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Advanced methods of visual analysis and visualization of various aspects of the COVID-19 outbreak in Poland

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Abstract

The COVID-19 epidemic propagation computational models generate datasets that exhibit multi-level and time granulation. The Predictive Modelling of the Spatial Propagation of the COVID-19 Pandemic Project (ProME) has produced multi-scenario, multi-agent models for decision making support assessing the impact on the healthcare and the general population. In this paper we present the interactive software developed for models’ calibration and visual analysis, addressing the needs of all aspects of data analytics and modeling that arise within ProME system. In order to deal with the Project’s tasks we developed the application based on multi-modal, open-source VisNow platform.

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1. Introduction

The ProME project was aimed to develop an IT/ AI / ML (Information Technology / Artificial Intelligence / Machine Learning) system and a set of tools supporting the monitoring and limiting the spread of the COVID-19 epidemic in Poland, that enabled the management of epidemic risk by supporting the decision-making process based on high-quality spatial forecasting of epidemic development. Several models were develop in the Project: 1) a predictive multi-agent simulator (ProMES), 2) predictive neural networks model (ProMENN), 3) nearest neighbors...

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model (NN), 4) predictive model of cellular automata (ProMECA), 5) medical procedure demand prediction model (ProCME), and 6) optimal relocation of medical procedures models (OptiLOC).

The results of each model can be visualized and analysed with the use of specially designed ProME application based on VisNow platform [1]. Despite the wide range of visualization systems the VisNow platform was chosen, due to its extensive support to different interfaces, the ability to read and write many different file formats, support for various data structures or geometries, large data handling, and usefulness in many applications [2,3]. VisNow platform was a solution in development of which we have participated ourselves, therefore, the deep interference into the core of the programming platform was possible. The wide range of VisNow’s applicability became an important asset for further development. The diversification of models and simulations required special approach to be developed, which included the analysis of users’ time-dependent, multi-feature data.

The VisNow platform is an open-source software under GNU General Public License, written in the Java programming language, can be downloaded from visnow.org website, and is divided into several smaller libraries [4]:

- JLargeArrays - a low-level library that provides support for big data.
- JSeiC - Java Scientific Containers - a library of data structures and basic algorithms used in the processing and visual analysis of data.
- VisNow - the kernel of the visualization system using the above two libraries; includes a graphical user interface and an extensive collection of visualization modules.
- VisNowPlugin - a set of additional modules for the VisNow platform developed outside the kernel, in particular modules for medical applications.
- VisNowApplication - a dedicated platform for designing applications based on the VisNow platform.

The VisNow visualization platform, containing a comprehensive set of functionalities, enables the visualization and visual analysis of various types of data accounting for wide range of their characteristic features such as geometry, structure and numerical attributes. The variety of possible features were useful in the presentation of the ProME system, in which the 1D or 2D datasets can be projected to third dimension using interactive geometry and structure changing tools available at VisNow platform and the application created on its basis. VisNow enables setting geometry (coordinates of points in n-dimensional space) and structure (logical connections between the points) in advanced or based on calculated data. Numerical values are derived from the simulations and stored in components (classes) specified for each geometry points. New components can be created in order to highlight the most relevant data and to generate new coefficients. Components might be time dependent and contain a mask - an array of boolean data indicating which points contain relevant data and which can be visualized. Therefore, the information layers of the datasets can be analyzed in terms of variability over time.

In view of the large amount of data from simulations and models, a need has been identified to develop IT tools or application that allow extracting the relevant information hidden in the data. Significant data reduction and procedures for the extraction of appropriate information are needed to efficiently manage the outbreak and make life-saving decisions. In this paper we present the interactive ProME application developed for models’ calibration addressing the needs of all aspects of data analytics and modeling that arise within ProME system.

2. Methods

The ProME application was implemented in Java on the basis of the VisNow platform with commitment of VisNow-Medical Plugin and VisNow-Application libraries. The graphical interface for selection of specific simulation was developed with the possibility for the user to select a suitable model and adjust its parameters.

