Advances in Geographic Information Science

Vasily Popovich
Jean-Claude Thill
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Information Fusion and Intelligent Geographic Information Systems

Computational and Algorithmic Advances (IF & IGIS'2019)

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Editors
Vasily Popovich
SPIIRAS Hi-Tech Research and Development Ltd.
St. Petersburg, Russia

Jean-Claude Thill
Department of Geography and Earth Sciences
University of North Carolina
Charlotte, NC, USA

Manfred Schrenk
CORP - Competence Center of Urban and Regional Planning
Vienna, Austria

Christophe Claramunt
BRCM Brest, ENCEP
Institut de Recherche de L'Ecole navale
Crozon, France

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Preface

This book contains a number of original scientific papers that were selected after a peer-review process for presentation at the 9th International Symposium "Information Fusion and Intelligent Geographical Information Systems (IF&IGIS'2019)." The symposium was held from May 22 to 24, 2019, in St. Petersburg, Russia, with a specific focus this year on computation and algorithmic advances in IGIS. A separate part of the symposium was devoted to the discussion of achieved results of the international project CRISALIDE. This symposium was organized by SPIIRAS Hi-Tech Research and Development Office Ltd, St. Petersburg, Russia.

The main goal of the IF&IGIS'2019 symposium was to bring together leading world experts in the field of spatial information integration and intelligent geographical information systems (IGIS) to exchange cutting-edge research ideas and experiences, to discuss perspectives on the fast-paced development of geospatial information theory, methods, and models, to demonstrate the latest achievements in IGIS and for applying these research concepts to real-world use cases. The full papers, selected by the international program committee of IF&IGIS'2019, address fundamentals, models, technologies, and services of IGIS in the geoinformational and maritime research fields including underwater acoustics, logistics, environmental management, as well as other modeling and data-driven matters critical to the effectiveness of information fusion processes and intelligent geographical information systems.

The call for papers for the symposium attracted 20 abstracts from 10 countries; 15 papers were selected at the first step of a blind review process for presentation at the conference. After the second step of the review process, the program committee accepted 13 full papers contributed by authors from 6 countries for presentation and publication in this book. In accordance with subjects of accepted papers, four parts of the book were formed: (1) Advances in Intelligent Geographic Information Systems; (2) IGIS integration with acoustics and remote sensing; (3) IGIS Algorithms and Computation Issues; (4) IGIS for Urban and Land-based Research. Special guests of the symposium were two invited speakers who provided us with high-profile lectures on information fusion and intelligent geographical information systems: Professor Vasily Popovich from the SPIIRAS Hi-Tech Research and

Development Office Ltd, St. Petersburg, Russia, and Pierre Laconte President of the Foundation for the Urban Environment, Brussels, Belgium.

The success of the symposium is, undoubtedly, a result of the combined and dedicated efforts of our partners, organizers, reviewers, and participants. We would like to acknowledge the program committee members for their help with the review process. Our thanks go to all participants and authors of the submitted papers as well.

St. Petersburg, Russia	Vasily Popovich
Brest, France	Christophe Claramunt
Charlotte, USA	Jean-Claude Thill
Vienna, Austria	Manfred Schrenk
May 2019	

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IGIS Algorithms and Computation Issues

IGIS for Urban and Land-Based Research

Abbreviations

AI	Artificial intelligence
AIS	Automatic identification system
ASS	Active sonar system
AV	Autonomous vehicles
CA	Course angle
CI	Contextual information
CRF	Conditional random field
CRISALIDE	City replicable and integrated smart actions leading innovation to develop urban economies
CSIA	Community urban space innovative agenda
DCNN	Deep convolutional neural network
ES	Expert system
GIS	Geographic information systems
ICT	Information and communications technologies
IDMS	Innovative development governance scheme
IDMSSCM	Intelligent decision-making support system for city management
IDMT	Innovative decision-making tool
IDS	Innovative development schemes
IGIS	Intelligent geographical information system
IHM	Infinite homogeneous medium
IT	Information technology
KPIs	Key performance indicators
LIM	Layered inhomogeneous medium
MAE	Mean absolute error
NBS	Nature-based solutions
NLP	Natural language processing
OOM	Object-oriented modeling
OSM	OpenStreetMap
PCC	Platform Cooperativism Consortium
PCD	Probability of correct detection

