Medical Transdisciplinary Cluster Development for Multivariable COVID-19 Epidemiological Situation Modeling

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***Abstract* — The paper proposes to solve the relevant problem of providing public access to scientific and technical information about coronavirus infection by means of cognitive tools for the formation of network-centric management system of distributed processes of accumulation, systematization, storage and presentation of various knowledge-oriented resources, namely medical transdisciplinary cluster that will present current COVID-19 data. It will be harmoniously integrated and synchronized in content with other multilingual information resources and network digital arrays based on interoperability protocols of interaction to form a holistic view of the pandemic. The developed knowledge system will provide organization, processing, analysis and visualization of data and information that extend the methods of COVID-19 research, including prognostic modelling based on the principles of mathematical epidemiology taking into account regional, age and other features of the epidemic process.**

Keywords — transdisciplinarity, ontology, cluster, knowledge, network resources, coronavirus (COVID-19), mathematical epidemiology, prognostic modelling

I. Introduction

At the beginning of 2020, one of the most pressing problems for humanity was the new coronavirus infection COVID-19, which humanity had not encountered before. So, in December 2019, an outbreak of SARS caused by an unknown type of coronavirus, called Coronavirus 2019-nCoV, which was subsequently renamed SARS-CoV-2, was recorded in the Wuhan, China. Very quickly, SARS-CoV-2 spread beyond China and spread to all continents of the world (except Antarctica) and hit the populations of developed countries such as the USA, South Korea, Italy, Spain, Germany, Great Britain, Iran, Japan, countries of Central and Eastern Europe, including Ukraine. On March 11, 2020, WHO announced the COVID-19 pandemic. In less than 5 months from the first reports of cases of a new respiratory disease, as of May 6, 2020, the incidence of COVID-19 in the world is approaching 4 million cases and is 3,778,016 with a mortality rate of about 7%, which ranges from 4.17% in Germany up to 13.8% in Italy. According to the Center for Public Health (CPH), 13184 cases of COVID-19 were registered in Ukraine on the same date, 327 people died, mainly the elderly with chronic concomitant diseases (mortality 2.48%). [1]

Therefore, identification of features, substantiation of approaches to mathematical modelling and information technology development for comparative analysis and the coronavirus infection COVID-19 epidemic process forecasting based on existing domestic and world trends and available epidemiological data, combined into a cognitive network-centric system for managing distributed processes of accumulation, systematization, storage and access to various informational knowledge-oriented resources (COVID-19 Transdisciplinary Knowledge Cluster) are relevant.

This study provides comprehensive collection, integrated use and aggregated presentation of multylingual information resources from open sources based on cognitive procedures of semantic-linguistic analysis of spatially distributed unstructured medical information of various domains, its structuring and classification based on establishing contextual relations between medical documents and medical systems knowledge, forecasting and support of rational choice processes in assessing medical processes related to the versatile understanding of COVID-19 in Ukraine and the world, justification and development of a relevant mathematical model of the COVID-19 epidemic process, verification of the validity of the developed model and analysis of regional modelling features, creation and implementation of the information technology for comparative analysis and forecasting of the coronavirus infection COVID-19 epidemic process in healthcare practice.

The structure of the paper is the following: Section 2 gives analyses of related works and backgrounds for the research. Section 3 describes main characteristic features of COVID-19 Transdisciplinary Knowledge Cluster. In section 4, the methods that are used for COVID-19 Transdisciplinary Knowledge Cluster development are given. Section 5 describes expected result of the research implementation. Section 6 presents conclusions and plans for future work.

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II. State of Art and Related Works

At present, the results of scientific research, theoretical and practical developments aimed at improving knowledge about the coronavirus are disseminated by means of "scientific communication" that is a complex system, the environment of which is designed to facilitate the intellectual exchange of information through a wide range of networked IT tools primarily between experts and specialists. Today, many specialized resources (websites, electronic libraries, knowledge bases, etc.) related to COVID-19 and intended for the needs of clinicians and medical organizations (dissemination of experience, comparison of practices and protocols, etc.) have appeared on the Internet, the content of most of them is not reviewed by medical professionals for accuracy and relevance. The World Health Organization has already taken the first steps in establishing a multilingual coronavirus database in collaboration with leading medical organizations, but the process is still ongoing [2]. Numerous organizations such as Pan American Health Organization, Bloomfire, Fraunhofer Institute for Algorithms and Scientific Computing SCAI, Startup Genome, Scientific Knowledge Services, etc. have created databases and knowledge about coronavirus, the functionality of which allows you to search for content by keywords or tags, but most of them use their own software, requiring from the user certain knowledge or experience with databases of this kind and complicates the process of aggregation of information resources into a single virtual environment.

