Informational and analytical support of the Network of Intelligent Situational Centers in Russian Arctic

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Abstract

The paper describes brainware means to support interconsistent functioning of a system of cognitive situational centres in solving various tasks of regional management in Arctic areas. The system has to provide unified logical-analytical data processing and situational analysis of the state of the object under study in conceptual spaces with incorporation of expert knowledge and consideration spatial-temporal dependencies in characteristics of the territory, carried out with using cartographic information.

Keywords: intelligent situational centers, Russian Arctic.

1 Introduction

At present, development of a system of distributed situational centers (CS) is considered a basis for digital transformation of public management [https://spbu.ru/news-events/calendar/sistema-raspredelennyh-situacionnyh-centrov-kak-osnova-cifrovoy-transformacii]. CSs' effectiveness problems in solving a wide range of monitoring issues in various fields of activity, for sustainable development in particular, are analyzed in a number of publications [Ily11, Zat15] and are developed with our participation within projects # 16-29-12901 and 16-07-00562 supported by the Russian Foundation for Basic Researches. However, additional research is needed for problems of information and analytical support of the network of intelligent CSs in Russian Arctic. In this paper, we propose a solution to these problems within the framework of situational approach [Pos86, Fri15]. The purpose of our research is to create technologies and methods for intelligent analysis of situations for information and analytical support of functioning of cognitive situation centres (CSCs) that carry out strategic forecasting, planning of development and operational management within regional systems of various nature, considering specifics of the Arctic zone of the Russian Federation [Ole17].

Relevance of such research is determined by the necessity to advance means of computer analysis and forecasting used in CSs with tools for operative cognitive classification of situations and automated selection of predictive models that are most appropriate for a particular class of situations. Classification is proposed to be carried out within a generalized interdisciplinary conceptual space (CS) based on quality dimensions (QDs) that characterize complex modeling objects from the point of view of different subject domains.

During the research, methods will be created for formation of an interdisciplinary CS as well as an information technology to use this CS for situational modeling, both for rapid assessing of the current state and forecasting

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options to improve complex spatial systems of the Russian Arctic. We will also propose a prototype of an integral CS as well as techniques to estimate situational awareness (SA) [End15] exemplified with a generalized CS for situational modeling of industrial-natural systems and freshwater ecosystems of the Russian Arctic, taking into account their mutual influence and risks of occurrence of non-standard situations caused by large-scale atmospheric phenomena that are typical for these territories. The scientific value of this research consists in intellectualization of systems for modeling complex objects in a dynamic environment in order to improve their information security and efficiency of making decisions on management of similar objects under different conditions.

To achieve this goal, it is necessary to solve the following tasks:

- specify a set of SA' indicators taking into account the specifics of the Russian Arctic and properties of the modeling object;
- develop a methodology to form a generalized interdisciplinary CS considers specific character of complex characterization of situations typical for spatial systems in the Russian Arctic;
- within an integrated CS, propose techniques for searching and describing structures of sufficient situations [Fri15] that are robust to variations in initial conditions for each class of situations, as well as for assessing the degree of SA in these situations [Fri16];
- investigate features of solutions for problems of coordination and planning of control impacts in the presence of several decision makers (DMs) in a system;
- develop a system of quantitative measurement of SA at solving tasks of strategic and operational planning in the conditions of the Russian Arctic;
- analyze possibilities of accelerating and reducing complexity of inference control algorithms and handling situations in the situational modelling system (SMS) [Fri15] for the Russian Arctic;
- develop a set of information resources and problem-oriented models that ensure dynamic forecasting of parameters for the integrated CS that is being formed within investigated subject domains.

Software and hardware implementation of the CSCs will be carried out within the framework of modern network-centric approach [Mas14]. As a result, some forms of information presentation and methods of its processing should be unified in order to integrate means aimed at studying territories of the Russian Arctic as not-enough-formalized complex non-stationary spatial objects. These means include: combined logical and analytical data processing and situational analysis of the state of the object under study in SCs using expert knowledge and considering spatial-temporal dependencies in characteristics of the territory, carried out with using cartographic information, as well as supporting the mutually coordinated functioning of the CSCs' system in solving diverse tasks of regional management.

2 Features of Arctic Areas

Arctic territories have a number of features that must be taken into account when implementing various types of activities, including, development of information and analytical support for CSCs. In order to exemplify forecasting technologies which can consider factors of different nature within the framework of the presented study, we will analyze possible effects on the analyzed situations of the state and dynamics of the Earth's lower atmosphere, as well as reactions of freshwater reservoirs to the situations under study.