PPPP	Public–private–people partnership
RMSE	Root-mean-squared error
SS	Surface ship
Stderr	Standard errors
SZ	Surveillance zone
TS	Target strength
UIA	Urban innovative actions
VRP	Vehicle routing problem

Advances in Intelligent Geographic Information Systems

The Concept of Space in Philosophy and in Computer Science

Vasily Popovich and Alexander Vitko

Abstract In this paper, we continue the discussion about the phenomenon that incorporates two concepts: geoinformation system (GIS) and space. Discussion of our previous works with various experts in computer science, mathematics, philosophy, system monitoring did not change our opinion on this topic. We still believe that the discourse on this subject needs to be conducted from computer science point of view since the expansion of the topic of discussion will lead to a sharp increase in the amount of submitted material and will result in the loss of clarity of the idea that we are trying to convey to the experts. References to philosophical and mathematical sources have been refined after the discussion of the previous paper published in proceedings of IF&IGIS'17 symposium. In this paper, we again emphasise the idea that every abstraction like "point" has its own interpretation and can be represented in different dimensions: 1D, 2D, 3D or nD. We also wish to note that we again base our arguments on well-known concepts of "space" and "time" from the basic university course of linear algebra [1]. In this paper, we specify the relation of these concepts with algebraic analogue of "space" concept from GIS ("point" concept and its generalisations). Specific characteristics and physical parameters of basic concepts like "point" and "space", their dynamic transformation and variability play an important role for GIS applications. But even more important is the computability of such characteristics using various methods in the interest of the end-user. In this paper, we provide examples of tasks that illustrate our theoretical foundations as a result of computer modelling. We also provide examples of variants of implementation of basic philosophical and computer ideas based on serial products produced by SPIIRAS-HTR&DO Ltd. for more than a decade. This series of products is called "Aqueduct".

Keywords GIS · Space theory · Monitoring system · Measure concept in GIS · "Aqueduct" system

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V. Popovich (✉) · A. Vitko
SPIIRAS Hi Tech Research and Development Office Ltd., St. Petersburg, Russia
e-mail: popovich@oogis.ru

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1 Introduction

In various scientific approaches and disciplines, e.g. in philosophy, one can find many definitions of space derived from such basic notions like existence and time [2]. Full spectrum of ideas related to notions such as space and time can be divided into two global directions:

- Substantial—Plato, Democritus, Newton, Descartes. Absolute existential autonomy of space and time that remains for all transformations of objects.
- Relational—Aristotle, Leibnitz, Einstein. Dependence of space and time on relations between objects, mass and velocity (here P. denotes the order of coexistence of objects, and B. denotes the order of relation and the order of events).
- Subjective-idealistic—Berkeley, Avenarius. P. and B. are derived from human capabilities to live through and to order events, to place them one after another.

For Kant, P. and B. are a priori forms of sensory contemplation, eternal categories of scene. In his theory of knowledge, Kant for the first time shifts focus from the object of cognition to the cognitive capabilities of the human himself [3]. Kant noted that two worlds exist: actual world (world of things-in-themselves), this world is unknowable, and the second one, visual world (phenomenal world), this world is knowable.

Fundamental remark made by classic metaphysicist Immanuel Kant states that concepts of space and time have no empirical source; i.e. this understanding cannot be derived directly from experience or directly from physical world. These concepts (space and time) are given, synthetic for human understanding and application in practice and in theory.

As a rule [4], modern scientists roughly fall under two groups: overt opponents and adherers of Kant's idea. We have no intention of getting involved in this debate, and we leave metaphysical problem of space and time beyond our focus. Since we regarding artificial systems united under the title computer science and technologies, for the given subject area there is enough evidence to suggest that Kant's idea is close enough to ideology of specialists in computer science and especially in geoinformation as well as modern means of design and development of large heterogeneous and distributed computer systems.

