

№ЛД-16 ИИ

**Federal State Budget Educational Institution higher education  
"NORTH-OSSETIAN STATE MEDICAL ACADEMY"  
Ministry of Health of Russia**

---

**CHAIR OF CHEMISTRY AND PHYSICS**

**Collection of guidelines in Digital technologies  
in medicine for 2 nd year students of medical  
faculty**

**Vladikavkaz 2021**

**Collection of guidelines drawn up in compliance with:**

- FGEF VO in the direction of training (specialty) "medicine", approved by the Ministry of Education and Science of the Russian Federation August 12, 2010
- The curriculum for the specialty "medicine", approved by the Academic Council of Medical University SOGMA Ministry of Health of the Russian Federation.
- Work program of the discipline medical informatics.

Compiled by:

Associate Professor AV Babenko

Reviewers:

Associate Professor of Chemistry and Physics, Medical University SOGMA,

Approved at the meeting of the Central Committee of UMS

“ 28 ” January 2021г. Protocol № 3

## **Table of contents**

**Topic 1:** Fundamentals of the digital economy and digital health

**Topic 2:** Medical Image Recognition Algorithms

**Topic 3:** Virtual and Augmented Reality in Medicine

**Topic 4:** Big Data and Artificial Intelligence in Healthcare

**Topic 5:** Strategy for creating a new model of medical institutions based on digitalization

**Topic 6:** Biomedical Signal Analysis - Digital Signals and Images in Medicine

**Topic 7:** Digital images in Matlab, their application in medical research, visualization of information processes

**Topic 8:** Software for the implementation of information processes in medicine. Medical image processing - basic technologies of discrete orthogonal and wavelet transformations of medical information

**Topic 9:** Pre-processing of medical signals and images using digital technologies

**APPENDIX** Matlab Labs

# **Topic 1: "Fundamentals of the digital economy and digital health"**

## **1. Scientific and methodological substantiation of the topic:**

Topic 1 is devoted to the history and modern problems of digital health care. The issues of using information and communication technologies for remote delivery of medical care to the population and remote training of specialists are considered. The structure, subjects and objects of digital health care in Russia and abroad are presented, the role of social networks in the process of spreading telemedicine services is assessed. The different efficiency of digitalization for different branches of medicine is shown, according to sociological surveys, patient, professional, institutional problems of digital health care and its prospects in the context of self-preserving behavior of the population are revealed.

*The purpose of the practical (seminar) lesson is to study the following issues:*

1. Concept and history of digital health
2. Structure, subjects and objects of digital health care
3. Needs of self-preservation behavior of the population and the possibilities of digital health
4. Problems of digital health (patient, professional, institutional)
5. Prospects for digital health in self-preservation behavior

## **2. Brief theory:**

The actual goals of the demographic development of Russia are an increase in the birth rate and an increase in life expectancy, the achievement of which is impossible without an effective health care system. The specificity of modern health care, based on the application of technological innovations, presupposes the active participation of the population in maintaining their health and responsibility for it, i.e. the formation of self-preserving behavior that meets the individual needs of a person, on the one hand, and takes into account the rapidly growing possibilities of medicine, on the other. ... In this regard, the task of studying the correspondence of the needs of the population and the responses to them on the part of public health arises, the results of which are reflected in the change in qualitative demographic indicators. Today, these problems are of particular importance in the context of digital healthcare as part of Russia's innovative "digital economy".

### 2.1. Matlab software environment:

2.1.1. The main windows of the MATLAB environment. The main windows (in the default settings, some windows are presented as tabs in the main window) of the MATLAB environment are:

- ✓ the Command Window tab - a command window for running individual commands from the keyboard, displaying numerical and text results, calling the simplest help for a specific function (using the help <function name> command), as well as interpreter messages about errors;
- ✓ Workspace tab - a window with a list of variables stored in memory, as well as information about their type, dimension and size in bytes;
- ✓ Command History tab - a window with the history of commands entered into the command window;

- ✓ An editor window for typing, saving, editing and debugging programs and functions (called through the File menu, the New or Open submenu);
- ✓ A help window representing a cataloged hypertext help system with search capabilities by function name or keyword (accessed from the Help menu, MATLAB Help submenu).

### 2.1.2. MatLab as a scientific calculator.

A detailed description is given in the APPENDIX (Laboratory work No. 1).

### 3. The purpose of the students in the classroom:

*The student should know the following:*

1. Matlab as a package of applied programs for solving problems of quantitative analysis in medicine and a programming language of the same name;
2. the principle of work in interactive mode;
3. the basics of working with mental maps

*The student should be able to:*

1. work in Matlab environment
2. work with mental maps

### 4. Learning content:

1. Concepts and definitions;
2. Digital economy and digital health;
3. Matlab as a scientific calculator.

### 5. List of questions to check the level of knowledge:

1. What is an algorithmic language?
2. Features of work in the Matlab environment?

### 6. List of questions to check the final level of knowledge:

1. How are real numbers represented in MatLAB calculations?
2. How to change the format of representation of real numbers in the command window?
3. How are variables declared in MatLAB?
4. How to make sure that the result of the actions recorded in the next line a) was displayed in the command window; b) was not displayed on the screen?
5. What role does the ans system variable play?
6. How to return a previously entered command to the command line?
7. How to enter the value of a complex number, and in what form will it be displayed on the screen?
8. How to provide addition, subtraction, multiplication, division and exponentiation of complex numbers in MatLAB?
9. What functions for working with complex numbers are provided in the MatLAB language?

## **7. The practical part.**

Perform laboratory work No. 1 on the topic - MatLab as a scientific calculator (see APPENDIX or Yandex - disk).

### **Tasks:**

1. Prepare mental maps for basic theoretical concepts;
2. To study the Matlab software environment - interactive mode - calculator mode to complete tasks on laboratory work No. 1.

## **8. Independent work of students:**

For the theoretical part of Chapter 1 of this guideline, study:

1. Fundamentals of the digital economy and digital health;
2. Basic concepts of Matlab language.

*Topic 1 is designed for one practical lesson.*

### **Chronocard of one training lesson:**

1. Organizational moment - 5 min.
2. Current control of knowledge - 30 min.
3. Analysis of the topic - 20 min.
4. Practical work - 30 min.
5. Summing up the results of the lesson - 10 min.

## **9. List of educational literature for the lesson:**

1. Kobrinsky B.A., Zarubina T.V. "Medical informatics", M., Publishing house "Academy", 2009.
2. Zhizhin K.S. "Medical Statistics", Higher Education, 2007.
3. Lecture on this topic.

## **Topic 2: "Algorithms for recognition of medical images"**

### **1. Scientific and methodological substantiation of the topic:**

Topic 2 is devoted to the problems of visualization of medical images. In the field of scientific research, medical imaging is a sub-discipline in biomedical engineering, medical physics or medicine depending on the context: research and development in instrumentation, imaging (e.g. radiography), biomedical engineering, medical physics and informatics ... Many of the techniques developed for medical imaging also have scientific and industrial applications. The purpose of the practical (seminar) lesson is to study the following issues: the concept of medical imaging and its types - radiography, magnetic resonance imaging (MRI), nuclear medicine, ultrasound, elastography, tactile imaging, photoacoustic imaging, thermography, echocardiography

### **2. Brief theory:**

Medical imaging is a method and process for creating visual representations of the internal structures of the body for clinical analysis and medical intervention, as well as visual representation of the functions of certain organs or tissues.

Medical imaging allows you to look into the internal structures hidden by skin and bones, as well as diagnose diseases. Medical imaging also creates a database of normal anatomy and physiology to enable the identification of abnormalities.

Although imaging of the removed organs and tissues can be performed for medical reasons, such procedures are usually considered as part of pathology rather than medical imaging. As a discipline, it is part of biological imaging and includes radiology, which uses imaging technologies for x-ray, magnetic resonance imaging, ultrasound, endoscopy, elastography, tactile imaging, thermography, medical photography, and such nuclear medicine techniques. are known as positron emission tomography (PET) and single photon emission computed tomography.

Although imaging of the removed organs and tissues can be performed for medical reasons, such procedures are usually considered as part of pathology rather than medical imaging. As a discipline, it is part of biological imaging and includes radiology, which uses imaging technologies for x-ray, magnetic resonance imaging, ultrasound, endoscopy, elastography, tactile imaging, thermography, medical photography, and such nuclear medicine techniques. are known as positron emission tomography (PET) and single photon emission computed tomography.

Measurement and recording is done by methods that are not designed for imaging, such as electroencephalography (EEG), magnetoencephalography (MEG), electrocardiography (ECG), and is a technology that produces data that is represented as a graph / time function or a map that contains data on the measurement sites. Until 2010, 5 billion medical imaging studies were conducted worldwide. Radiation exposure from medical imaging in 2006 accounted for about half of the total exposure to ionizing radiation in the United States.

Medical imaging is often perceived as a set of techniques that non-invasively (without the introduction of instruments into the patient's body) produce images of the internal aspect of the body. In this narrow sense, medical imaging can be viewed as a solution to mathematical inverse problems. This means that the cause (properties of living tissue) is deduced from the effect (the observed signal). In the case of ultrasound, the probe is made up of ultrasonic waves and echoes

that emanate from the tissue. In the case of projection radiography, the probe is X-ray radiation that is absorbed in various types of tissue, such as bone, muscle, and fat.