And although today there are many online resources in different languages that provide free (or relatively free) access to materials about the coronavirus, there is no single publicly available unified information space of open access to modern advances in medicine. This is primarily due to the heterogeneity and lack of interoperability of information resources and systems to ensure their availability when searching on the World Wide Web.

However, although the modern consumer of information seeks to receive it immediately and in full, rather than looking for scattered sites, the origin of information, its reliability, validity of expert opinion, availability of the original source in any language of knowledge in it assumes new significance. Therefore, the urgent task is to develop software and information tools to ensure compatibility and interoperability of data based on a transdisciplinary model of integration of physically and thematically distributed network of multilingual information resources created in different formats, according to different standards and technologies to form a COVID-19 Transdisciplinary Knowledge Cluster.

It is important to emphasize that the development of COVID-19 specific prophylaxis has not yet been completed, and no effective etiotropic antiviral drugs for the treatment of critically ill patients have been invented. Therefore, the peak incidence in the world has not passed yet, and it is not known for how long the COVID-19 pandemic will last. Well-known WHO experts predict a new wave of SARS-CoV-2 in the second half of 2020. This situation is fully applied to Ukraine. Extremely important and urgent task for the health of Ukraine was to predict the possible further development and features of the epidemic process based on available (official) epidemiological data and build a prognostic model of the COVID-19 epidemic process in Ukraine.

Recently, ontological models have become one of the most promising approaches to solve problems of information representation, storage and search. Systems designed on the basis of ontological models solve the problem of heterogeneous information search for non-connected subject domains. The ontological model allows to structure and systemize information, as well as organize its formalized presentation [3, 4]. Ontological models have also been used in the development of search engines. Using ontology it is possible to integrate huge amount of data and knowledge in different subject domains [5, 6]. Ontological models facilitate knowledge access, ensuring an adequate exchange of information between people and such heterogeneous systems.

In medical subject domains ontologies can help to organize and analyse large amounts of data that are too large to be managed by an individual physician. Ontologies will not only structure or classify medical knowledge, but also integrate information by formalizing standard medical terminology. The ontology consists of a set of concepts (terms) and their synonyms, as well as a description of logical definitions that determine the formal relationships between concepts. Healthcare ontologies are designed to facilitate the reuse and exchange of medical knowledge [7, 8, 9].

Information systems based on ontologies, have found wide application in medicine. The following are the most influential ones:

– GALEN (Generalized Architecture for Languages, Encyclopaedias and Nomenclatures in Medicine) - an ontology that provides carrying out surgical operations [10];

– UMLS (Unified Medical Language System) - synthesis of medical dictionaries with more than 10,000,000 concepts [11];

– SNOMED (Systematized Nomenclature of Medicine). A comprehensive guide to compare data collection and collection throughout the treatment process [12];

– The Medical Subject Headings (MeSH) is a commonly used healthcare ontology. MeSH was developed by the National Medical Library to index, catalogue, and search for biomedical information and health-related documents [13];

– Disease Ontology (DO) is an open ontology designed to display the relationship between different data sets using disease descriptions. The mission of the disease ontology is to integrate biomedical data related to human diseases [14];

– Systematized Nomenclature of Medicine - Clinical Terms (SNOMED-CT) - organized, comprehensive, computerized, multi-axis and controlled medical terminology that describes clinical data, symptoms, diagnoses, procedures, body structures, organisms and causes of diseases, substances, pharmaceuticals and devices. It is widely regarded as the most complete clinical health terminology in the world. The main purpose of SNOMED-CT is the indexation of medical records [15].

