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INTELLIGENT DECISION-SUPPORT SYSTEM FOR EPIDEMIOLOGICAL DIAGNOSTICS. I. A CONCEPT OF ARCHITECTURE DESIGN*

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Abstract. *The problems of decision support for epidemiological diagnostics are investigated. The basis for supporting decision-making is mathematical tools for analyzing morbidity data, as well as modeling of epidemic processes. The current state of research in this area is analyzed. The features of decision-making in epidemiology and public health are formalized. Principles for the development of an intelligent information system for decision-making support for epidemiological diagnostics are proposed. A systemic model of the system, a model of the interaction of elements of the epidemiological diagnostics system and the interaction of logical components of the information system has been developed. Taking into account the identified features of these processes, the concept of the architecture of such an intelligent information system is proposed.*

Keywords: *decision support system, epidemic monitoring, infectious diseases control, information system, epidemic model.*

INTRODUCTION

The object of the research is the process of decision-making in epidemiological diagnostics.

The epidemic control system architecture is the subject of the paper. The main tasks of epidemiological diagnostics are to assess the current epidemic situation, identify causal relationships due to which it has developed, and analyze risk factors, that is, factors whose effect on the epidemic situation determines the probability of its complication.

In the modern period of human development, permanent social changes are taking place in society. The reasons for the changes are an increase in the level of digitalization of human life, communication using information systems, digital transformations of public services and states, the availability of travel around the world, etc. In addition, the global COVID-19 pandemic has shown the world that it is not ready for challenges of this magnitude. Changes affect the evolution of the epidemic process and should be taken into account when carrying out measures aimed at curbing the spread of infections among the population. To solve these problems, epidemiological diagnostics is used [1, 2]. The direct driving forces of the epidemic process itself are the source of infection, the transmission mechanism, and the

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susceptible human body, which create a chain of successive infections [3]. Without these links, the existence of the epidemic process is impossible.

The aim of the paper is to discuss the developed architecture of the intelligent information system for epidemiological diagnostics, taking into account the peculiar properties. By architecture we mean the basic organization of the system, embodied in its components, their relations between themselves and the environment, as well as the principles that determine the design and development of the system. By peculiar properties we mean various characteristics of the architecture in a given domain (epidemiology and Public Health), including performance, remote accessibility, security and personal data protection issues, etc.

The architecture of data storage and processing for intelligent information system of epidemiological diagnostics is, first of all, the delivery of data storage resources on demand in a highly-scaled and multi-tenant environment (the ability to serve users in isolation) [4–7]. The main task of the proposed information system is to collect the data about new cases of infectious diseases from the National system of the infectious morbidity center and medical institutions to preprocess, analyze, and investigate it to generate recommendations of effective grounded counter-measures.

The concept of developing a decision-support system for the epidemic morbidity control was proposed in [8]. The most important stage in the creation of such a system is the substantiation of its architecture. By architecture we mean the basic organization of the system, embodied in its components, their relations between themselves and the environment, as well as the principles that determine the design and development of the system.

Structurally, architecture is usually defined as a set of solutions of the following tasks:

— the purpose of the system (described in Sec. 2);
— components of the system (described in Sec. 3.1);
— interaction of the components (described in Sec. 3.1);
— location of the components (described in Sec. 3.2).

Thus, the IIS architecture is a logical structure, or model, and affects the total cost of ownership through a set of related decisions on the choice of implementation tools, data bases, operating platform, telecommunications facilities, etc., that is, through the fact that we call IIS infrastructure. At the same time, the infrastructure includes solutions not only for software, but also for hardware and organizational support.

The paper is structured as follows. Section 1, namely current research analysis, provides a brief overview of the current state of epidemic process models and intelligent information systems development. Section 2 discusses the peculiar properties of decision-making in epidemiological diagnostics. Section 3 proposes the concept of the architecture design of intelligent information system of epidemiological diagnostics. Conclusions describe outcomes of the proposed architecture design.

1. CURRENT RESEARCHES

In the design of the architecture of medical systems, scientists are engaged in the development of digitalization in this area. The article [9] presented the results of the development of theoretical and practical foundations for the design of medical information systems. Particular attention was paid to the formalization and modeling of various stages of the treatment and diagnostics process and development of information tools for the analysis of medical data on the health of the population of Ukraine.