### **2.1. Matlab software environment:**

2.1.1. The simplest operations with vectors and matrices. A detailed description is given in the APPENDIX (Laboratory work No. 2).

### **3. The purpose of the students in the classroom:**

*The student should know the following:*

1. Matlab as a package of applied programs for solving problems of quantitative analysis in medicine and a programming language of the same name;
2. the principle of work in interactive mode;
3. the basics of working with mental maps.

*The student should be able to:*

1. work in Matlab environment
2. work with mental maps

### **4. Learning content:**

1. Concepts and definitions;
2. Visualization of medical signals and image recognition;
3. Matlab operations with vectors and matrices.

### **5. List of questions to check the level of knowledge:**

1. What is an algorithmic language?
2. Features of work in the Matlab environment?

### **6. List of questions to check the final level of knowledge:**

1. How vectors are entered in MatLAB language? What functions can be used to form vectors in MatLAB?
2. What MatLAB functions allow to transform a vector element-by-element?
3. By what means are basic operations with vectors carried out in MatLAB?
4. How are matrices entered in the MatLAB system?
5. What functions are available in MatLAB for the formation of matrices of a certain type?
6. How to form a matrix: a) by the given vectors of its rows? b) given vectors of its columns? c) given vectors of its diagonals?
7. What functions of element-by-element matrix transformation are there in MatLAB?
8. How are the usual matrix operations carried out in MatLAB?
9. How to solve a system of linear algebraic equations in MatLAB?
7. The practical part.

Perform laboratory work No. 2 on the topic - Operations with vectors and matrices (see APPENDIX or Yandex - disk).

### **Tasks:**

1. Prepare mental maps for basic theoretical concepts;
2. To study the Matlab software environment - interactive mode - Operations with vectors and matrices to complete tasks in laboratory work No. 2.



## **8. Independent work of students:**

For the theoretical part of Chapter 2 of this guideline, study:

1. Algorithms for recognition of medical images;
2. Basic concepts of Matlab language.

*Topic 2 is designed for one practical lesson.*

## **Chronocard of one training lesson:**

1. Organizational moment - 5 min.
2. Current control of knowledge - 30 min.
3. Analysis of the topic - 20 min.
4. Practical work - 30 min.
5. Summing up the results of the lesson - 10 min.

## **9. List of educational literature for the lesson:**

1. Kobrinsky B.A., Zarubina T.V. "Medical informatics", M., Publishing house "Academy", 2009.
2. Zhizhin K.S. "Medical Statistics", Higher Education, 2007.
3. Lecture on this topic.

## **Topic 3: "Virtual and Augmented Reality in Medicine"**

### **1. Scientific and methodological substantiation of the topic:**

Topic 3 is devoted to virtual and augmented reality in medicine. For several decades, the world has changed dramatically. If earlier human life proceeded in a three-dimensional coordinate system defining four-dimensional space, now space is at least five-dimensional and in the coordinate system a new coordinate has been added to time and length, measuring bits. In recent years, the development of information technology has made it possible to create technical and psychological phenomena, which are called "virtual reality" and "cyberspace" in popular and scientific literature. The development of programming techniques, the rapid growth of the performance of semiconductor microcircuits, the development of special means of transmitting information to humans, as well as feedback - all this has created a new quality of perception and experience, perceived as virtual reality.

*The purpose of the practical (seminar) lesson is to study the following issues:*

1. What is virtual reality (VR)
2. Types of virtual reality
3. Pros and cons of virtual reality
4. Perspectives of virtual reality
5. Examples of VR in medical practice

### **2. Brief theory:**

The lecture considered the definition of virtual technologies and related concepts, presented and characterized various types of virtual reality and VR systems, as well as suggested possible prospects for further penetration of virtuality into people's lives. It is obvious that virtual technologies - like any others, by the way - do not have a day with not only many advantages, but also a whole bunch of hitherto unknown problems. However, progress cannot be stopped, and it is clear that, despite the statements of individual technophobes, virtual reality, one way or another, will take its place in our lives.

#### **2.1. Matlab software environment:**

- 2.1.1. The simplest operations with vectors and matrices. A detailed description is given in the APPENDIX (Laboratory work No. 3).

### **3. The purpose of the students in the classroom:**

#### **The student should know the following:**

1. Matlab as a package of applied programs for solving problems of quantitative analysis in medicine and a programming language of the same name;
2. the principle of work in interactive mode;
3. the basics of working with mental maps.

*The student should be able to:*

1. work in Matlab environment
2. work with mental maps

### **4. Content of training:**

1. Concepts and definitions;

2. Visualization of medical signals and recognition of images;
3. Matlab operations with vectors and matrices.

#### **5. List of questions to check the level of knowledge:**

1. What is an algorithmic language?
2. Features of work in the Matlab environment?

#### **6. List of questions to test the final level of knowledge:**

1. How vectors are entered in MatLAB language? What functions can be used to form vectors in MatLAB?
2. What MatLAB functions allow to transform a vector element-by-element?
3. By what means are basic operations with vectors carried out in MatLAB?
4. How are matrices entered in the MatLAB system?
5. What functions are available in MatLAB for the formation of matrices of a certain type?
6. How to form a matrix: a) by the given vectors of its rows? b) given vectors of its columns? c) given vectors of its diagonals?
7. What functions of element-by-element matrix transformation are there in MatLAB?
8. How are the usual matrix operations carried out in MatLAB?
9. How to solve a system of linear algebraic equations in MatLAB?

#### **7. Practical part.**

Perform laboratory work No. 3 on the topic - Operations with vectors and matrices (see APPENDIX or Yandex - disk).

##### **Tasks:**

1. Prepare mental maps for basic theoretical concepts;
2. Study the Matlab software environment - interactive mode -
3. Operations with vectors and matrices to complete tasks in laboratory work No. 3.

#### **8. Independent work of students:**

- ✓ For the theoretical part of Chapter 3 of this guideline, study:
- ✓ Virtual and Augmented Reality in Medicine;
- ✓ Basic concepts of Matlab language.

**Topic 3 is designed for one practical lesson.**

##### **Chronocard of one training lesson:**

1. Organizational moment - 5 min.
2. Current control of knowledge - 30 min.
3. Analysis of the topic - 20 min.
4. Practical work - 30 min.
5. Summing up the results of the lesson - 10 min.

##### **9. List of educational literature for the lesson:**

1. Kobrinsky B.A., Zarubina T.V. "Medical informatics", M., Publishing house "Academy", 2009.
2. Zhizhin K.S. "Medical Statistics", Higher Education, 2007.
3. Lecture on this topic.

## Topic 4: "Big Data and Artificial Intelligence in Health Care"

### 1. Scientific and methodological substantiation of the topic:

Currently, artificial intelligence (AI) is considered one of the most important areas of IT research, the engine of breakthrough industrial growth, which has recently been called "Industry 4.0". Just as the invention of electricity led to the industrial revolution in the 19th century, so artificial intelligence and information technology are perceived today as a source of profound transformation of society and the economy. However, unlike previous industrial revolutions, the main driver of these tectonic changes is neither technology nor IT.

Society itself, its way of life is changing. Informatization is transforming consumer behavior. Having access to different quality of information, they become more sophisticated and demanding.

Applying IT, the management received high-quality professional tools for supervision, management and control. The policy of the state and investors is changing: they no longer want to invest in activities that have inherited a routine in which low-skilled manual labor is used.

Robots and cognitive information systems are replacing old technologies. According to the International Data Corporation (IDC), the market for cognitive systems and AI technologies in 2016 in monetary terms was approximately \$ 7.9 billion.

In 2017, it is expected to grow by 59.3% to reach \$ 12.5 billion. Analysts believe that by the end of this decade, the average annual growth rate will be at the level of 54%.

As a result, in 2020 the value of the industry's products will exceed \$ 46 billion. The largest share of this market will be made by cognitive applications that automatically study data and make various estimates, recommendations or forecasts.

Investments in AI software platforms that provide tools, technologies and services based on structured and unstructured information will be measured at \$ 2.5 billion per year.

The market for artificial intelligence in health and life sciences, according to Frost & Sullivan estimates, will also grow by 40% per year and will reach 6.6 billion dollars in 2021.

*The purpose of the practical (seminar) lesson is to study the following issues:*

1. History of artificial intelligence
2. Current trends
3. What is artificial intelligence
4. Neural networks and machine learning

### 2. Brief theory:

History of Artificial Intelligence.

Artificial intelligence has a relatively long history, dating back to Turing's theoretical studies in cybernetics dating back to the early 20th century. And conceptual prerequisites appeared even earlier - with the philosophical work of Rene Descartes "Discourse on Method" (1637) and Thomas Hobbes "Human Nature" (1640).

In the 1830s, the English mathematician Charles Babbage proposed the idea of a complex digital calculator, an analytical machine that the developer claimed could calculate the moves for a game of chess. In 1914, the director of a Spanish technical institute, Leonardo Torres Quevedo, manufactured an electro-mechanical device capable of playing out the simplest chess endgames almost as well as a human.

Since the mid-30s of the last century, with the publication of Turing's works, in which the problems of creating devices capable of independently solving various complex problems were discussed, the problem of artificial intelligence in the world scientific community began to be treated with attention.

Turing suggested that an intellectual machine should be considered such a machine that a test subject cannot distinguish from a person in the process of communicating with it. At the same time, the concept of the Baby Machine appeared, which implies teaching an artificial intelligence like a small child, and not immediately creating an "intelligent adult" robot - the prototype of what we now call machine learning.