Wide variety of researches on medical ontologies development is held nowadays. Research [16] proposes an approach to provide clinical management at a deeper and more personal level in home-based telemonitoring scenarios

by developing an ontology-driven solution that enables a wide range of services such as health status monitoring, real-time alerts, and reminders. Paganelli et al. [17] described an ontology based context model and a related context management middleware, providing a reusable and extensible application framework for monitoring and assisting patients at home. In [18] an upper-level ontology is proposed to cope with the clinical terms in that SNOMED-CT and support its quality assurance based on the Ontology for General Medical Science (OGMS). Bhatt [19] designed a prototypical system called ontoMove to develop applications in the medical information systems using semantic web standards such as the Resource Description Framework (RDF), RDFs schema, and the W3C Web Ontology Language (OWL)language's unified medical language system (UMLS) knowledge sources. In [20] XOntoRank system is proposed to address the ontology-aware XML keyword search of electronic medical records.

Thus, the use of ontologies to accumulate data and knowledge on the COVID-19 incidence is efficient.

III. COVID-19 Transdisciplinary Knowledge Cluster Features

The novelty of the research is to use an ontological approach [21] to the management and presentation of physically and thematically distributed multilingual information resources created in different formats, according to different standards and technologies, which will provide the technological basis of a single knowledge-oriented network information space - COVID-19 Transdisciplinary Knowledge Cluster. The components of the Cluster based on built-in language-invariant tools of semantic analysis and automatic and dynamic structuring of network information resources will provide integrated access to aggregated digital data sets about coronavirus, presented in the form of a certain system of knowledge (ontological transdisciplinary interactive information) [22]. They also will permit search for relevant information about COVID-19 in open sources (statistical databases, collections of scientific papers, archives of medical reports, etc.) regardless of the language of the search query.

The interoperability and integrativeness of information resources in a COVID-19 Transdisciplinary Knowledge Cluster will ensure network-centric synchronization of the interaction of all categories of participants in the COVID-19-related research and knowledge generation process in their national languages [23]. A distinctive feature of the tools for forming the Cluster is their cognition, that allows to perceive and process information in the most appropriate way for the human brain, turning it into knowledge through operations of semantic analysis, structuring and self-learning, synthesis, decision making and selection, prediction, planning, forming a logical conclusion, etc.

For the first time, transparent and understandable to a wide range of experts principles of forecasting the possible consequences of the implementation of various health programs to control COVID-19 will be proposed, that will be based on a comprehensive study of the epidemic process of the disease as a whole and for certain periods of time and building the adequate prognostic model [24]. A mathematical model of the COVID-19 epidemic process will be proposed and its main parameter of SARS-CoV2 transmission will be determined, that is a complex characteristic of the structure of population contacts and the probability of infection by contact with a sick person. For the first time, the analysis of the dynamics of the SARS-CoV-2 transmission parameter and the study of the conditions for establishing the endemic equilibrium of the prevalence of COVID-19 among the population of Ukraine and the expected number of COVID-19 cases are envisaged. Our research will allow for the first time to investigate the intensity of the COVID-19 epidemic process in different regions of Ukraine and identify potentially the most problematic of them. The developed model will be a simple, but at the same time effective tool for predicting the COVID-19 epidemic process in the form of a computer module and can be useful in the practical work of health professionals.

IV. Methods of COVID-19 Transdisciplinary Knowledge Cluster Development

To achieve the goal of the research it is necessary to form COVID-19 Transdisciplinary Knowledge Cluster, for which a comprehensive methodology will be used, due to the specifics of the tasks of software development:

– big data processing by semantic-linguistic analysis of network information resources created in different formats, according to different standards and technologies, which have a significant number of interdisciplinary relations, with support of Semantic Web formats and protocols;

– aggregation and transdisciplinary integration with other network information arrays, systems and web-oriented medical applications;

– taxonomization of narratives of arbitrary medical documents and reflection of their conceptual structure and intercontextual relations;

– ontological presentation of information arrays about the coronavirus in the form of ontological interactive documents based on the semantic-linguistic analysis;

– interactive interoperable semantic connectivity of coronavirus information array contexts;

– determination of synonymous equivalence between information arrays and detection of latent information in the analysed information resources;

– Cluster formation, which will include a network ontological representation of information arrays about COVID-19, semantically related network information resources and connected indexes of contextual connectivity with thematically related scientific information, WHO data and other materials;

– supporting the interaction of Cluster users with network information resources and with each other, regardless of the language of queries and statements;

– providing medical knowledge deep learning and machine learning in the Cluster based on semantic-linguistic processing of the latest medical information;

– providing open access taking into account different stamps to the descriptions of scientific and technical products for different medical domains in accordance with the principles of "open science".