The authors of the paper [10] proposed four architecture views for Health Information System, based on hospital information system. Each view shows the architecture of the HIS from a different angle, suitable for various stakeholders. Also, the research discusses various issues of architecture development for healthcare, such as supporting emergency medical services staff at the incident location from a remote Competence Centre [11], integration and interoperability, which are the most important requirements of healthcare organizations and their systems [12], remote access to medical information systems by network-based system architecture adopting wireless personal area network and 3G communication networks for remote medical applications [13], etc.

Date handling is the most challenging problem when designing the architecture of medical systems. Different architectures and approaches to work with data are proposed: architecture of medical big data Hadoop-based data warehouse [14], security aspects of using medical systems [15], the data architecture of the National mental health information systems in different countries [16], architecture of medical data transfer [17].

Most of the studies analyzed are aimed at medical diagnostic systems and do not take into account the specifics of epidemiology and public health.

However, scientists have been engaged in the construction of intelligent information systems to support decision-making before that. The article [18] is devoted to the development of the mathematical methods of representation, processing, classification, clustering, and transmission of various communication information, as well as creation on their basis of the new applications for the existing operating systems or their add-ons. The proposed methods and algorithms made it possible to improve the available tools and propose new ones for converting communication information to create interfaces with a computer environment in text, voice, and visual forms. A. V. Palagin et al. proposed a functional approach to research design based on the technology of scientific and technical creativity with its morphological and transformational methods [19]. The use of the proposed transdisciplinary approach made it possible to provide significant information technology support at the main stages of research-related design.

One of the challenges in the design of an intelligent system for epidemiological diagnostics is the development of tools and methods for presenting information for an information system about epidemiology and public health in the form of knowledge focused on solving problems in this subject area. In the paper [20], the domain model and possible problems can be formalized using a mathematical scheme presented in the form of appropriate categories. For correct interpretation, an ontological description in the form of knowledge is used, because even when a solution to a problem exists at the level of the logic used, it cannot always be determined at the level of a complete solution, including an ontological description.

The article [21] describes the technology of objective functional assessment of a patient at home, which can be useful for designing data transfer in our information system. A new approach to the analysis of information and telecommunication needs of the community, introducing concepts such as the Scenario for the provision of information services, which determines the totality of user needs for information services and telecommunications is proposed in [22]. The proposed strategy defines the ways to implement the current Scenario based on the available telecommunication resources.

The proposed architecture design eliminates the drawbacks of the models of current epidemic processes and takes into account previous outcomes on information systems development.

2. THE CONCEPT OF DECISION-SUPPORT SYSTEM OF EPIDEMIOLOGICAL DIAGNOSTICS

Epidemiological diagnostics is associated with many difficulties that arise for decision-makers, because with the rapid development of the epidemic process of dangerous diseases epidemics pose a very significant threat to human life and health. At the same time, long-term quarantine and restrictive measures causes colossal economic losses that stop the economic life. That is why decisions in epidemiological diagnostics require special accuracy and preliminary risk assessment, because the consequences of wrong decisions can bring not only significant economic losses, but also a threat to the life and health of many people.

To take into account the influence of uncertain factors, as well as for the calculation and modeling of many epidemiological indicators, it is proposed to use a decision-support system that will help decision-makers to choose a rational assessment strategy and anti-epidemic measures. The proposed decision-support system will be based on the mechanisms of the corresponding mathematical apparatus, in particular, random processes and fields, machine learning methods, fuzzy logic, game theory, optimization methods, etc.

A decision support system is defined as a man-machine system that allows managers to use their knowledge, experience, and interests, objective and subjective models, and data for the implementation of computer methods of decision-making [23]. The sources [24, 25] define it as a computer program that can organize and sort large amount of data in order to provide companies and organizations with assistance in making decisions based on data. Different interpretations of the terms can be explained by the wide scope of application of decision-support systems in human activity and different functional requirements for such systems.

The paper [23] proposes the following classification of the models on which the decision-support system is based: the “as is” model, the “as it should be” model, and the “decision-making problem” model. To build models of the first type, data mining is widely used, which is defined as a decision-support method based on the analysis of dependencies between data. At the same time, the analysis of the situation is the most important stage in supporting decision-making.