In 1954, the American researcher Newell decided to write a program for playing chess.

Analysts from the RAND Corporation were involved in the work. The method proposed by the founder of information theory Shannon was used as the theoretical basis of the program, and its exact formalization was carried out by Turing.

In the summer of 1956, at the University of Dartmouth in the USA, the first working conference with the participation of scientists such as McCarthy, Minsky, Shannon, Turing and others, who were later named the founders of the field of artificial

mind. For six weeks, scientists discussed the possibilities of implementing projects in the field of artificial intelligence. It was then that the term itself appeared artificial intelligence (AI) - artificial intelligence.

It should be clarified that work in the field of AI has not always turned out to be successful. After explosive interest in the 1950s and fantastic expectations,

that the computer is about to replace the human brain, in the 1960s and 70s came

heavy disappointment. The capabilities of computers of that time did not allow for complex calculations. Research on the development of the mathematical apparatus of AI has also reached an impasse. This pessimism has colored many textbooks on applied informatics that are still being published. In public culture, the image of a robot or a cybernetic algorithm has been formed as a pathetic, unworthy agent who can perform his functions only under the control of a person. However, in the mid-1990s, interest in AI began to revive, and with Since then, there has been an explosion of research and patent work in this area.

Modern tendencies.

In 2005-2008 there has been a quantum leap in work on AI. The mathematical scientific world has found new theories and models for learning multilayer neural networks, which have become the foundation for the development of another theory - deep machine learning. And the IT industry began to produce high-performance and, most importantly, low-cost and affordable computing systems. The joint efforts of mathematicians and engineers have resulted in outstanding achievements over the past 10 years, including a variety of practical results. The first examples of impressive results from the use of AI have been achieved in activities that require taking into account a large number of frequently changing factors and a flexible adaptive human response, for example, in entertainment and games.

In 1997, an IBM computer called Deep Blue became the first computer to defeat world chess champion Garry Kasparov.

In 2011, the cognitive learning system IBM Watson defeated the Replaceable Champions in Jeopardy! (the Russian analogue is the program "Own Game").

In early 2016, Google's AlphaGo program beat European Champion Go Fan Hui in a game. Two months later, AlphaGo defeated Li Se-share, one of the best Go players in the world, 4-1. This became a historical borderline: it was previously believed that a computer could not

beat a player of this level - the degree of abstraction was too great and there were too many scenarios for the development of events to brute-force. In a sense, a computer in a Go game needs to be able to think creatively.

In January 2017, Carnegie Mellon University's Libratus program won the Brains Vs. 20-day poker tournament. Artificial Intelligence: Upping the Ante ", won over \$ 1.7 million. The next victory was won by an improved version of AI called Lengpudashi, against the participant of the World Series of Poker (WSOP) Alan Du, as well as a number of scientists and engineers. The peculiarity of this situation was that the player was planning to defeat the AI, using its weaknesses. However, the strategy did not work, and the advanced version of Libratus was victorious again. According to Blomberg, Libratus co-developer Noam Brown said that humans underestimate artificial intelligence: "People think that bluff is characteristic of

people, but it is not. The computer can figure out that if you bluff, you can win more. "

Over the past few years, AI-based solutions have been implemented in many areas of activity, having achieved increased efficiency of processes, and not only in the entertainment sector. Technological giants Facebook, Google, Amazon, Apple, Microsoft, Baidu and a number of other companies are investing huge amounts of money in AI research and are already applying various developments in their practical activities. In May 2017, Microsoft issued a statement that it plans to use AI mechanisms in each of its software products and make them available to any developer.

Reducing the cost of AI platforms and increasing their availability made it possible to work with them not only for large corporations, but also for specialized companies and even startups. In the last couple of years, a lot of small research teams have appeared, numbering several people and not having huge financial resources, which nevertheless manage to offer new and promising ideas and concrete working solutions,

built on the basis of AI. One of the most famous examples is a startup that created

the most popular mobile application Prisma: the development team offered a service for processing photos with the ability to stylize for a particular artist. The massive development and implementation of AI in many directions at once became possible due to several key factors in the development of the IT industry: the penetration of high-speed Internet, a significant increase in the productivity and availability of modern computers with simultaneous

lower cost of ownership, development of "cloud" solutions and mobile technologies, growth of the free software market. The most susceptible to the use of AI are the industries of mass and distributed consumer services: advertising, marketing, trade, telecom, government services, insurance, banking and fintech. The wave of changes has reached such conservative spheres of activity as education and health care.

What is artificial intelligence.

In the early 1980s, computational scientists Barr and Feigenbaum proposed the following definition of AI: "Artificial intelligence is a field of computer science that develops intelligent computer systems, that is, systems that have the capabilities that we traditionally we associate with the human mind, - understanding the language, learning, the ability to reason, solve problems, etc. ". Jeff Bezos (CEO of Amazon) writes about AI this way: "Over the past decades, computers have automated many processes that programmers could describe through precise rules and algorithms. Modern machine learning techniques allow us to do the same with tasks for which it is much more difficult to set clear rules. "

At present, artificial intelligence actually refers to various software systems and the methods and algorithms used in them, the main feature of which is the ability to solve

intellectual problems in the same way as a person thinking about their solution would do. Among the most popular areas of AI application are forecasting various situations, evaluating any digital information with an attempt to give

conclusion, as well as analysis of various data with the search for hidden patterns

(data mining). Let us emphasize that so far the computer is not capable of simulating complex processes of human higher nervous activity, such as the manifestation of emotions, love, creativity. This refers to the field of the so-called "strong AI", where a breakthrough is expected no earlier than 2030-2050s.

At the same time, the computer successfully solves the problems of "weak AI", acting as a cybernetic automaton, working according to the rules prescribed by a person. The number of successfully implemented projects of the so-called. "Average AI", where the IT system includes elements of adaptive self-learning, improving as accumulation of primary data, reclassifying text, graphic, photo / video, audio data in a new way.

Neural networks and machine learning are the basic concepts of AI.

A wide variety of approaches and mathematical algorithms for building AI systems have now been accumulated and systematized, such as Bayesian methods, logistic regression, support vector machines, decision trees, ensembles of algorithms, etc. Recently, a number of experts come to the conclusion that pain - the majority of modern and really successful implementations are solutions based on deep neural networks and deep learning technologies. Neural networks are based on an attempt to recreate a primitive model of the nervous system of biological organisms. In living things, a neuron is an electrically excitable cell that processes, stores and transmits information using electrical and chemical signals through synaptic connections. The neuron has a complex structure and narrow specialization. By connecting to each other to transmit signals using synapses, neurons create biological neural networks. The human brain has an average of about 65 billion neurons and 100 trillion. synapses. In fact, this is the basic mechanism of learning and brain activity of all living beings, that is, their intelligence. For example, in the classical experiment of I.P. Pavlov, a bell rang each time just before feeding the dog, and the dog quickly learned to associate the bell-chime with food. From a physiological point of view, the result of the experiment was the establishment of synaptic connections between the regions of the cerebral cortex responsible for hearing and the regions responsible for the control of the salivary glands. As a result, when the cortex was excited by the sound of a bell, the dog began to salivate. This is how the dog learned to react to signals (data) coming from the outside world and make the "correct" conclusion.

It was the ability of the biological nervous system to learn and correct its mistakes that formed the basis of research in the field of artificial intelligence. Their initial task was an attempt to reproduce the low-level structure of the brain, that is, to create a computer "artificial brain". As a result, the concept of an "artificial neuron" was proposed - a mathematical function that transforms several input facts into one output, assigning influence weights to them. Each artificial neuron can take a weighted sum of input signals and, if the total input exceeds a certain threshold level, transmit the binary signal further.

## **2.1. Matlab software environment:**

2.1.1. The simplest operations with vectors and matrices. A detailed description is given in the APPENDIX (Laboratory work No. 4).

### **3. The purpose of the students in the classroom:**

*The student should know the following:*

1. Matlab as a package of applied programs for solving problems of quantitative analysis in medicine and a programming language of the same name;
2. principle of work in interactive mode;
3. the basics of working with mental maps.

*The student should be able to:*

1. work in Matlab environment
2. work with mental maps

### **4. Learning content:**

1. Concepts and definitions;
2. Big data and artificial intelligence in health care;
3. Matlab operations with vectors and matrices.

### **5. List of questions to check the level of knowledge:**

1. What is an algorithmic language?
2. Features of work in the Matlab environment?

### **6. List of questions to check the final level of knowledge:**

1. How vectors are entered in MatLAB language? What functions can be used to form vectors in MatLAB?
2. What MatLAB functions allow to transform a vector element by element?
3. By what means are the basic operations with vectors carried out in MatLAB?
4. How are matrices entered in the MatLAB system?
5. What functions are available in MatLAB for the formation of matrices of a certain type?
6. How to form a matrix: a) by the given vectors of its rows? b) given vectors of its columns? c) given vectors of its diagonals?
7. What functions of element-by-element matrix transformation are there in MatLAB?
8. How are the usual matrix operations carried out in MatLAB?
9. How to solve a system of linear algebraic equations in MatLAB?

### **7. The practical part.**

Perform laboratory work No. 4 on the topic - Operations with vectors and matrices (see APPENDIX or Yandex - disk).

#### **Tasks:**

1. Prepare mental maps for basic theoretical concepts;
2. To study the Matlab software environment - interactive mode - Building the simplest graphs to perform tasks for laboratory work No. 4.