Therefore, to solve the tasks it is planned to use the following methods:

– for text data processing – theory of lexicographic systems, theory of semantic states, data and knowledge models;

– for ontology-driven model of a COVID-19 Transdisciplinary Knowledge Cluster development – methods of linguistic and structural-logical modelling, theory of complex systems, systems analysis, set theory, graph theory, lambda calculus;

– to formalize the presentation of transdisciplinary knowledge in the form of interactive documents – algebraic-logical and axiomatic methods, theory of categories, theory of architectural-structural organization of knowledge-oriented information systems, methods of ontologically controlled systems, theory of fuzzy sets and probable processes, theory of categories, methods of associative representation of information resources;

– for software implementation – object-oriented design and programming, system engineering design of distributed virtual information systems.

V. Expected Results

As a result of the research implementation, a COVID-19 Transdisciplinary Knowledge Cluster will be created in the form of a cognitive network-centric system for managing distributed processes of accumulation, systematization, storage, and access to various information and knowledge-oriented resources, which will provide:

– accumulation of descriptions of scientific and technical products for various medical domains in the form of repositories, knowledge bases and index links to other sources and network repositories;

– providing and maintaining access to descriptions of scientific and technical products of various medical domains, including network, based on natural language requests;

– selection of semantically equivalent descriptions of scientific and technical products of medical domains in other languages while formulating a request in one of the natural languages;

– transdisciplinary indexing of descriptions of scientific and technical products localized in the network environment or can be implemented to it;

– analysis of scientific and technical products in various medical domains;

– scientometric assessment of the quality of scientific and technical products in various medical domains;

– support for systemic medical research;

– computer-aided systematization, classification and ordering according to certain parameters of descriptions of medical scientific and technical products and publications that reflect their content;

– reflection of the state of use of scientific and technical products in different medical domains;

– forecasting and forecasting assessment of thematic domains of development and application of scientific and technical products of different medical domains;

– computer-aided formation of registers of medical scientific and technical products by thematic domains, taking into account the network repository and library location of its descriptions;

– formation of indicators of levels of compliance with the potential and actual use of medical scientific and technical products according to the content of their descriptions;

– identification of system features of medical scientific and technical products descriptions that characterize them as innovative;

– formation of recommendations for innovative use of scientific and technical products of various medical domains;

– raising user awareness by organizing access to scientific peer-reviewed information and the latest advances in various fields of science in countering the pandemic;

– creating conditions for the organization of full-scale interaction between experts from around the world through the formation of joint multilingual network-centric laboratories of the COVID-19 study;

– reducing the risks of future infections due to the accumulation of experience and analysis of the results of international studies of coronavirus by means of cognitive tools for the formation of the Cluster.

It is proposed to use cognitive software platform "POLYHEDRON" [25] designed to support the processes of linguistic and semantic analysis of large volumes of spatially distributed unstructured information (Big Data), their structuring, establishing contextual relations between processed documents, forecasting and support of rational choice processes with the subsequent formation of information-analytical web-oriented solutions. "POLYHEDRON" tools allows to form most relative result to users' search request (Fig. 1, Fig. 2).

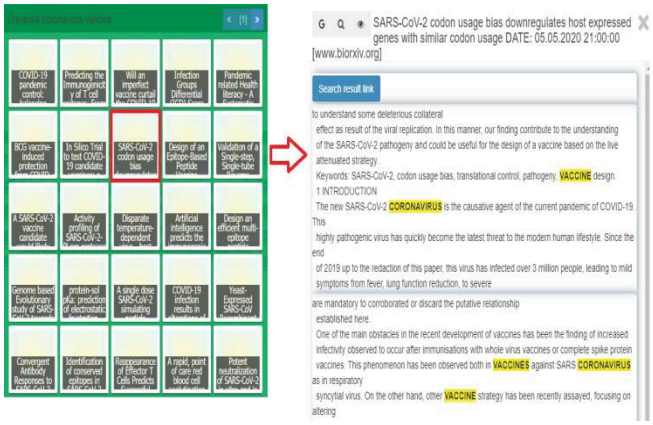

Fig. 1. Search query result pop-up.

Based on information from the COVID-19 Transdisciplinary Knowledge Cluster, system will be create and prepare for implementation in medical practice, to solve the following tasks:

1. Multifactor analysis and simultaneous consideration of the impact of many interrelated variables on the epidemiological process.