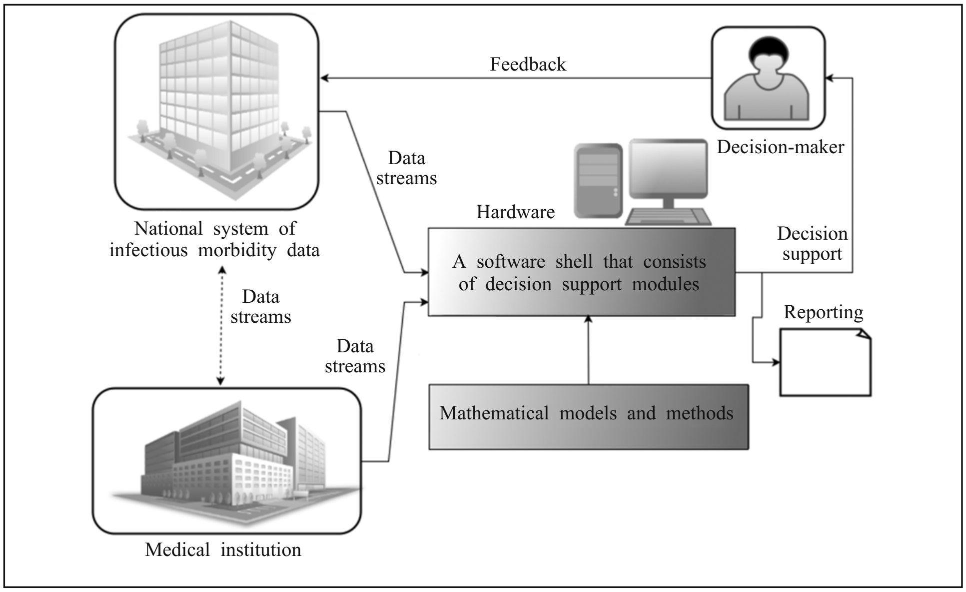

Fig. 1. Diagram of the interaction of elements of the epidemiological diagnostics system.

In the context of epidemiological diagnostics, decision-support system should have a number of functions:

— analysis of factors influencing the development of epidemic threats and problems of society's biosafety;

— determination of the mortality rate caused by infectious diseases (the information of the State Statistics Service of Ukraine on the general mortality rate, statistics in other countries, etc. are analyzed);

— assessment of the number of asymptomatic infected individuals (the correlation of tests and the number of patients in Ukraine and in other countries is analyzed, such as tests and testing methods);

— calculation of the base reproductive number (the scenarios of the development of epidemics in different countries are compared, the changes in virulence and the rate of mutation of the pathogen are determined);

— calculation of the recovery index (determined by statistical methods based on morbidity statistics);

— generation of scenarios for the development of infectious diseases for different values of the input data;

— calculation of the percentage of cases detected (determined by the comparative analysis of statistical data on morbidity in Ukraine and other countries, taking into account testing methods);

— imitation of decisions made and assessing the consequences of such decisions; support for feedback from the decision-makers (Fig. 1); use of data mining.

The main factors that determine the need for decision support in epidemiological diagnosis are:

— the epidemic process is characterized by stochastic dynamics, which makes it difficult to predict;

— models and systems created to support decision-making allow experiments on epidemic processes, which cannot be done on real processes;

— with a large number of factors influencing the epidemic process, decision-maker expert knowledge may not be enough;

— factors of the influence on epidemic processes are poorly formalized, which makes it difficult to take into account the influence of certain factors when making decisions.

To make evidence-based decisions on control measures, it is proposed to use the banks of simulation models, which are divided into two groups: machine learning models and population dynamics models.

The global COVID-19 pandemic has stimulated many studies towards the analysis of epidemic processes. For example, the paper [26] implements the SEIR model for calculating the infected population and the number of victims of the COVID-19 epidemic in Italy. The authors assume that the parameters of the model will not change throughout the entire epidemic; however, we see that this hypothesis is false since the virulence of the virus changes with the emergence of new strains. The current data on infected cases of COVID-19 in the Kingdom of Saudi Arabia using a new Gaussian curve fitting method are analyzed in [27]. The results show that the expected pandemic curve is flattening. The disadvantage of the proposed method is that it does not take into account the control measures used to contain the epidemic dynamics that affect the further development of the pandemic. Authors of the article [28] proposed a model that considers eight stages of infection: susceptible (S), infected (I), diagnosed (D), ailing (A), recognized (R), threatened (T), healed (H), and extinct (E), collectively termed SIDARTHE. The main disadvantage of the proposed approach is the high complexity of the model. This does not allow making operational changes to it in the context of changing rules for the spread of the epidemic process, and taking into account the implemented control measures. The compartment model of COVID-19 epidemic process with geo parameters is proposed in [29]. The disadvantage of the study is the impossibility of scaling of the proposed model to other territories.