Polar cyclones, which are large-scale atmospheric vortices, can cause emergency situations in systems of various types localized in the Arctic. There exists extensive scientific literature concerning studies of cyclones. Polar cyclones have been studied not only by experimental [Tan12] and theoretical [Gol09] methods, but also by mathematical modeling [For12]. In particular, researchers from Polar Geophysics Institute of RAS developed a regional three-dimensional nonstationary non-hydrostatic mathematical model of horizontal and vertical wind in the lower atmosphere of the Earth, which was used to study the mechanisms of formation of polar cyclones [Min12]. Despite the progress achieved for last years, the problem of predicting origination of cyclones and hurricanes, predicting their trajectories and evolution of their characteristics remains unresolved.

Many years of intensive industrial activity in a number of regions of the Russian Arctic has led to a sharp deterioration in the quality of the region's natural waters used for industrial and domestic purposes [Kas17]. In recent decades, these processes have occurred against the background of global changes in the Arctic climate system, which lead to difficultly predictable phenomena in aquatic ecosystems. In order to adequately assess and forecast further changes in Arctic water reservoirs, we need more knowledge not only about the ecology and current status of aquatic ecosystems, but also data on activity of industrial objects, dynamics of emissions and discharges, their composition, changes in climatic and meteorological parameters, including large-scale atmospheric vortices. Socio-economic factors are significant as well since they determine intensity and ways of using water resources. This explains relevance of planned studies in terms of providing SA of the state of aquatic ecosystems of the Arctic zone and managing their rational "nondestructive" use.

3 Situational Centers in Russia

From the emergence of the idea of creating SCs as systems to support managerial decision making in the 1970s both abroad and in Russia, significant experience in their construction and operation has been accumulated. The main tasks of SCs are: monitoring of the state, integrated assessing and forecasting of situational development of managed objects, as well as modeling consequences of options for managerial decisions aimed at their comparative analysis and optimization [Ily11, Zat15]. Topical issues of functioning and development of the SCs' system are regularly analyzed at specialized scientific-practical events in Russia, for instance, "System of Distributed Situation Centers-2015" in Yaroslavl city, October 7-9, 2015; "Scientific and Personnel Support of the System of Distributed Situational Centers as a Key Factor in Improving Efficiency of Public Administration" in Moscow, October 18-20, 2016, and "The System of Distributed Situational Centers as a Basis for Digital Transformation of Public Administration" in St. Petersburg, 25-27 October 2017. As shown in the title of one of the listed conferences, development of a system of distributed SCs is considered the basis for digital transformation of public administration. One of the key components that ensure effectiveness of SCs is tools for computer analysis and predictive modeling of the situations in question.

Recent surveys show that SCs are the optimal tools for informational monitoring of threats to security of regional socio-economic systems (RSESs) and for crises response. Informational support for implementation of the "Strategy for Development of the Arctic Zone of the Russian Federation and Ensuring National Security until 2020" is carried out under the coordinating role of the Security Council of the Russian Federation by attracting information resources of interested state authorities and state scientific institutions with using a distributed SCs' system. However, technologies to provide functioning and informational interaction of SCs have a number of weaknesses, namely [Mas17]:

support of decision-making on the basis of retrospective information and archival reports only;

centralized architecture of the information systems used;

technological and organizational heterogeneity of functional and information components of SCs;

need to automate selection and implementation of techniques and tools for data analysis and processing under conditions of known sources of primary information;

absence of a unified regulations for informational interaction and data exchange;

need to focus SCs to different categories of users (implementation of the concept of "user as an expert").

Advancement in modern technologies for creating and managing SCs can be gained by using CSCs as information systems for strategic forecasting of RSESs' development. A prototype of the future design system based on usage of CSCs was implemented in the Center for Computer Modeling and Expert Analysis of the Institute of Applied Mathematics named after M.V. Keldysh of the Russian Academy of Sciences (RAS). This cognitive center provides support to manage development of complex decentralized systems, such as a region, territory, industry, enterprise. The basic method of this cognitive center is computational experiment, which involves usage of modern information technologies and applied mathematics to model behavior of dynamic systems and processes of various natures.