Mindful of the fact that we regard relative spaces in GIS subject area, it makes sense to address special branch of mathematics that operates notion such as space. In doing so, we must not forget that, despite the elements of applied science in it, geoinformation is fully anthropological and oriented firstly on human as a user, as a rule, in the form of convenient and intuitive interface. This topic is discussed in more detail in [4].

Furthermore, it must be noted that today traditional concepts such as "space", "set", "point" are widely used not only in theoretical research but also in practice, e.g. in programming. And here arise serious contradictions that come into sharp focus in geoinformation and in GIS applications. The notion of "point" is so abstract that it becomes harder and harder to apply it in practice, but at the same time it is necessary to preserve theoretical interpretation with affiliation with one of the types of mathematical objects that are applied to describe a subject area or a process. From an everyday perspective, from "human physical sense" point of view, it is impossible to define the concept of "point" as some universal, separate concept (only for the most simple cases, e.g. abstract for coordinate indication). GIS users along with common people always operate in at least three-dimensional space, unlike the point concept that can be understood as a centre of some local coordinate system only in some exceptional cases. This being said, it is difficult to talk about any stable positivity of this abstraction. Any attempts to apply GIS to solving practical tasks result in operations with a large number of abstractions and relations between them. It slows the development, support and efficiency of GIS operation. It is no secret that in various programming languages, e.g. Java, there is a sufficient amount of complex abstractions like point and line, familiar from prior programming languages. As a rule, these abstractions are used for identical notation of abstractions like "point" in Euclidean space. However, in object-oriented, or rather in object languages, we have "object" as an initial abstraction. The notion "object" cannot be interpreted in a similar way to algebraic notion "set". We are dealing with new concept that is closer to "category" concept [5]. Let us also note that "point" concept cannot be interpreted as a coordinate vector. Moreover, we cannot find analogue of abstract data types or algebraic types other than "object" concept itself. Note: It should be noted that many specialists–programmers believe that "object" concept is a further development of idea of abstract data types (N. Wirth et al.).

Thus, a question arises: What is an abstract notion "space" in GIS? For example, if we take the "point" concept for the basis, seeing that it is intuitively understandable concept for practical application in any space, after generalisation of "point" concept we can understand what space we have defined in GIS. The complexity of analysis of this concept increases from the fact GIS is at the same time a theory, a technology and a practical tool for the end-user, sometimes for the simple user, not a specialist. In the light of that, theory, technology and practice very closely interact and often change places in time in non-natural order (considering that we compare existing tradition in fundamental science, application-oriented technologies and pure practice). In computer science, it has been long indicated that practice-oriented technologies often outpace fundamental theoretical research [6]. It happens due to various reasons. Opportunity to start direct implementation of ideas using computer's functionality allows to "skip" the stage of fundamental research; however, as a matter of fact it is untrue. Stage of fundamental research is not "skipped", it is just not reflected in scientific papers and monographs, since it leads to lost time in idea implementation, and it is unfortunately required by modern business. Plus, an important factor is a problem of competition and many results are intentionally withheld by authors or employers with purpose of overtaking opponents.

As an interim conclusion, it may be noted that spaces in GIS can be defined through a set of formats (data, information and knowledge) that are necessary for realisation of required (by client or end-user) business analytics and logic. On the other hand, space in GIS can be defined (similarly to mathematics) as space with defined business analytics and logic. In the scientific literature [7], GIS is represented as a multidimensional space. Because of this, practically all paradigms of mathematical notion of "space" are either trivial and/or useless in the sense of complexity of interpretation. Nevertheless, it is necessary to clearly understand what we are working with and what are the capabilities (requirements) of interpretation. Without the formal definition of GIS, it is difficult to hope for successful development and implementation of GIS application in the long-term perspective. In this sense, space is a basis for systems and its modules specified (defined) for this space. Models act as blocks (initial) for business logic applications which are created for similar representation, study and analysis of objective and\or abstract reality. Indeed, when GIS is applied for relatively simple and traditional task like cartography and local system monitoring, this problem can be not so evident [8]. But when objective is to create, develop and implement global monitoring system (for example) based on GIS, the situation starts to spiral towards loss of control and the system takes life of its own incomprehensible for both developers and especially for users.

