max} \geq \Delta x_1 \cdot \Delta x_2 \geq Z_{min}$, where Z_{max} and Z_{min} is some constants for a given subject in a particular state. Z_{max} and Z_{min} have nothing in common with Z_{max} and Z_{min} from quantum mechanics, but they are real constants that constrain our phase coordinates (x_1 is the finger coordinate, x_2 is the rate of change of $x_1(t)$). On the vector plane $x=x(t)=(x_1,\ x_2)^T$ in biomechanics we have some phase trajectories (see Fig.) of $x(t)$ motion, which characterize tremor (or any other human movement) in the phase space of states (PSS) [3–5].

A B



$S_1 = 4{,}61 \cdot 10^{11}$ units $S_2 = 8{,}21 \cdot 10^{11}$ units

Figure. *Phase trajectories and their PAs for the same subject: A – during relaxation; B – during loading, F=3 N*

Fig. shows the character of TMG phase trajectories of the same subject in two different physical states (finger tremor without load, F_1=0 and finger tremor with load, F_2=3 N). In two different physical states, the biomechanical system demonstrates two different phase trajectories. Moreover, each phase trajectory occurs inside a rectangle with sides Δx_1 (variation spread over x_1) and Δx_2 are the areas S_1 and S_2, within which the vector $x(t)$ moves continuously and chaotically [14–15].

The bounded region of the PSS, within which the state vector $x(t)$ of a homeostatic system moves (chaotically and continuously), we denote as the pseudo attractor (PA) (or the Eskov quasi attractor (QA)). We will present the exact definition of the PA (or QA) below, but now only note that the PA area and the coordinates of its center (see Fig. 1) are invariants. They are statistically conserved for the same GS being in an unchanged (from the position of the new chaos-self-organization theory (CSO) [3–5]) state.

When evaluating the state (in Fig. we move from PA^1 without load to PA^2 with load) of the system, we observe a change in the area S for the PA and a change in the coordinates $x^c{}_i$ of the center of the PA. Let us emphasize again that the functions $f(x)$, SSD, $A(t)$, etc., change continuously and chaotically. Let us present the definition of a PA (or Eskov's QA) in the framework of functional analysis.

Formally, the definition of a PA is as follows: PA is a nonzero subset Q of the phase m-dimensional space D l= of a dynamic biological system (3TS), which is the union of all values $f(t_i)$ of the state of the biological dynamic system at a finite time interval $[t_j, \ldots, t_e]$ ($j << e$, where t_j is the initial time moment and t_e is the finite time moment of biosystem states):

$$Q = \bigcup_{l=1}^{m} \bigcup_{i=j}^{e} f^l(t_i), Q \neq 0; Q \in D, \quad (1)$$

where m is the number of coordinates of x spatial dimensions.

To illustrate the invariability (statistical stability) of samples of parameters S for PA in the case of biomechanics (TMG registration) we present Table 3. Here we present the results of calculations of area S for PA of the same subject in two different physical states: without load on the limb (F_1=0) and with load (F_2=3 N). Obviously, after 15 repeated TMG recordings in the same subject, we have significant differences between the mean $< S_1 >$=3.02 units (at F_1=0) and the mean $< S_2 >$=4.93 units (at F_2=3 N) for the same subject. The S areas for PA are statistically robust and significantly different.

In general, in the phase coordinates x_1 and $x_2 = dx_1/dt$ we have biomechanical invariants (in the form of pseudo attractor area S) for the same subject. A change in physical status (transition to F_2) leads to a

Table 3

Values of pseudoattractor areas S of samples of tremorograms of the same subject

	$S_1 \cdot 10^8$ units,off-load	$S_2 \cdot 10^8$, units, $F_2 = 3$ N load
1	5,78	3,55
2	2,29	3,87
3	1,42	5,74
4	3,89	2,92
5	1,61	6,82
6	3,03	5,71
7	3,86	3,67
8	1,69	4,77
9	1,77	6,78
10	6,27	7,24
11	1,92	5,06
12	2,02	5,28
13	3,42	2,91
14	3,98	6,24
15	2,27	3,36
<*S*>	3,02	4,93
	Wilcoxon test, significance of differences in *f(x)* functions $p = 0.01$	

change in area *S*. Let us emphasize that all statistical characteristics change chaotically and continuously when the biosystem state is unchanged (see Table 1 and Fig.).

Thus, we prove the absence of invariants for the parameters of biosystems within stochasticity (all samples *x(t)* are continuously and chaotically changing), which imposes limitations for further application of stochasticity in biomechanics and the study of electro generating biosystems [9–12]. On the other hand, new quantitative characteristics emerge that will be invariant for real (in the biological sense) stationary modes of various biosystems. All biophysics and biocybernetics now need to create a new theory and new models in the description of 3TS-*complexity*, special homeostatic systems with statistical instability of *x(t)* samples [13, 16].

Conclusion

The problem in the study of statistical stability of parameter samples in biomechanics and the theory of electrogenesis moves to a special (new) point of view. Now it is already firmly proved the absence of statistical stability of samples of parameters of tremorograms, teppingrams (and also many bioelectrical processes which provide regulation of movements, for example, electromyograms and electroencephalograms). There are no repeats not only of statistical distribution functions *f(x)* of samples $x_i(t)$ but also their spectral signal densities, autocorrelations, etc. for other 3TS-*complexity* parameters [14–16].

All this brings us to a conclusion about the end of further application of stochastic methods in the estimation of biomechanical parameters (and electro generating systems), which is so widely used now in biophysics, theory of electro generation, brain sciences. There is a need to create new invariants, new models and new theory to describe systems of the third type (according to W. Weaver's classification). From this point of view, we propose to introduce an analogue of the Heisenberg uncertainty principle in describing such unstable systems. In this case parameters of pseudo attractors are preserved and we can register static states of 3TS or their evolution (kinematics in phase state spaces).

In 3TS-*complexity* kinematics, we observe the motion of the center of the PA in the PSS or the change in the volume of the PA. Criteria are now being developed to estimate velocities and accelerations in 3TS kinematics (in PSS), which will avoid problems that are associated with the statistical instability of *x(t)* samples in the form of the Eskov-Zinchenko effect [14–15].

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