Another adequate approach that provides a significant effect when solving problems of synthesis of trajectories for RSESs' risk-resistant development taking into account the need for integration, processing and analysis of a large amount of diverse information is forming a network of virtual cognitive centers (VCCs) for complex security management of RSESs [Mas16]. This approach is based on implementation of models for implicit management of RSESs' development by means of creating an adaptive intelligent environment for supporting regional management within a regional information space. VCC is a training and modeling complex designed for intelligent support of decision-making in the field of managing complex security of a region in emergency and crisis situations. Means for implementation of such a center are developed at the Institute of Informatics and Mathematical Modeling of FRC KSC RAS. Main tasks of a VCC are modeling and forecasting, strategic planning, synthesis of interaction specifications and coordination models of managed subjects for solving specific managerial tasks in various fields, including the sphere of informational support for managing complex security during development of regions as complex socio-economic systems.

As a technological basis for creation of VCCs, we suggested to use multi-agent, cloud and web technologies, as well as means of their integration, which provides an opportunity for comprehensive informational and analytical support for decision-making in crisis situations at the operational, tactical and strategic levels based on virtualization and adaptive modeling of problem-oriented activity of subjects of regional management. Positioning of VCCs as a hybrid cloud solution makes its tools accessible not only to subjects of management of different levels and and experts, but also to all interested state and commercial organizations that use Internet technologies and telecommunications in their practical activities.

4 Basics of Situational Approach

Situational approach is used in various subject domains, including the area of modeling and management of dynamic spatial systems considered in this paper, and is formalized in different ways [Lun15, Osi10, Pos86]. No formal definition of the term "situation" is given usually, informal definitions to some extent correspond to description of situation adopted in system analysis, namely as a certain snapshot that fixes values of all variables essential for the task being solved and all relations between them at some fixed time. In general, a situation is determined by knowledge of the structure of the object and the environment, the state of the control system and the technology (strategies) of management [Lun15] at this time.

Complexity of the situational control method looks significantly reducible by adapting it to specific models of subject domains. When creating the SMS [Fri15], formal definitions of situation and main aspects of situational approach for this specific model were given, problems of classification and generalization of situations were solved. However, there are difficulties in constructing classes of situations because of insufficiently flexible procedure for such constructing. In this connection, it is necessary to study feasibility of using cognitive categorization [Fri16, Ros73] to develop this situational approach to study dynamics of spatial objects on the basis of the conceptual model that forms the core of the SMS.

5 Conceptual Spaces and Situation Awareness

Since Russian-language literature does not always provide established terminology on the topic under consideration, further, if necessary, corresponding English constructions are given. Conceptual spaces (CSs) [Ban04, End15] represent geometric structures based on quality dimensions (QDs), which determine degree of similarity or difference of objects. Judgments about similarity and difference usually give rise to an ordering relationship on a set of certain objects. In particular, QDs include color, pitch, temperature, weight and three conventional spatial dimensions. Some dimensions are closely related to types of information that are analyzed by our sensory receptors, but there are also abstract QDs.

To convert judgments about similarity in a CS, multidimensional scaling is usually used [Bor05].

In CSs, objects are characterized by a set of attributes or qualities. Each quality takes values in a specific domain [Gar13], which can be continuous or discrete. Objects are identified by points in the CS, which is the Cartesian product of domains, and concepts correspond to domains in this space.

Similarity relations are fundamental to CSs. They fix information from judgments about similarities. To model some similarity relations, a CS is endowed with a measure of distance.

Categorization allows splitting CSs into subregions. Geometric nature of the CSs associated with notions of prototypes and the ability to manipulate dimensions independently of one another, provides a flexible and practicable representation of context-dependent categorization. A context is formed by QDs' weights and/or addition/removal of individuals (objects) including prototypes. The degree of typicality for individuals is determined by their distance to the prototype. Accordingly, in each category, some members are considered more representative than others [Ban04, Dec14, End15, Gar13, Ros73]. Classification of objects is carried out by determining their similarity to the prototype. Instances above some threshold of similarity to the prototype are accepted as members of a category, all other instances are not members. A prototype is not always one of real instances that fall into the category, it may be some ideal set of attribute values.

The main idea of cognitive categorization is that Voronoi's tesselation [Vor08], constructed around prototypes according to the rule of the nearest neighbor, can be used to determine the threshold of similarity that forms boundaries of categories. In other words, prototypes and the basic similarity relation with them are applicable to partitioning a CS into categories; when using the Euclidean metric, these categories will have the convexity property.