### **8. Independent work of students:**

For the theoretical part of Topic 4 of this guideline, study:

- ✓ Big data and artificial intelligence in healthcare;
- ✓ Basic concepts of Matlab language.

**Topic 4 is designed for one practice session.**



*Chronocard of one training lesson:*

1. Organizational moment - 5 min.
2. Current control of knowledge - 30 min.
3. Analysis of the topic - 20 min.
4. Practical work - 30 min.
5. Summing up the results of the lesson - 10 min.

**9. List of educational literature for the lesson:**

1. Kobrinsky B.A., Zarubina T.V. "Medical informatics", M., Publishing house "Academy", 2009.
2. Zhizhin K.S. "Medical Statistics", Higher Education, 2007.
3. Lecture on this topic.

# **Topic 5: "Strategy for creating a new model of medical institutions based on digitalization"**

## **1. Scientific and methodological substantiation of the topic:**

Digital innovations are rapidly transforming modern industries. Health care facilities and health systems are using these tools to improve public health, reduce costs and improve quality of care.

More new technologies are now in the service of medicine, allowing the use of evidence-based methods of treatment, and new systems of interaction improve the process of providing medical care not only for patients, but also for doctors. These technologies are integral to the development of the industry and its movement towards effective integration, collaboration between different healthcare structures and value-based treatment.

The future of healthcare lies in new levels of patient focus. The industry is shifting from quantitative models of paid health services to value-based care aimed at improving overall health. To cut costs, find new development opportunities and deliver high-quality health care to people, healthcare organizations will need better data management, communication, and more accurate measurement of outcomes.

*The purpose of the practical lesson is to study the following problems:*

- 1. What is the transformation in healthcare*
- 2. Digital transformation in healthcare*
- 3. Transformation of healthcare and value-based treatment*

## **2. Summary.**

### ***What is transformation in healthcare for?***

The healthcare sector is constantly faced with a variety of challenges, including tight regulation, privacy concerns and skyrocketing costs. But doctors are already noticing the positive impact of the digital revolution and seeing how the industry is changing radically. Changes include:

- ✓ Health IT is evolving into a centralized and holistic corporate IT infrastructure that helps improve data management, interoperability and integration of health systems.
- ✓ Medical devices are becoming more interconnected, helping healthcare providers work faster and more efficiently, which in turn frees up more time to work directly with patients and helps reduce costs.

But these are not all changes. It is also worth noting artificial intelligence (AI) and data analysis tools - revolutionary technologies that, in the future, should help to quickly scan and process huge volumes of medical data, significantly speeding up the search and receipt of patient medical records for doctors.

The convergence of healthcare and corporate IT networks should improve interoperability between technologies and ultimately give healthcare providers more tools so that they can spend time not on routine administrative tasks, but on patients.

### ***Digital transformation in healthcare.***

The evolution of the ways and times of using technology in healthcare consists of three stages: digitalization, abandonment of old models, and transformation. At the stage of digitalization, digital tools are being introduced to support routine processes or services in healthcare. Examples of changes in healthcare services as a result of digitalization include

computed tomography and MRI, as well as tools for automating account management and similar tools for managing administrative processes. Ultimately, digitalization makes it easier to store, access and share data.

In the second phase, old technologies are replaced by new ones, such as artificial intelligence, mobile technologies, analytics and the cloud. This is changing the way people, organizations and governments interact. All of these disruptive innovations are helping to establish new channels of communication between people and take customer focus to the next level. As healthcare evolves, systems will become increasingly integrated, bringing together digital functions or processes in enterprises that were previously disparate. Advances in EMR and other technologies are also helping to create closer synergies between healthcare providers and other healthcare organizations.

Digital transformation in healthcare is an ongoing process that involves a complete restructuring of the way healthcare institutions and other organizations operate and their interactions with patients, customers and shareholders. In this way, healthcare is transforming from disparate fragments into an integrated ecosystem that allows healthcare providers to successfully solve problems of a larger scale, while maintaining a patient focus and value-based care.

*Healthcare transformation and value-based treatment.*

medical care, organizations need more accurate and reliable information, as well as effective data management tools. Fortunately, the sheer volume of medical, genomic, demographic, and performance data opens up a whole host of possibilities for using medical technology to support decision-making. So, to analyze this amount of data and extract meaningful information from it, you can use analytical tools and solutions based on AI, so that medical institutions and heads of healthcare organizations can conduct research and innovate. AI and interoperable systems can potentially help organizations find useful insights that can improve the quality of patient care.

**The purpose of the students' activity in the class:**

*The student should know the following:*

1. Matlab as a package of applied programs for solving problems of quantitative analysis in medicine and a programming language of the same name;
2. Matlab - programming language of the same name;
3. the principle of work in interactive mode;
4. a short list of used Matlab functions.

*The student should be able to:*

1. work in Matlab environment
2. be able to form a signal for its processing

**4. Learning content:**

1. Concepts and definitions;
2. Classification of biomedical signals and algorithms for their modeling in MATLAB;
3. A short list of the used functions of the MATLAB environment

**5. List of questions to check the level of knowledge:**

1. What is an algorithm?
2. What is simulation?

3. Formulate what is the physiological process
4. What is a signal, their classification?

#### **6. List of questions to test the final level of knowledge:**

1. What is the transformation in health care?
2. Digital transformation in healthcare - what is it?
3. Health transformation and value-based treatment comment on.

#### **7. The practical part.**

To carry out laboratory work No. 5 on the topic - Operators of control of computational processes (see APPENDIX or Yandex - disk).

#### **Tasks:**

1. Prepare mental maps for basic theoretical concepts;
2. To study the software environment Matlab - interactive mode - Operators of control of computational processes to complete tasks on laboratory work No. 5.

#### **8. Independent work of students:**

For the theoretical part of Topic 5 of this guideline, study:

- ✓ Strategy for creating a new model of medical institutions based on digitalization;
- ✓ Basic concepts of Matlab language.

#### **Topic 5 is designed for one practical lesson.**

*Chronocard of one training lesson:*

1. Organizational moment - 5 min.
2. Current control of knowledge - 30 min.
3. Analysis of the topic - 20 min.
4. Practical work - 30 min.
5. Summing up the results of the lesson - 10 min.

#### **9. List of educational literature for the lesson:**

4. Kobrinsky B.A., Zarubina T.V. "Medical informatics", M., Publishing house "Academy", 2009.
5. Zhizhin K.S. "Medical Statistics", Higher Education, 2007.
6. Lecture on this topic.

## **Topic 6: "Analysis of biomedical signals - digital signals and images: MatLAB (PYTHON) as a scientific calculator"; programming in the MatLAB environment (PYTHON);the MatLAB interface (PYTHON) and general-purpose commands, classes of computational objects in MatLAB (PYTHON).**

### **1. Scientific and methodological substantiation of the topic:**

The state of a biological object is characterized by a set of data on the structure, consisting of a subset of the elements and connections of the object, as well as a subset of their properties. Information about an object is a value determined by a set of terms (signs, symbols, signals) that display the state of the object in a given language and are fixed on a particular medium. Biomedical signals carry information about the physical manifestations of physiological processes (events) of a living organism, which can be measured and presented in a form convenient for processing using computers. An example of an event is the work of the heart and the resulting electrical potentials on the surface of the body. The biomedical signal corresponding to this event is an electrocardiogram (ECG.)

It is known that, regardless of their physical nature, signals are divided into deterministic and random. Deterministic signals are signals whose instantaneous values are precisely determined at any time. Random signals are signals whose instantaneous values cannot be predicted in advance. Random parameter changes can be caused either by the transmitted information about changes in the system under study, or by the action of some interfering factors. In the latter case, they talk about the effect of interference on the transmitted information.

Signal parameters that change over time in accordance with changes in physiological processes in the human body are informative. In other words, these parameters carry data on changes in the state of the object or process under study. In biomedical signals, informative parameters can be amplitude or power, frequency (period), phase (time shift).

Only random signals can carry information. A deterministic signal does not carry any information, since its behavior is known in advance. In practice, the conclusion about whether a process is random or deterministic is made on the basis of the results of its reproduction: if, during several experiments, the observation result is repeated within the measurement error, then the process is considered deterministic, if not, it is random.

Processing of biomedical signals is carried out in order to isolate informative signs in them or to determine diagnostic indicators.

The first step in the study of biological systems is the development of sensors and equipment for converting the studied phenomena into measurable electrical signals. The next step is filtering and elimination of signal distortions (artifacts). For example, artifacts of the ECG signal can be caused by mechanical body movements, interference in the network, and interference from an electromagnetic field. The third step is the detection in biomedical signals of events and analysis of their information characteristics, modeling of processes and systems that generate biomedical signals.

Biomedical signals reflecting changes in functional processes in the human body, including the brain, cardiovascular system, sensory systems, motor and motor functions, are continuous. If such signals are converted using analog-to-digital conversion into time series, then the operations performed at the second and third steps of the study of biological systems can be performed using the theory and methods of digital signal processing.

In digital signal processing, a signal is understood as its mathematical description, that is, some real function containing information about the state or behavior of a physical system under some event, which can be determined on a continuous or discrete space of time or spatial coordinates. In a broad sense, digital signal processing systems mean a complex of algorithmic, hardware and software tools.