Despite the drawbacks of current researches, some of them propose novel outcomes and methods, which can be useful in designing the information decision-support system of epidemiological diagnostics. A model for the spread of infection, generated using Markov field tools, is described in [30]. The authors have developed a practical algorithm based on a stochastic quasi-gradient method for solving convex stochastic programming problems for the numerical search for an estimate of the Gibbs distribution using the maximum likelihood method for describing hidden carriers of infection.

The paper [31] proposes different lockdown scenarios based on the compartment model. The results suggest that reducing work contacts is more efficient for mitigating the disease burden than reducing school contacts, or implementing shielding for people over 60. But the authors do not consider the estimated number of real, not registered infected individuals.

In conducting epidemiological diagnostics, the concept of the efficiency of decision-making is important. There are various approaches to the definition of efficiency [32]. Efficiency is defined as the conformity of the result or process to the maximum possible, planned or ideal; efficiency is understood as a certain, specific result. Efficiency is considered as a certain numerical characteristic of the satisfactory operation of the system under certain conditions. Target efficiency is understood as the degree of correspondence between the operation of the system under study and its purpose, that is, the measure of achieving the research aim.

To increase the target efficiency of decision-making when conducting epidemiological diagnostics, it is necessary to use more complete and accurate models and methods than existing ones, as well as to increase the efficiency of processing large amount of data through the use of appropriate means.

For more convenient decision-making in biosafety, a software implementation in the form of a web application is planned. To be able to be used by users who do not have special mathematical training, a user-friendly interface and documentation of the software product is being developed.

3. DESIGN OF THE INTELLIGENT INFORMATION SYSTEM FOR EPIDEMIOLOGICAL DIAGNOSTICS ARCHITECTURE

Depending on the field of application, intelligent information systems can differ greatly in their functions and architecture; however, it is possible to distinguish common features that are characteristic of all modern intelligent information systems.

The main features of modern intelligent information systems are as follows:

- information processing by means of computation technologies;
- storage of large amount of information on servers;
- transmission of information to any distance in the shortest possible time.

In the realities of modern technical development of the society, the development of any information technology is impossible without the use of software.

Large projects that use software can be characterized by the following general properties [33]:

- the complexity of the description and formalization of the subject area;
- the presence of a large set of components that closely interact with each other;
- limited use or complete absence of similar software products with an atypical task that needs to be automated;
- significant length of the project in time;
- the information needs of users of such software may experience permanent changes associated with changes in the external environment.

TABLE 1

Tools for Data Processing	Stages of Data Processing in Intelligent Information System of Epidemiological Diagnostics and Models and Methods Used			
	Data formation	Organization of data storage	Data manipulation	Data transmission
Scope of Work with Intelligent information system	1. Data preprocessing and data mining: — data cleaning; — data optimization; — data normalization. 2. Formation of data structures depending on the class of the disease	1. Data warehouse infrastructure development. 2. Loading data into a data warehouse from different databases. 3. Arranging access to the repository	1. Analysis of morbidity by classes of diseases. 2. Development of machine learning models for epidemic processes. 3. Development of agent-based models of epidemic processes. 4. Formation of a database of recommendations for the epidemic diseases control	1. Saving and displaying simulation results. 2. Formation of reports on the carried-out simulation
Models and methods used	Data mining models Data preprocessing methods	Standard data warehouse technologies	Machine learning models for analyzing epidemic data Methods for analyzing factors influencing the epidemic process	Standard data transmission technologies

In addition, the introduction of personal computers and various software into the information sphere leads to additional requirements for intelligent information systems today, such as:

— integration of intelligent information system with various software tools;
— interactivity of the developed intelligent information system;
— flexibility to changes in input data and problem settings.