Situational awareness (SA) plays an important role in operative decision-making. Situational awareness is recognized as an important but often difficult to achieve basis for successful decision-making in a wide range of complex and dynamic systems. Formal definition of SA is divided into three segments, namely perception of "significant" elements in the environment, understanding of the situation and forecasting of future status [Ban04, End15, Lun15]. Obtaining a complete, accurate and relevant SA is especially important when complexity of a process and a situation raises doubts about ability of a decision maker to deal with this independently. Basic principles of SA proposed by M. Endsley [End15], the author of this approach, seem to become realistic only in relation to a specific model of decision-making in a particular subject domain. Within our research, they are interpreted for the SMS.

Management of complex organizational and organizational-technical systems involves analysis of large amounts of information concerning both composition of significant parameters of these systems and values of parameters. Essential assistance in forming of a CS can be provided by using accumulated data and knowledge presented in the information system on researches regarding Arctic territories [Ole17]. This information system combines two types of structured representation of data and knowledge. The first is a relational DB about researches results from various scientific fields. For a more adequate representation and subsequent automated processing of the semantic component of the accumulated information, it is suggested to use a formal ontology. Within this ontology, a subject domain is represented as a logical theory that includes concepts of the subject domain and relations between them. Despite of heterogeneity of knowledge integrated into the ontology, its common "territorial" binding allows either elimination or significant reduction of conceptual and terminological ambiguity of such knowledge. This simplifies joint usage of such knowledge in the systematic description of research objects. When constructing a CS for a certain research object, queries to ontology and the database can be defined both as an initial set of parameters that can correspond to "coordinate axes" of the space being formed and as values of these parameters obtained in various earlier studies of the object under consideration.

6 Intelligent Situation Centers and Their Interactions

The concept of the industrial-natural system (INS) [Fri14, Fri15] is used in this work to ensure methodological integrity of CSs' formation and analysis. Categorization of situations and their comparative analysis is carried out in specialized CSs with a metric induced with consideration of expert knowledge [Fri14]. At the same time, models of dangerous and critical situations are formed as an extension of the models of normal INS' operation [Fri15], which allows to unify the means of conceptual and simulation modeling of an INS as well as to expand possibilities of identifying bottlenecks in the INS' structure and to predict complex (multiple) failures, which lead to the most severe consequences, as the experience of operating modern INSs shows.

For the tasks of situational modeling and management for spatial systems of the Arctic zone of the Russian Federation, we propose to develop a set of methods for cognitive multicriteria classification and generalization of description of situations, taking into account hierarchical structure of the research object. Methods should consider the degree of typicality of representatives within one category according to semantic similarity measures of categories modeled in generalized interdisciplinary CSs, which will improve the classification flexibility and its stability to data inaccuracy, as well as the speed of search for analogues of a current situation.

Compared to traditional areas of application of cognitive categorization, the main distinction of CSs used within the SMS is in significant variability in their composition and number of dimensions during modeling, even for the same decisive object (DO). In addition, QDs' domains in the SMS generally have a hierarchical structure.

The first distinction is due to availability of implementation alternatives in each complete situation. When transferring a model into another class of situations, the structure of the subject domain model (SDM) also changes: some or other model elements can appear or be excluded; these can be either objects or processes. Accordingly, the CS should obtain or lose domains of these elements. The hierarchy of domains is structured as follows: each process defines one QD with a domain equal to the Cartesian product of domains of input resources of this process. Since an object can be attributed with several processes, its domain is the Cartesian product of domains of those processes that consume resources from other objects or from the outside world. The DO's domain is the Cartesian product of domains of all the leaf objects that are subordinate to it and, obviously, will change in an abrupt way when passing from one sufficient situation to another. Therefore in the processing of situations, composition of the included sets of attributes may change, and the procedures for automatic correctness control of the SDM have to monitor correctness of selection of the current CS.

General principles of SA for the SMS are concretized as follows:

1) perception is modeled by setting an initial situation, understanding is gained by forming a complete situation and defining the organizational level of the solution for a problem, forecasting is done by simulation experiments;

2) the goal of modeling is set by a DM by choosing a desired class of situations during the simulation;

3) specificity of information is taken into account by choosing an initial situation and automatic rejection of unpromising alternatives;

4) expectations of a DM in the SMS are formalized by selecting a dominant particular criterion in the generalized quality criterion of functioning for the entire INS or its constituent parts, as well as by defining a composition of permissible alternatives stipulated during constricting a SDM.