As a rule, the systems contain specialized technical means for preliminary (or primary) signal processing and special technical means for secondary signal processing. The preprocessing means are designed to process the initial signals observed in the general case against the background of random noises and interferences of various physical nature and presented in the form of discrete digital samples, for the purpose of detecting and extracting (selecting) a useful signal and evaluating the characteristics of the detected signal. The useful information obtained as a result of preliminary processing enters the secondary processing system for classification, archiving, structural analysis, etc.

To solve the above problems, the mathematical programming system MATLAB (SCYLAB) & SIMULINK, developed by the American company MathWorks, is used. At present, the MATLAB package is a developed integrated software environment that includes its own programming language. It allows the user to quickly perform various operations on vectors and matrices, such as multiplication and inversion of matrices, calculating determinants, finding eigenvalues and vectors. In addition, MATLAB has built-in operations for calculating ordinary functions (algebraic, trigonometric, logical), solving algebraic and differential equations, plotting operations, and a number of others. MATLAB is a high level language. Its individual commands can be used to perform such complex operations as finding the roots of polynomials, solving linear and nonlinear algebraic equations, and modeling linear dynamical systems. These operations are standard MATLAB functions. Built-in and standard functions form the core of MATLAB.

In addition to the kernel that performs general-purpose computational algorithms, the MATLAB package contains several dozen toolboxes (libraries of specialized subroutines) designed to solve various practical problems.

This discipline deals with HRV signals. The analysis of this signal has been a fairly popular study of the functional state in medicine and physiology over the past decades. The reason for this is the simplicity of recording this signal and the constant updating of theoretical concepts and methodological approaches.

The "classical" approach to HRV analysis includes statistical, correlation and spectral processing methods, the basics of which were studied by students in the course "Informatics", "Statistics" and other subjects studied up to the 2nd year of this specialization.

The above traditional methods of analysis of biomedical signals are based on the assumption that the signal remains stationary within the analyzed fragment. In practice, especially during functional-load studies, this condition often turns out to be impossible. Therefore, when analyzing biomedical signals, it is relevant to use mathematical processing methods that do not have any specific requirements for the characteristics of these signals.

So, recently, for the analysis of the time series (VR) of the heart rate, methods of nonlinear dynamics have been actively developed, which are not only applicable to non-stationary processes, but also make it possible to numerically evaluate the processes of self-organization of biological systems.

The process of heart rhythm formation is determined by the interaction of the circulatory system with numerous regulatory mechanisms dependent on the state of the autonomic and

central nervous systems, hormonal, humoral and reflex processes. Moreover, in this multi-circuit, hierarchically organized system, the dominant role of individual links is determined by the current needs of the body.

This system is complex: its most obvious feature, like any biological system, is the ability to self-organize and manifest the properties of dynamic chaos. According to Takens' theorem, the properties of the system under study can be restored from measurements of only one observed signal.

The theory of self-organizing systems interprets the concept of chaos in a new way. Chaos is viewed as a multifaceted material factor that not only destroys systems and processes, but also has potential creative power, contributing to the emergence of new objects and phenomena.

Self-organization is a process of spontaneous emergence of order and organization from disorder and chaos. Self-organizing systems, being complex objects, are characterized by a large number of degrees of freedom.

A distinctive feature of self-organizing systems is their high sensitivity to initial conditions. The slightest changes in the initial state of the system can lead to unpredictable large-scale consequences. Thus, the dynamics of this process is complex, far from linear, in nature. On the way of its development, there may be turning points (bifurcation points), when the further fate of the system is fundamentally unknown: will it go into a state of chaos or will it transform into a qualitatively different structure with a higher high level of orderliness. To analyze the nonlinear properties of HRV, the Poincaré section, cluster spectral analysis, attractor plots, singular expansion, Lyapunov exponent, Kolmogorov entropy and others are used. However, for short-term HRV time series, obtaining statistically stable estimates of fractal dimensions, Lyapunov exponents and entropy encounters certain problems due to the insufficient length of the series and the noisiness of the HRV signal. Some authors came to the conclusion that the information encoded in the variability of (R - R) intervals cannot be fully estimated using only one method of HRV analysis. The presence of specific fluctuations (R - R) intervals determines the need to use different mathematical approaches to its assessment. Until recently, different approaches were perceived as separate phenomena that did not have a common theoretical basis. Integral approaches to the assessment of HRV signals help to avoid one-sided views and combine different methods into an integral system of ideas about the HRV signal as a process containing huge reserves of information about the nature of such a complex system as a living organism.

*The purpose of the practical lesson is to study the theoretical foundations of the principles of analysis of heart rate variability (HRV) and recommendations for practical research of its statistical, spectral, correlation and non-linear characteristics.*

## **2. Brief theory:**

### 2.1. About biomedical signals:

Living organisms are composed of many interconnected systems. The human body, for example, includes the nervous, cardiovascular, and other musculoskeletal systems. Methods for the study of physiological processes used in modern devices for clinical monitoring should ensure the continuity of registration of biological signals with a high diagnostic value of the obtained indicators. These requirements are met by a number of methods for studying biomedical signals that are widely used in functional diagnostics. Below is a summary of some of the common biomedical signals.

Electrocardiogram signals. Electrocardiography is a technique for recording and studying the electric fields generated during the work of the heart. The result of electrocardiography is an electrocardiogram, which is an electrical manifestation of the contractile activity of the heart.

Phonocardiogram signals. A phonocardiogram is a record of vibrations and sound signals emitted during the activity of the heart of the blood vessels. A phonocardiogram allows you to assess the general condition of the heart and blood vessels.

Electroencephalogram signals. Electroencephalography records the electrical activity of the brain. Its changes are determined by functional changes in the central nervous system, and according to the data of the power and spatial characteristics of the rhythms of the brain, it is possible to determine its dysfunction.

Action potential signals. Action potential is a kind of biopotential arising on the membrane of electrically excitable cells in response to irritation by an electric field, chemical or other stimulus. The action potential is the physiological basis of the nerve impulse.

Galvanic skin reaction signals. The galvanic skin response research method combines a number of indicators: skin potential level, potential response, spontaneous potential response, resistance level, resistance response, spontaneous resistance response. The appearance of electrical activity in the skin is mainly due to the activity of the sweat glands in human skin, which in turn are under the control of the sympathetic nervous system.

Rheogram signals. Rheography is a method for studying central and peripheral hemodynamics based on the study of tissue resistance to alternating electric current. The rheogram signal makes it possible to assess the pulsating component of tissue resistance, which arises as a result of changes in the intensity of blood flow.

Photoplethysmogram signals. Photoplethysmography uses the coefficient of light transmission or light reflection of tissues as a measured characteristic. The registered plethysmogram reflects changes in the volume of a limb or organ caused by changes in the amount of blood in them.

Electromyogram signals. Electromyography is the registration of electrical processes in the muscles, that is, the recording of the action potentials of the muscle fibers that cause it to contract. The superficial electromyogram summarizes the discharges of the motor units causing contraction. In addition, the myogram acts as an indicator of muscle tension.

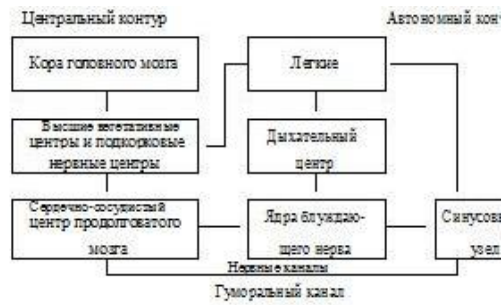
Speech signal. Most often, the speech signal is considered as a signal for communication. However, it can be used as a diagnostic one, to study disorders of the sound and vocal tracts. The sound of speech is formed by the passage of exhaled air from the lungs into the vocal tract.

## **2.2. Heart rate variability.**

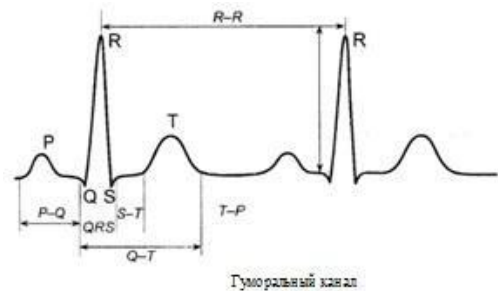
In a practical lesson, it is proposed to study the HRV signal, which is a time sequence (R - R) of ECG intervals, recorded according to the Einthoven first derivation scheme.

HRV is a consequence of the effect on the circulatory system of numerous regulatory mechanisms (nervous, hormonal, humoral). The functional system of blood circulation regulation is a multi-circuit, hierarchically organized system in which the dominant role of individual links is determined by the current needs of the body. A two-circuit model of heart rate regulation is based on a cybernetic approach, in which the sinus node regulation system can be represented as two interconnected levels (circuits): central and autonomous with direct and feedback. In this case, the effect of the autonomous level is identified with respiratory, and the central one - with non-respiratory arrhythmia.



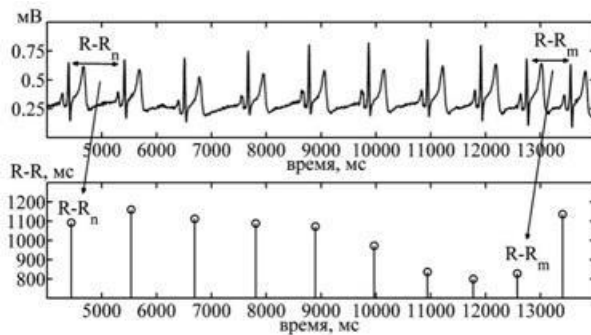


Physiological nature of the ECG signal. The main informational characteristics of the ECG signal are the P wave, the QRS complex and the T wave, which are caused by atrial depolarization, ventricular depolarization and ventricular repolarization, respectively. In fig. 2 shows a standard view of an ECG segment.