2. Regularities of mathematical adjustment of the effects of the studied variables to identify the independent

action of one factor (a subset that makes an independent and significant contribution to the result), ranking the variables by the strength of their influence on the prediction result.

3. Development of scenario biomodelling principles.

4. Substantiation of the principles of adaptation of the proposed methodology for other epidemiological analyses necessary for effective control of various diseases.

5. Substantiation of the paradigm change procedure of epidemic development data processing, their deep multilateral analysis.

6. Research of the principles of computer-aided new medical and biological knowledge extraction from empirical data and giving the epidemiologist the opportunity to use it to solve practical problems.

7. Improving analytical capabilities in the primary information processing and improving the algorithm for the use of epidemiological data to substantiate prognostic decisions.

8. Creating an ontological knowledge base and expert system for the epidemiological process forecasting to support the decision on the need to intensify anti-epidemic actions.

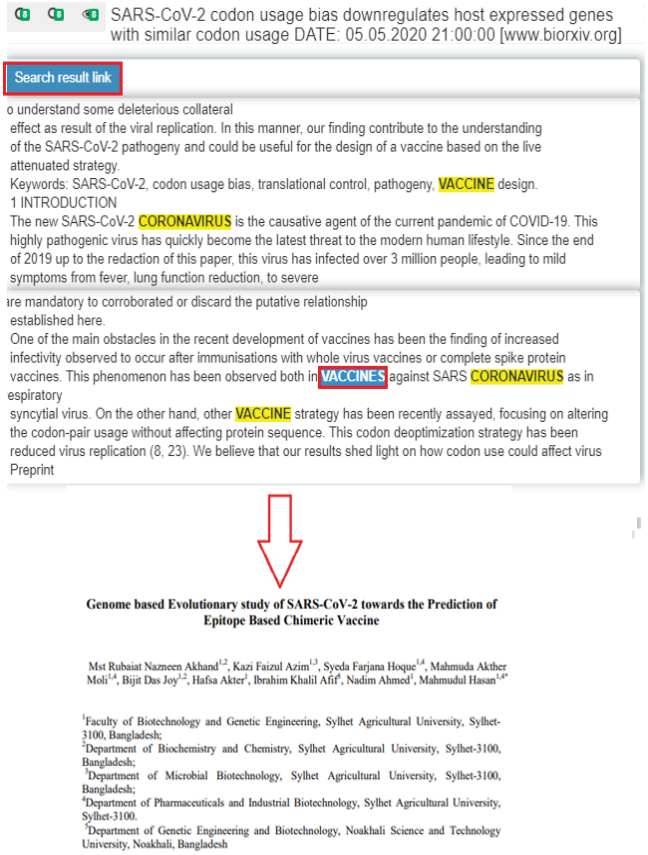

Fig. 2. Opening the search result.

VI. Conclusions

The main task of the research is to create a technology for using multifactor models to forecast the epidemics development based on scenario plans and recursive functions. This is the first time such a solution has been solved. In addition, the implementation of the research will provide opportunities to solve the problems of modelling the epidemic in silico. It is planned to create algorithms for effective research of policies and procedures related to complex control measures, such as: targeted multi-level deterrence, quarantine, social distancing, as well as targeted antiviral prevention. Finally, the foundations will be laid for creating a coronavirus knowledge ontology. Today in Ukraine and in the world there is no ontology in this area.

The research results dissemination will provide invaluable experience for students and graduate students - future scientists that will undoubtedly give impetus to the development of not only medical but also technical, economic and socio-political innovations. In the long run, the results of the work are transformed into an information channel for public health, science, education and business in the field of innovative research of COVID-19 in order to develop a joint strategy to overcome the pandemic and its consequences.

The COVID-19 Transdisciplinary Knowledge Cluster can be the first step towards the development and implementation of scientific, technological and methodological foundations of STEM-education in Ukraine in the field of systems biomedicine, combining a wide range of disciplines from mathematics (statistics, graph theory, etc.) to systems bioengineering, systems bioinformatics, etc. Today, when the issue of distance and integrated education is very important, the use of a COVID-19 Transdisciplinary Knowledge Cluster in the initial process will improve the quality and speed of knowledge acquisition by taking into account the mechanisms of cognitive load and ergonomics.

The research results can be used in educational activities in the training of medical personnel, in the analytical activities of the authorities of the health care system, research activities in the field of development of innovative solutions.

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