ProMES model that constitutes a core component of the decision supporting system, developed within the ProME project, provides the widest range of parameters’ selection possibilities which determines various hygienic and sanitary scenarios, and the impact of the applied interventions (restrictions, vaccinations, etc.) on the development of epidemics at the level of individual administrative units. In contrast to other predictive models developed within the ProME project (ProMENN, NN, ProMECA) the ProMES model, not only gives a possibility for direct region selection and time of simulation, but also the risk of infection or exposition, chance of developing severe or critical symptoms, death rate probability, the effectiveness of the immunization program in specific age groups and the effectiveness of each intervention (indoor, outdoor masks, regular temperature measurements, social distancing etc).
The relocation models developed within the ProME project (ProCME, OptiLOC) require the selection of the source and destination regions with the time of the beginning and end of relocation, the percentage of total number of procedures which undergo relocation. Pandemic might have limited the performance of medical procedures, therefore, it is assumed that the performance of procedures in given regions is reduced with the possibilities of increasing the performance of medical procedures in other regions. The feasibility of relocation of individual procedures (patients) to free hospital beds is determined with the total costs of the procedures and relocation. Relocation takes place first in the same voivodeship, and in the event of a lack of available hospital beds in the voivodeship, the procedure is relocated at the national level.

The settled parameters in ProME application are transferred through the representational state transfer application programming interface to invoke simulations. The results, which are submitted back to application, differ from each other in terms of geometry, structure, components’ types. The application unifies the properties of obtained datasets, that the visualization of all models proceeds in a similar manner. The visualization is performed in the resolution provided by the model and corresponds to the administrative division of the Republic of Poland (the first level – voivodeship, the second level – county/poviat, the third level – gmina and district). User selects the component to be presented and the colormap. The application allows to present the results in typical charts, tables or maps as a dependence of the number of cases over time. The visualization is created on the basis of a list of components containing information about the simulation.

3. ProME Application to decision-supporting solutions

The visual analysis of simulation results for all system components developed within ProME project, is enabled by employing a wide range of visualization methods, from simple to rather advanced approaches. The utilized simple functionalities include:

- map-based visualization in accordance to the administrative division of Poland and with the granulation to resolution available from the model,
- time-dependent simulation with a current time step presentation in the main window,
- components’ mapping according to the selected colormap,
- components’ numerical values range selection,
- color-legend visualization with the expression of the number of cases,
- multi-component chart and table visualization.

The advanced approaches utilize quite special 3D visualization techniques:

- three-dimensional graph with the number of cases visualized on the z-axis; cases are marked both on the graph and on the tooltip option; simulation takes into account time-dependent changes in the graph geometry caused by differences in numerical values; color and height of the graph are determined independently by selectable input data components,
- ribbon-plot creates three dimensional graphs of scalar regular 2D fields in the form of narrow stripes and is used for visual analysis of the numerical values changes in datasets that contains numerous components,
- new data coefficient generation by performing mathematical operations on the existing components obtained from the simulation; mathematical operations, functions, logical operations, statistical operations and others can be used for computation of new coefficients to assess the outbreak in more comprehensive manner.

The employed visualization methods are applicable to all outputs of the ProME system. ProMES model provides numerous components such as a number of new, active or total COVID-19 cases (light, severe, and critical), deaths, convalescents, diagnosed, quarantined, vaccinated and number of performed tests, and transmission rate value. The assessment of each component for each region and time step would be much more complicated without the visual analysis on maps. An example of the three-dimensional graph visualization of the number of active cases for Poland and corresponding chart visualization of single region is presented in Fig. 1.

The use of visual analysis and visualization methods is particularly useful when assessing the model of relocation of medical procedures. As an illustrative implementation we refer to the urology-related context. Antoniewicz et al. showed that the most affected urological procedures by the COVID wave’s lockdowns, caused the significant increase in waiting queue of patients [5]. Over past year, more than 100 000 patients in Poland may be affected with suspending
urological procedures, due to conversion of urological clinics into COVID stations. The urological health care system recovery would require more than 10% increase in capacity as well as relocation of the procedures to avoid consecutive increase of number of waiting patients.