The time interval from the beginning of the P wave to the beginning of the QRS complex is called the PQ interval and indicates the time it takes for the action potential to travel through the atrial AV node. During the last part of the PQ interval, the electric voltage on the body surface is not recorded. Immediately after the cardiac impulse leaves the AV node and enters the Pur-kinje fiber system at a high conduction rate, all the cells of the ventricular musculature depolarize for a very short time, which leads to the appearance of the QRS complex. The R wave is the largest mark on the electrocardiogram, since the muscle cells of the ventricles are very numerous and depolarize almost simultaneously. The QRS complex is followed by the ST segment. Normally, during the registration of the ST segment, no potentials arise on the surface of the body, since at this time in any cells of the heart there are no rapid changes in membrane potentials. The atrial cells have already returned to the resting phase, and the ventricular cells are in the action potential plateau phase. When the cells of the ventricles begin to repolarize, tension appears again on the body surface and the T wave is recorded on the electrocardiogram. The T wave is wider and not as high as the R wave, since the repolarization of the ventricles is less synchronized than depolarization.. By the time the T wave completes, all heart cells are in a dormant state.

**2.4 Formation of the HRV signal.** Heart rate variability is a time series (R - R) of intervals over an observation interval. The largest spread (R - R) intervals indicates the influence of the vagus nerves and respiration and is known as respiratory sinus arrhythmia. According to the severity of high-frequency respiratory oscillations of the heart rate, the state of the vagal mechanisms of regulation is assessed. In fig. 3 shows the rhythmogram of the HRV signal.



**2.5. Methods of analysis of biomedical signals:** Mathematical methods of analysis of biomedical signals are divided into the following groups: statistical; variation; spectral; correlation; nonlinear dynamics - (a brief description will be considered in the next practical lesson on this topic).

**2.6. Integrated software environment MATLAB** - description. Brief list of used MATLAB environment functions

The software complex for mathematical modeling MATLAB (abbreviation from the English "Matrix Laboratory", in Russian is translated as "Matlab") is a package of applied programs for solving problems of technical calculations and the programming language of the same name used in this package. The MATLAB language is a high-level interpreted programming language, the structural unit of the program code is an m-file. The MATLAB environment has the ability to obtain estimates with a wide range of methods for a variety of biomedical signals, such as electrocardiograms, electroencephalograms.

**2.6.1. The main windows of the MATLAB environment.** The main windows (in the default settings, some windows are presented as tabs in the main window) of the MATLAB environment are:

- ✓ the Command Window tab - a command window for running individual commands from the keyboard, displaying numerical and text results, calling the simplest help for a specific function (using the help <function name> command), as well as interpreter messages about errors;
- ✓ Workspace tab - a window with a list of variables stored in memory, as well as information about their type, dimension and size in bytes;
- ✓ Command History tab - a window with the history of commands entered into the command window;
- ✓ An editor window for typing, saving, editing and debugging programs and functions (called through the File menu, the New or Open submenu);
- ✓ A help window representing a cataloged hypertext help system with search capabilities by function name or keyword (accessed from the Help menu, MATLAB Help submenu).

**2.6.2. Main objects.** The main objects when working in MATLAB are arrays of numbers of arbitrary dimensions. However, MATLAB works most efficiently with two-dimensional arrays, that is, with rectangular matrices. In this case, scalars are considered 1-by-1 matrices, and vectors (row vectors and column vectors) are 1-by-n and n-by-1 matrices, respectively.

**In the simplest case, the matrix is entered using the symbols:**

- ✓ "=" (equal sign) - assignment operator;
- ✓ "[" and "]" (square brackets) - matrix framing;
- ✓ ";" (semicolon) - matrix row separator;

- ✓ "," (comma) - separator of elements in a line (can be omitted).

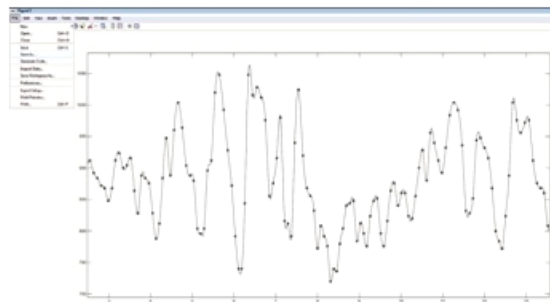
Line vectors whose elements are members of the arithmetic progression can be specified using the ":" (colon) character. The default step is +1 and, if necessary, can be changed by the user to any real number within the double data type, including negative.

Text variables are entered by framing their values with the "" (stroke) character, while the text is represented as a string vector.

Access to individual elements, rows and columns is carried out using the corresponding indices, enclosed in the symbols "(" and ")" (parentheses) and separated by the symbol "," (comma). In this case, indices can be specified both explicitly and through variables, as well as row vectors. In addition, it is possible to select the entire range of rows (columns) by replacing the indices with the character ":" (colon). In the text of the m-file, the "%" (percentage) symbol indicates the beginning of a comment.

All m-files that MATLAB works with fall into two categories: scripts and functions. A script is simply a sequence of commands that uses variables from the main MATLAB workspace. A function is a subroutine that takes arguments (parameters) and returns results.

2.6.3 Saving images. To save plots drawn in MATLAB, open the plot window that you want to save. Then, in the top menu bar, click on the File button, then select the Save As ... option (see Fig. 4).



in the Save As menu that opens, fill in the File name field, in the Explorer window select the directory for saving. Then, in the File type line, select the Portable Network Graphics file (\*.png) format. Then click on the Save button.

**2.6.4. Operations on matrices and their elements.** In the MATLAB environment, unlike many other programming languages, matrices can be operated directly without using cycles of transitions from one matrix element to another. In addition to the actual operations on matrices, it is possible to carry out element-by-element operations, that is, to operate with individual (but simultaneously with all, without exception) elements of the matrices. In this case, the matrices being operated must have the same dimension. Element-wise operations of addition and subtraction are identical to matrix operations, therefore they do not have their own designations; to denote the rest of the element-by-element operations, an additional symbol "." (dot). MATLAB is rich in its functions, therefore, below in the text, we will cite only those knowledge of which is necessary for the successful completion of practical tasks.

Below are the MATLAB environment functions that will be used in class:

Clear all - removes all current variables;

- ✓ save ('filename', 'X') - saves the variable X to a mat file with the name filename. If several variables are saved in one mat file, they should be specified separated by commas. If there is no directory in the file name, then the corresponding mat file will be saved in the standard MATLAB directory;

- ✓ load ('filename') - reads from the file filename, while the read variables retain their original names;
- ✓ length (X) - returns the length of the array X;
- ✓ max (X) - returns the maximum element of the X array;
- ✓ [y, N] = max (X) - writes to the variable y the maximum element of the array X, and to the variable N - its index;
- ✓ min (X) - returns the minimum element of array X;
- ✓ mean (X) - returns the average value of the X array;
- ✓ std (X) - returns the standard deviation of the elements of the X array;
- ✓ sum (X) - sums up the elements of array X;
- ✓ hist (X, n) - a histogram is plotted using the X array containing n columns; if the number n is not specified, then 10 intervals are taken by default;
- ✓ [Y, Z] = hist (X, n) - a histogram is built using the X array, containing n columns, with the data saved. The Y variable contains the number of hits in the intervals, and Z - the data on the centers of the intervals;
- ✓ fft (X, n) - returns the n-sharp Fourier transform of array X. If the length of array X is less than n, then the missing elements are filled with zeros. If the length of the X array is greater than n, then the extra elements are removed;
- ✓ cwt (X, A, w) - returns the wavelet coefficients of the X array. A - the scaling parameter array, w - the name of the used wavelet;
- ✓ centfrq (w) - Returns the center frequency for the w wavelet;
- ✓ linspace (a, b, N) - generates an array containing N uniformly distributed numbers from number a to number b;
- ✓ interp1 (X1, Y1, X2, 'method') - returns a vector that contains elements corresponding to elements X2 and obtained by interpolating vectors X1 and Y1, method - interpolation method;
- ✓ detrend (Y) - deletes the constant component of the Y array;
- ✓ convhull (X, Y) - constructs a convex hull from a set formed by X and Y coordinates;
- ✓ [Y1, Y2, Y3 ...] = deal (X1, X2, X3 ...) - sets the correspondence between input variables Xi and output variables Yi
- ✓ zeros (n, m) - creates a matrix containing n rows and m columns, filled with zero elements;
- ✓ ceil (X) - rounds the array X up;
- ✓ floor (X) - rounding of X array downward;
- ✓ diff (X) - returns the difference of adjacent elements of vector X: [X (2) -X (1), ..., X (N) -X (N - 1)], where N is the length of vector X;
- ✓ polyfit (X, Y, N) - returns the coefficients of the polynomial dependence of the degree N of the data array Y on the array of arguments X using the least squares method;
- ✓ polyval (C, X) - returns polynomial values, X - vector of arguments, C - vector of polynomial coefficients;
- ✓ sign (X) - sign function: returns 1 if X is a positive number; returns 0 if X is 0; returns -1 if X is negative;
- ✓ circshift (X, N) - returns a vector containing elements of vector X, shifted by N positions;

- ✓  $[N, M] = \text{findpeaks}(X)$  - finds the local peaks of the vector X, the value of the peak is written to the variable N, and the ordinal number of the peak in the vector X is written to the variable M.