The remaining SA principles are related to the mental model of a subject domain, which is defined in the SMS by means of the SDM. The cognitive categorization principles described above play an important role here too.

During our research, a series of experiments was conducted on software implementation of a VCC prototype in the form of a hybrid cloud based on the IaaS (Infrastructure as a service) service architecture. For this purpose, the following special software was installed and used: hypervisor (virtual machine monitor) Microsoft Hyper-V Server, cloud platform OpenNebula, Apache web server, MySQL DBMS, Ubuntu 12.04 LTS operating system, control kernel and distributed agent platform components for execution and support functioning of mobile software agents, as well as specialized web services: OpenMeetings, GeoServer, FreeBase, Redmine, Ushahidi, Sage, etc., used for operative analytical processing of distributed spatial-related data, integrating of heterogeneous information resources and ensuring the collective work of users on the Internet. The basic templates of software agents for different types of managed subjects were developed on the JADE platform with using the AgentBuilder and Cougaar tools in the Java language in accordance with the FIPA standard and the GAIA multi-agent application design methodology. Integration of services of agents, cloud and web services within the framework of the VCC allows regional subjects to use modern cognitive information technologies and modeling tools in order to develop coordinated strategies and to make managerial decisions in crisis situations under conditions of uncertainty and risk.

The main toolkit of the VCC includes tools for rapid and comprehensive analysis of current business and socio-economic processes, as well as operative forecasting and strategic planning of socio-economic development for tasks of informational support for managing regional systems in poorly-structured crisis situations. In addition, the core toolkit of the VCC incorporates technologies for supporting collective work of experts in real time for providing information services to regional managed subjects and business structures of various industries and areas of activity related to provision of operative analytical processing tools and problem-oriented information retrieval for assisting managerial decisions on overcoming crisis and extreme situations. This toolkit provides solutions to a set of tasks of formalization, integration, harmonization, processing, analysis and interactive visualization of collective expert knowledge for informational support of decision-making in the field of regional security, as well as modeling of the behavior of managed subjects under different types of crisis situations.

7 Conclusion

Methods and technology to form and practically use an integrated interdisciplinary conceptual space for assessing the state and situational modeling of development of complex spatial systems in the Russian Arctic provide analysis and optimization of scenarios for operation of these systems under "normal" conditions, as well as objectify recommendations for responding to possible non-standard and crisis situations. A system for quantitative measurement of situational awareness based on an interdisciplinary conceptual space is intended for solving strategic and operational planning tasks in Arctic regions. The scientific value of this result consists in intellectualization of modeling systems for complex objects in a dynamic environment aimed at improving informational security and efficiency of making decisions on management of objects under different conditions. Usage of developed methods to classify situations in the toolkit for computer analysis and predictive modeling within a system of situation centers will provide an opportunity to increase efficiency of issuing recommendations for managing complex systems by both "selecting" existing solutions for prototypes in an appropriate class (if any) and by automated choice of the most appropriate tools for predictive modeling of likely situations.

The database and the ontology of interdisciplinary research in the Russian Arctic offered by the authors constitute an informational basis to create technologies for forming problem/object-oriented conceptual spaces.

A research prototype of a virtual cognitive center for managing regional security in crisis situations was developed and implemented as a hybrid cloud service based on the IaaS architecture with using a technology of software mobile agents and web-services. The virtual cognitive center is a software simulator complex designed to solve the following tasks on the basis of distributed modeling: strategic planning and forecasting of risk-resistant development of regional socio-economic systems, synthesis of specifications for interactions between subjects of management to provide various types of regional security in crisis situations at the planning stage of joint anti-crisis measures.

The main factors limiting implementation of the virtual cognitive center in the practical activities of security subjects both at the regional and federal levels are determined by imperfection of statutory conditions and, as a consequence, by difficulties in positioning such centers in the structure of public administration,. In the course of our research, a model of the VCC functional organization for regional security management was proposed, and software implementation of the control core and active components of the VCC on the basis of cloud and agent technologies was performed.

Results of our research were used during implementation of the "Strategy for Development of the Arctic zone of the Russian Federation and Ensuring National Security for the Period until 2020" in Murmansk region to solve problems of informational and analytical support for regional situation centers on monitoring and modeling development of regional crisis situations.

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