The relocation visualization is especially useful when planning scenarios for converting the regular hospitals into COVID ones. These models support planning patients transfer procedures from hospitals in the regions where admissions have been restricted due to a pandemic to hospitals where these restrictions do not exist. Patients must be relocated to other hospitals in order to ensure adequate medical care at the lowest possible cost. The application provides the ability to easily manage the relocation and the appropriate display of the number of patients relocated from source to destination. The data from the model is time-dependent, therefore, relocations in various time steps might differ. Two types of visualization are especially useful and are associated with three-dimensional graph and ribbon-plot.

A sample relocation model was used to create simulations of patient transfer from individual counties, assuming that admissions in large cities would be reduced by approximately 50%. All procedures from group 57 (Operations On Urinary Bladder) of the ICD-9 classification were analyzed. Simulation was conducted for three months. The results were obtained for each subprocedure separately. The exemplary visualization with tree-dimensional graph for Łódzkie voivodeship is presented in Figure 2 and shows the number of prognosed patients relocated from the source (with negative values) to the destinations (with positive values) for each month. Second visualization with the ribbon-plot shows the procedures that have to be relocated from/to each region taking into account the time of the relocation in the Legionowo poviat are shown in Fig. 3.

![Fig. 1. ProMES simulation results with graph 3D and chart visualization.](image1)

![Fig. 2. Relocation of medical procedure (57.95) visualization of Lodzkie voivodeship for three time-steps.](image2)
In conclusion, the interactive application for settlement input parameters, visual analysis of different aspects of the COVID-19 outbreak, prediction and healthcare management was developed. ProME system allows to predict the effects of the pandemics long before their occurrence, that will hopefully help to reduce its impact. The ability to easily adapt new analytical solution to the capabilities of VisNow platform might be useful as the pandemic continues to evolve, especially when it becomes necessary to consider an increasing number of possible variants of the situation caused by emergency of the new virus strains.

4. Discussion

The ProME application allows the user to choose the best suitable visualization method adjusted to specific simulation. Due to the variety of project’s models, an operator has the possibility to present and analyze datasets in 1D, 2D or 3D manner. Aggregation of data into larger components and maps provides the comprehensive and insightful visual analysis. Furthermore, the employment of VisNow platform as a basis for this application provided a large amount of modules and functionalities that were useful for the realization of the objectives of this project. The available templates in the VisNow platform enabled the easy and approachable development of new modules and functionalities. The option of saving and loading the simulations into the main VisNow platform expands the possibility of performing large number of visual analysis on the results from each simulation. Attempts were made to use the simulation results in the analysis of correlation between individual regions. There is also a possibility to create new coefficients related to the propagation of the pandemic with the component calculator tool.

The VisNow platform gained some benefits due to developing new and adjusting existing modules during the ProME project. The time-dependent three dimensional graphs and ribbon plots were added to the core version, as well as modules associated with charts and table visualization. The abovementioned modules and the integration with the Open Street Maps servers is planned to be available in the newest, stable release of VisNow platform and its dependent libraries. Newly developed modules and the VisNow platform will have potential in further projects.

Platforms, such as MeVisLab, ParaView were taken into consideration for development the application [6,7]. MeVisLab is a cross-platform application framework for scientific visualization and image processing (especially in medicine). It also contains advanced algorithms for image reconstruction, segmentation, and functional and morphological image analysis. ParaView is an open-source application for interactive, scientific visualization with a client–server architecture to facilitate remote visualization of datasets. It can be applied to create visualizations to explore data using quantitative and qualitative methods. However, the disadvantages related to these platforms outweighed the potential gains. Difficulties related to large segmentation of functionalities and the need for the creation of a multi-platform application resulted in the employment of the VisNow platform which one of the advantages is the ability to open the application on different operating systems due to the fact that it was written in Java.

In conclusion, the interactive application for settlement input parameters, visual analysis of different aspects of the COVID-19 outbreak, prediction and healthcare management was developed. ProME system allows to predict the effects of the pandemics long before their occurrence, that will hopefully help to reduce its impact. The ability to easily adapt new analytical solution to the capabilities of VisNow platform might be useful as the pandemic continues to evolve, especially when it becomes necessary to consider an increasing number of possible variants of the situation caused by emergency of the new virus strains.
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