3.1. Concept of the Intelligent Information System for Epidemiological Diagnostics. Intelligent information system for epidemiological diagnostics will contain all the characteristics described above: information processing will be carried out using the developed decision-support modules; data storage will be implemented using a data warehouse; remote and simultaneous access of many users will be implemented using a web application; the results of the work will be presented in the form of recommendations, reports, graphs, and will facilitate data transfer; the results obtained can be drawn up in the form of documents for their further processing; interactivity will be achieved by the presence of a large number of dialog boxes and interconnected modules; flexibility to changes in input data and problem statements will be achieved by the presence of dynamic control, which will allow changing decisions during the modeling process. Intelligent information system will be a flexible mechanism in relation to the input data, providing a solution for the tasks of analytical activities of a different plan and varying degrees of complexity under uncertainty. This intelligent information system will be flexible with respect to input data and will provide support for solutions for problems of various types and degrees of complexity. Thus, the main users of the intelligent information system will be decision-makers in epidemiological diagnostics (for example, epidemiologists and public health specialists). Intelligent information system for epidemiological diagnostics will contain stages of data processing, described in Table 1. Work with an intelligent information system consists of four stages.

Stage 1. Data Formation. At this stage, data preprocessing and data mining are carried out: if necessary, data cleaning, data optimization and normalization are carried out. At the same stage, data structures are formed depending on the class of the disease.

Stage 2. Organization of Data Storage. The collected data are loaded into the data warehouse. The data are stored in an accessible form for further data processing. Separate decision-support modules are combined in a common software shell, which allows the user to select the necessary module for making calculations, implemented by each decision-support module.

Such an approach allows the user to use all the intelligent information system tools as a whole, inside one shell. The transfer of information between individual decision-support modules is convenient for the user, who at any time can revise the result of the work and save the information in the form of a report or a graph.

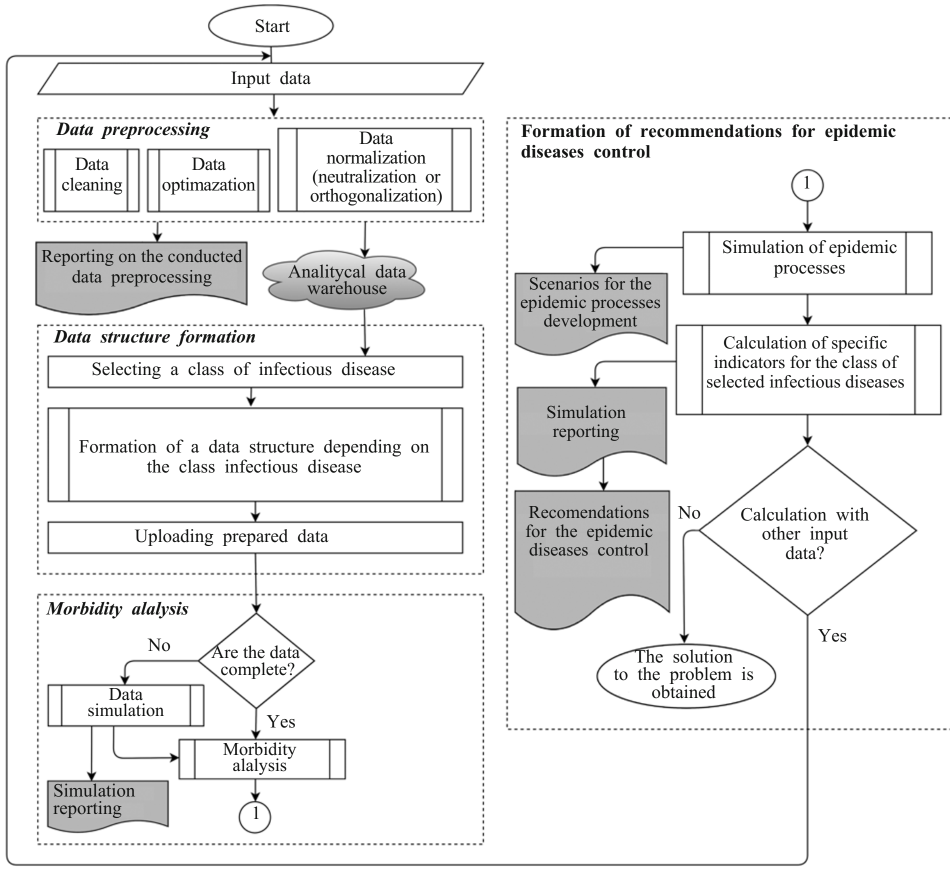

Fig. 2. System model of information and analytical support of the decision-making process in epidemiological diagnostics.