### 3. The purpose of the students' activity in the class:

*The student should know the following:*

1. Matlab as a package of applied programs for solving problems of quantitative analysis in medicine and a programming language of the same name;
2. Matlab - programming language of the same name;
3. the principle of work in interactive mode;
4. a short list of used Matlab functions.

*The student should be able to:*

1. work in Matlab environment
2. be able to form a signal for its processing

### 4. Content of training:

1. Concepts and definitions;
2. Classification of biomedical signals and algorithms for their modeling in the MATLAB environment;
3. A short list of the used functions of the MATLAB environment

### 5. List of questions to check the level of knowledge:

1. What is an algorithm?
2. What is simulation?
3. Formulate what is the physiological process
4. What is a signal, their classification?
6. List of questions to check the final level of knowledge:
  1. Give the definition of the signal.
  2. Types of biomedical signals.
  3. Algorithm for analyzing heart rate variability
  4. Numerical modeling of HRV
  5. A short list of the MATLAB environment functions used to generate HRV

### 7. The practical part.

Develop a signal modeling program (biomedical) in Matlab.

Let us consider the problem of the formation of single impulse processes. Algorithm for solving the problem by means of the Matlab language:

The Matlab Signal package provides several procedures that form data sequences that represent some single impulse processes of standard forms. The `rectpuls` procedure provides a single rectangular pulse. Inversion of the form  $y = \text{rectpuls}(t, w)$  makes it possible to form a vector  $y$  of the signal values of such a pulse of unit amplitude, width  $w$ , centered relative to  $t = 0$  by a given vector  $t$  moments time. If pulse width  $w$  is not specified, it defaults to one. The program for the implementation of the task:

```
t = 0 : 0.01 : 10;  
y = 0.75*rectpuls(t-3, 2)+0.5*rectpuls(t-8, 0.4)+1.35*rectpuls(t-5, 0.8);
```

```

plot(t,y), grid, set(gca,'FontName','Arial Cyr','FontSize',16)
title('Пример применения процедуры RECTPULS')
xlabel('Время ( c )')
ylabel('Exit process Y(t)')

```

The formation of a triangular pulse with a unit amplitude can be carried out using the tripuls procedure, which has the form  $y = \text{tripuls}(t, w, s)$ . The arguments  $y$ ,  $t$ , and  $w$  have the same meaning. The argument  $s$  (-1s defines the slope of the triangle. If  $s = 0$ , or not specified, the triangular pulse has a symmetrical shape. Let's give an example

```

t = 0 : 0.01 : 10;
y = 0.75*tripuls(t-1, 0.5)+0.5*tripuls(t-5, 0.5, -1)+1.35*tripuls(t-3, 0.8,1);
plot(t,y), grid, set(gca,'FontName','Arial Cyr','FontSize',16)
title(' An example of the application of the procedure TRIPULS') xlabel('Время ( c )')
ylabel('Exit process Y(t)')

```

The gauspuls procedure is used to generate a pulse that is a sine wave modulated by a Gaussian function. If we refer to it in the form  $y = \text{gauspuls}(t, fc, bw)$ . Here is an example of creating a single Gaussian pulse:

```

t = 0 : 0.01 : 10;
y = 0.75*gauspuls(t-3, 1,0.5);
plot(t,y), grid, set(gca,'FontName','Arial Cyr','FontSize',16)
title(' An example of the application of the procedure GAUSPULS') xlabel('Время ( c )')
ylabel('Exit process Y(t)')

```

Finally, consider the sinc procedure, which generates a vector of values for the sinc ( $t$ ) function:

```

t=0 : 0.01 : 50;
y1=0.7*sinc(pi*(t-25)/5);
plot(t,y1), grid, set(gca,'FontName','Arial Cyr','FontSize',16)

title(' Function SINC Y(t) = 0.7* SINC(pi*(t-25)/5)') xlabel('Время ( c )')
ylabel('Exit process Y(t)')

```

*Students need to skip the selected scripts in the Matlab system, having previously studied the program interface.*

### **Tasks:**

1. Prepare the intelligence of the card according to the basic theoretical concepts;
2. Study the Matlab software environment - interactive mode and programming mode

### **8. Independent work of students:**

*For the theoretical part of Topic 6 of this guideline, study:*

- ✓ Theoretical foundations of medical signals;
- ✓ Basic concepts of signal theory and Matlab language.

**Topic 6 is designed for three practical sessions.**

*Chronocard of one training lesson:*

1. Organizational moment - 5 min.
2. Current control of knowledge - 30 min.
3. Analysis of the topic - 20 min.
4. Practical work - 30 min.
5. Summing up the results of the lesson - 10 min.

**9. List of educational literature for the lesson:**

1. Kobrinsky B.A., Zarubina T.V. "Medical informatics", M., Publishing house "Academy", 2009.
2. Zhizhin K.S. "Medical Statistics", Higher Education, 2007.
3. Lecture on this topic.

**Topic 7: Digital images in MATLAB, their application in medical research,  
visualization of information processes:  
Fourier transform (PF);  
Windowed Fourier Transform.**

**1. Scientific and methodological substantiation of the topic:**

The theory and practical applications of spectral analysis of time series are used to simulate biomedical signals.

The history of spectral analysis goes back to I. Bernoulli, Euler and Fourier, who was the first to build the theory of the expansion of functions in trigonometric series. However, this decomposition was used for a long time as a mathematical device and was not associated with any physical and biological concepts. Spectral representations were used and developed by a relatively narrow circle of theoretical physicists. ... Harmonic analysis has become the main tool for analyzing real physical processes, and the Fourier transform is the mathematical basis of analysis. The Fourier transform decomposes an arbitrary process into elementary harmonic oscillations with different frequencies, and all the necessary properties and formulas are expressed using one basis function  $\exp(j\omega t)$  or two real functions  $\sin(\omega t)$  and  $\cos(\omega t)$ . Harmonic vibrations are widespread in nature, and therefore the meaning of the Fourier transform is intuitively clear regardless of mathematical analytics. The Fourier transform has a number of remarkable properties. The domain of transformation is the  $L_2$  space of square-integrable functions, and many physical processes in nature can be considered functions belonging to this space. To apply the transformation, effective computational procedures such as the fast Fourier transform (FFT) have been developed. These procedures are included in all packages of applied mathematical programs and are implemented in hardware in signal processors.

It was also established that functions can be expanded not only in terms of sines and cosines, but also in terms of other orthogonal basis systems, for example, Legendre and Chebyshev polynomials, Laguerre and Hermite functions. However, they received practical application only in the last decades of the twentieth century due to the development of computer technology and methods for synthesizing digital linear data processing systems. Directly for the purposes of spectral analysis, such orthogonal functions have not found wide application due to the difficulties in interpreting the results obtained. For the same reasons, functions of the "square wave" type of Walsh, Rademacher, etc. were not developed in spectral analysis.

Theoretical studies of basic systems led to the creation of the theory of generalized spectral analysis, which made it possible to estimate the limits of the practical application of Fourier spectral analysis, created methods and criteria for the synthesis of orthogonal basic systems. An illustration of this is the theory of basis functions of the wave type, which has been actively developing since the beginning of the 80s of the last century. Due to the transparency of the physical interpretation of the analysis results, the similarity to the "frequency" approach in the Fourier transform, the orthogonal waveform basis  $T_{\omega}$  has become a popular and effective tool for signal and image analysis in medicine, acoustics, seismic, and other fields of science and technology.



## 2. Brief theory:

From the standpoint of the analysis of arbitrary signals and functions in the frequency domain power and accurate recovery after the transformations, a number of shortcomings can be noted the decomposition of signals into Fourier series, which led to the appearance of a window Fourier transforms and stimulated the development of the wavelet transform. Os-the most recent of them:

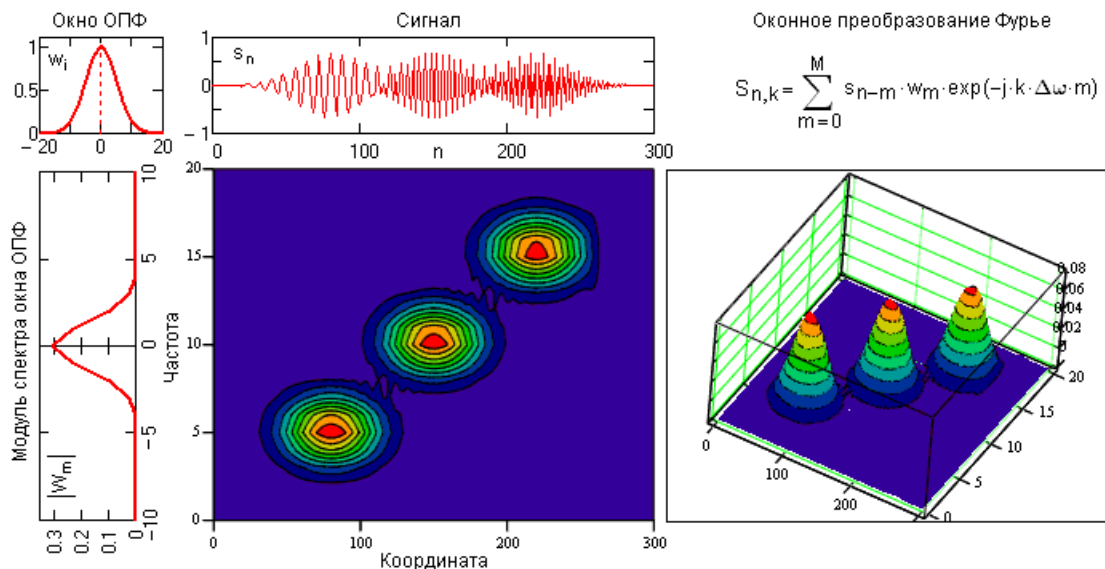
- ✓ Limited information content of the analysis of non-stationary signals and practical there is a complete lack of possibilities for analyzing their features (singular step), because in the frequency domain, there is a "smearing" of the features of the signal catches (breaks, steps, peaks, etc.) over the entire frequency range of the spectrum.
- ✓ Harmonic basis decomposition functions are not capable of displaying re-Signal pads with infinite slope like rectangular impulses, because this requires an infinitely large number of members of the series. With limitation the number of terms of the Fourier series in the vicinity of jumps and discontinuities during reconstruction
- ✓ When the signal is generated, oscillations appear (Gibbs phenomenon). Fourier Transform displays global information about the frequencies of the investigated signal and does not give an idea of the local properties of the signal at rapid strict temporal changes in its spectral composition. So, for example, pre-Fourier formation does not distinguish between a stationary signal with the sum of two sinusoidal from a non-stationary signal with two successively following sinusoids with the same frequencies, since spectral coefficients (2) are calculated by integration over the entire interval of the signal setting. The Fourier transform does not have the ability to analyze the frequency characteristics of the signal at arbitrary times.

Windowed Fourier Transform. A partial way out of this situation is the windowed Fourier transform with a window function moving along the signal and having a compact support. The time interval of the signal is divided into intervals and the conversion is performed sequentially for each subinterval separately. Thus, the transition to the frequency-time (frequency-coordinate) representation of signals is carried out, while within each subinterval the signal is "considered" stationary. The result of the windowing transformation is a family of spectra, which displays the change in the signal spectrum at the intervals of the transformation window shift. This allows you to select on the coordinate axis and analyze the features of non-stationary signals. The size of the window function carrier  $w(t)$  is usually set commensurate with the signal stationarity interval. In essence, by such a transformation, one non-localized basis is divided into a certain number of bases localized within the function  $w(t)$ , which makes it possible to represent the result of the transformation as a function of two variables - the frequency and the time position of the window.



An example of a windowed transformation for a non-stationary signal at a high noise level is shown in Fig. 5. By the spectrum of the signal, one can judge the presence of harmonic oscillations at three frequencies in its composition, determine the ratio between the amplitudes of these oscillations and concretize the locality of oscillations by the signal interval. The coordinate resolution of the window transformation is determined by the width of the window function and is inversely proportional to the frequency resolution. When the width of the window function is equal to  $b$ , the frequency resolution is determined by the value  $\Delta\omega = 2\pi / b$ . At the required value of the frequency resolution  $\Delta\omega$ , respectively, the width of the window function should be equal to  $b = 2\pi / \Delta\omega$ . For the windowed Fourier transform, these restrictions are fundamental. So, for Fig. 5 with the size of the data array  $N = 300$  and the width of the window function  $\Delta b = 100$ , the frequency resolution of the transformation results decreases by  $N / \Delta b = 3$  times compared to the initial data, and the  $Sw$  ( $n \times \Delta b \times Sw$ ) graphs along the  $n$  coordinate for a visual comparisons with the graph  $S$  ( $n \times \Delta b \times S$ ) are constructed with a frequency step  $\Delta\omega_{Sw} = 3 \times \Delta\omega_S$ , i.e., along the points  $n = 0, 3, 6, \dots, N$ .

The coordinate resolution of the window transformation is determined by the width of the window function and, due to the Heisenberg uncertainty principle, is inversely proportional to the frequency resolution. The optimal OPF is considered to be with a Gaussian window, which is called the Gabor transform. An example of transformation is shown in Fig. 6 (in a discrete version of calculations).



In fig. shows an example of the calculation and presentation (modulus of the right side of the main spectrum range) of the spectrogram results with a discrete setting of the noisy input signal  $s_q(n)$ . The signal is the sum of three consecutive radio pulses with different frequencies without pauses, with a signal-to-noise ratio close to 1. The window function  $w_i$  is set in a one-sided version with an effective window width  $b \approx 34$  and a total size of  $M = 50$ . The frequency step set for the results  $\Delta\omega = 0.1$  is slightly higher than the actual resolution  $2\pi / M = 0.126$ . To ensure the operation of the window function over the entire signal interval, the initial and final computational conditions were set (extension of both ends of the signal by  $M$  points by zero values).

The effective work of a medical specialist today implies knowledge not only of medical disciplines, but also a good command of the skills of automated processing of medical data.

The purpose of the practical lesson is to study the theoretical foundations of the principles of spectral analysis and practical application in quantitative medicine.

### 3. The purpose of the students' activity in the class:

*The student should know:*

1. Why does a medical specialist need the skills to carry out spectral transformations in their work?
2. The main structure of the Matlab package
3. Program interface, interactive and program mode of operation

*The student should be able to:*

1. Own basic tools for creating, editing, formatting signals and images in the Matlab package.
2. Be able to understand the theoretical description of spectral transformations - Fourier transforms.

### 4. Learning content:

- ✓ Basic concepts and definitions

- ✓  Creation of an image and a signal based on the results of work with medical equipment and biological processes.

### 5. List of questions to check the initial level of knowledge:

1. What is Spectral Analysis?
2. The role of information technology in biomedical research.

### 6. List of questions to check the final level of knowledge:

- ✓  Give mathematical definitions of spectral functions and transformations
- ✓  List the functions of the MATLAB package that generate spectral functions and transformations of original medical signals.

### Practical part:

Formation of medical signals and images by means of spectral functions and transformations.

**PROBLEM:** Consider the problem of mathematical modeling of a medical image using Matlab functions.

Fourier image of a rectangular pulse. Let's form a process consisting of a single rectangular pulse. Let us set the time discrete  $T_s = 0.01$  s, the process duration  $T = 100$  s, the pulse amplitude  $A = 0.75$  and its width  $w = 0.5$  s:

Listing of the program in Matlab:

```
Ts=0.01;
T=100;
A=0.75;
w=0.5;
t=0 : Ts : T;
y = A*rectpuls(t, w);
plot(t(1:100),y(1:100)), grid, set(gca,'FontName','Arial Cyr','FontSize',16),
title('Процесс из одиночного прямоугольного импульса ');
xlabel('Время (с)');
ylabel('Y(t)')
```

Let's apply the fft procedure to the vector  $y$  and plot the dependence of the modulus of the result on the frequency. At the same time, it is more convenient to display graphs in the frequency domain using the stem procedure

```
x=fft(y);
df=1/T;
Fmax=1/Ts;
f=0 : df : Fmax;
a=abs(x);
stem(f,a), grid, set(gca,'FontName','Arial Cyr','FontSize',14),
title('Модуль FFT-преобразования прямоугольного импульса ');
xlabel('Частота (Гц)');
ylabel('Модуль')
```

Now let's build a graph of the Fourier image module of the process:

```

xp=fftshift(x);
f1=-Fmax/2 : df : Fmax/2;a=abs(xp);
stem(f1,a), grid, set(gca,'FontName','Arial Cyr','FontSize',14),
title('Модуль Фурье-изображения прямоугольного импульса ');
xlabel('Частота (Гц)');
ylabel('Модуль')

```

Let's build the graphs of the real and imaginary parts of the Fourier image of a rectangular pulse:

```

dch=real(xp);
mch=imag(xp);
plot(f1,dch,f1,mch), grid, set(gca,'FontName','Arial Cyr','FontSize',16),
title('Фурье-изображение прямоугольного импульса ');
ylabel('Действит. и Мнимая части'), xlabel('Частота (Гц)');

```

The purpose of the work is to teach students some possibilities of processing and evaluating biomedical signals in the MATLAB environment. The knowledge and skills obtained in the course of this work can be used to study not only biomedical signals, but also signals of a different physical nature from various fields of science and technology.

Students need to skip the selected scripts in the Matlab system, having previously studied the program interface.

#### **Tasks:**

1. Prepare the intelligence of the card according to the basic theoretical concepts;
2. Study the Matlab software environment - interactive mode and programming mode.

#### **8. Independent work of students:**

*For the theoretical part of Topic 7 of this guideline, study:*

- ✓  Theoretical foundations of medical signals;
- ✓  Basic concepts of the spectral theory of signals and images
- ✓  The main functions of the Matlab language on the topic under consideration.

#### **Topic 7 is designed for four practical sessions.**

*Chronocard of one training lesson:*

1. Organizational moment - 5 min.
2. Current control of knowledge - 30 min.
3. Analysis of the topic - 20 min.
4. Practical work - 30 min.
5. Summing up the results of the lesson - 10 min.

#### **9. List of educational literature for the lesson:**

1. Kobrinsky B.A., Zarubina T.V. "Medical informatics", M., Publishing house "Academy", 2009.
2. Zhizhin K.S. "Medical Statistics", Higher Education, 2007.