Stage 3. Data manipulation is implemented using separate decision-support modules, which are parts of a common software shell. This stage includes the following tasks.

1. Analysis of morbidity by classes of diseases.
2. Development of machine learning models for epidemic processes.
3. Development of agent-based models of epidemic processes.
4. Formation of a database of recommendations for the epidemic diseases control.

The decision-support modules generate a base of decision-maker recommendations and support the correction of management decisions during the modeling process, as it is described in [8].

Stage 4. Data Transmission. At this stage, reports are generated, which are submitted in the form of tables, graphs, and various documents.

Figure 2 demonstrates a systemic model of information and analytical support for the decision-making process in epidemiological diagnostics. After entering the input data, they are prepared for use, reports are generated on data preprocessing (if used), and the data are transferred to the storage in a prepared analytical form. Further, the decision-maker selects a class of infectious disease for modeling; depending on this, data structures are formed according to the class and loaded into models. There is an analysis of morbidity, simulation of epidemic processes, and direct calculation of specific indicators of the selected class of infectious disease: determination of the mortality rate from infectious diseases; assessment of the number of asymptomatic infected individuals; calculation of the base reproductive number; recovery index calculation; calculation of the percentage of cases detected, as well as forecasting the dynamics of the spread of infectious morbidity in accordance with various scenarios of the adopted anti-epidemic measures.

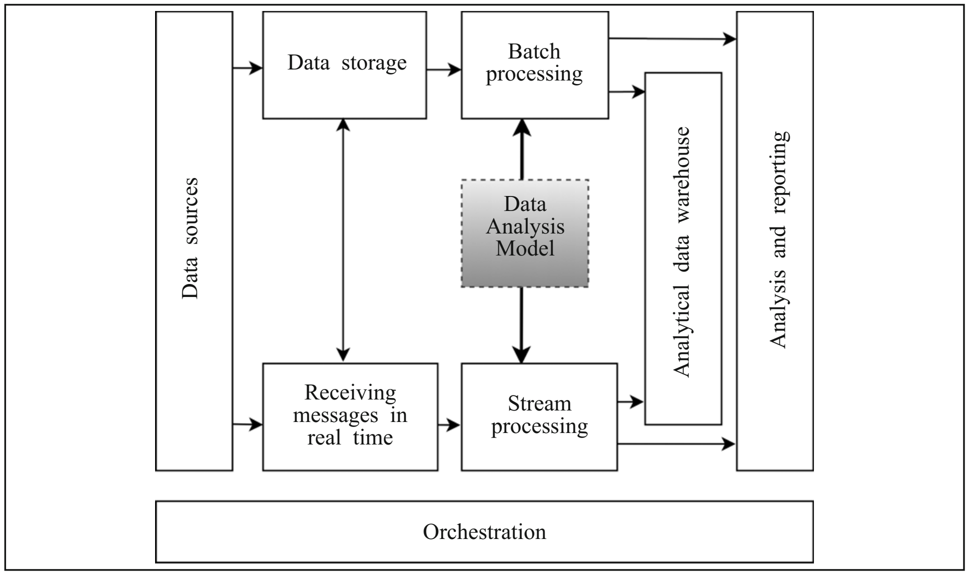

Fig. 3. Diagram of the interaction of the logical components of intelligent information system of epidemiological diagnostics.

To carry out calculations on another set of input data, the transition to the processing of a new set of data is carried out or the work with the intelligent information system stops, depending on the decision of the decision-maker.

3.2. Intelligent Information System of Epidemiological Diagnostics Architecture Concept. For intelligent information system of epidemiological diagnostics, it is proposed to use the architecture of a system for processing large amount of data, which allows receiving, processing, and analyzing data that are too voluminous or too complex for traditional database systems. The data landscape has changed over the years. In addition, there are new possibilities for data handling. The cost of storage has dropped significantly, while the cost of data collection and processing continues to rise. Some data come in at an accelerated rate and needs to be collected and viewed all the time. Other data arrive more slowly, but in very large blocks. Sometimes it is necessary to use data from medical journals over a decade. It might be experiencing an advanced analytics issue or a problem that requires the use of machine learning to solve. These are the tasks that the architecture of a system for processing large amount of data is designed to solve.

Big data solutions are typically designed for one or more of the following workload types:

— batch processing of inactive big data sources;
— processing of big data in real-time dynamics;
— interactive exploration of big data;
— predictive analytics and machine learning.

It is also possible to use the architecture of a large data processing system for the following scenarios:

— storing and processing data in the amount too large for a traditional database;
— converting unstructured data for analysis and reporting;
— recording, processing, and analysis of unattached data streams in real time or with low latency.

The diagram (Fig. 3) shows the logical components that are included in the architecture of the system for processing large amount of data and can be used for intelligent information system of epidemiological diagnostics. Individual solutions in the future may not contain all the components of this scheme.

The architecture of intelligent information system of epidemiological diagnostics has the following components.

1. Data Sources. All big data processing solutions start with one or more data sources. Examples are given below:

— application data stores, such as non-relational databases;
— static files that are generated by applications, such as statistics log files;
— real-time data sources.

In this case, the data sources contain information on the spread of infectious diseases.

2. Data Warehouse. Data for batch processing are usually stored in distributed file storage, which can contain significant amount of large files in various formats.

3. Batch Processing. Since the datasets are very large, intelligent information system often processes lengthy batch tasks. For them, filtering, statistical processing, and other processes of preparing data for analysis are performed. Typically, these tasks include reading the source files, processing them, and writing the output to new files.

4. Receiving Messages in Real Time. If the solution contains real-time sources, the architecture must provide a way to collect and store messages in real time for streaming processing. To receive incoming data, many solutions require storage that can be used as a buffer. Such storage must support scale-out processing, reliable delivery, and other message queue semantics. This part of the streaming architecture is often referred to as stream buffering.

5. Data Stream Processing. Having saved messages arriving in real time, the intelligent information system performs filtering, statistical processing, and other processes for preparing data for analysis for them. The processed streaming data are then output to the bin.

6. Warehouse of Analytical Data. In the intelligent information system, the data are being prepared for analysis. The processed data are then structured according to the format of requests from analytics tools. The analytics store used to process such queries that can be a relational database like Kimball, as can be seen in most traditional business intelligence solutions. In addition, data can be represented using low latency NoSQL technology such as HBase or Hive Interactive Database, which provides a metadata abstraction for data files in distributed storage.

7. Analysis and Reporting. Most big data processing solutions are designed for analysis and reporting, allowing intelligent information system to obtain important information. To expand the capabilities of intelligent information system in the direction of data analysis, data analysis models were included in the simulation architecture. Analysis and reporting can also be performed by interactively examining the data by experts.

8. Orchestration. Most big data processing solutions consist of repetitive workflows that transform the original data, move the data between multiple sources and sinks, load the processed data into an analytic data warehouse, or feed the results directly to a report or dashboard.

CONCLUSIONS

It has been shown that epidemiological diagnostics is associated with many difficulties in decision-making by epidemiologists and public health specialists. The main factors that determine the need to support decision-making in epidemiological diagnostics are presented, which in turn imposes additional conditions on the development of intelligent information system. It has been established that the intelligent information system for epidemiological diagnostics should contain a module with recommendations for decision-makers, based on data mining. The analysis of the features of modern intelligent information systems and the identified characteristics that should be in a modern intelligent information system are carried out.

A number of functions that will support intelligent information system have been determined. The diagram of the interaction of the elements of the epidemiological diagnosis system has been presented. Based on the analysis, the concept of intelligent information system for epidemiological diagnostics has been developed and it has been established which decisions can be made by the decision-makers using the intelligent information system and what information will be received. The stages of data processing for the intelligent information system of epidemiological diagnostics are determined and formalized, and the corresponding models and methods for each stage are presented. A systematic model of information and analytical support for the decision-making process in epidemiological diagnostics has been developed.

The architecture of the epidemiological diagnostics information system has been designed. The architecture components have been presented. It is proposed to use the architecture of a system for processing large amount of data, which allows receiving, processing, and analyzing data that are too voluminous or too complex for traditional database systems. The diagram of the interaction of the logical components of IIS for epidemiological diagnostics is presented.

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