If one addresses subject area such as "data fusion in GIS" that can be considered as one variant of theoretical justification of methodology of global monitoring systems' design, it is easy to see that we are dealing with at least six different non-overlapping spaces (e.g. the idea of JDL model design [9] is shown in [7]). Bearing in mind the fact that, following Kant's hypothesis, concepts such as space and time are artificial (nonobjective), and GIS such as a science, technology and practical application cannot have objective fundament (basis). The most objective data can be considered as measurement data which can later have various interpretations and applications in tasks. It can, therefore, be deduced that any space in GIS is artificial. In practical sense, it means that one must be able to work with external data flow, preferably consisting of measurement data. Consequently, we must clearly understand that there are three principal parameters (categories): measurement time, measurement point and measuring tool. With time, a lot of data lose their actuality or their meaning. That is why categories such as time and space are crucial for GIS and for any system that uses GIS platform.

2 Definition of Space Concept

Having discussed "time" and "space" categories as crucial concepts for GIS, let us note that actuality of this discussion is enhanced by practical application of GIS in global monitoring systems. The concept of time is universal for the whole area of applied science that is related to GIS subject, and it is now difficult to imagine something special related to this concept (time). It is only worth noting that we can have various relative timescales. For example, in modelling of processes or of business logic one is able to slow down or speed up time of execution; however, it has no effect on the time concept itself. Sometimes, one can witness up to five (according to our practice) different timescales going in parallel or in succession. As a rule, such approach is applied in interactive (interacting with human) modelling systems.

Everything is much more complicated with "space" concept. Let us consider the previously noted fact that monitoring systems based on GIS contain six basic types of spaces (scientific subject areas), yet in reality their number can significantly increase and they should be regarded both separately and jointly.

As was mentioned in the preface to this paper, for common user, on the one hand, the most simple notion is "point", but at the same time, "point" is the most abstract concept from scientific and technological points of view. The concept of "point" itself is indeed a primitive concept that includes or points at some set of properties. However, "point" concept is not independent or universal. Without common notion of "space" or its specification in mathematical sense, the concept of "point" is meaningless. Addressing our subject area (GIS), "point" is not only a mathematical abstraction, and, above all, "point" in GIS is associated with several coordinates. At least, it can always be translated into coordinates. But, depending on context, point not only denotes coordinates and usually it has a whole number of properties, sets of characteristics and even methods (functions) to go with it.

For simplicity, let us consider different variants of point definition:

(a) One-dimensional case (point itself). The point has one coordinate but at the same time can have or point at a number of other parameters.
(b) Two-dimensional case (Euclidean space). The point has two coordinates and points at some non-empty of other parameters.
(c) Three-dimensional case. The point has three coordinates and a reference (pointer).
(d) Multidimensional case. The point contains coordinate vector and a reference.
(e) All cases listed above plus time. The point has additional parameter—time.

On the one hand, point is a fundamental concept based on which all other derived abstractions in GIS are formed. On the other hand, "point" abstraction should not be constant and should change according to the type of space. If we again return to JDL model, let us once more note that every level has its own specific space with specified business analytics (structure). Drawing attention to the fact that at this point GIS is applied for specific tasks belonging to one subject area, thus such spaces ought to strictly be non-overlapping, and otherwise one can get the whole system of contradictions.

Let us make another important observation. It is quite difficult to build a GIS system based on the idea of non-overlapping spaces using algebraic axiomatic approach [7]. It means that it is practically impossible to formulate a universal set of notions and definitions (ontology or ontology system) for all types of spaces in GIS. It is thus expected to apply evolutionary (not axiomatic) approach to building a GIS platform. Apparently, the creation of consistent axiomatics and theory is hardly achievable in the nearest future. Our reasoning implies that we can address the system of typical spaces matching the levels of JDL model (Fig. 1). For example, let us consider the system of applied spaces implemented in maritime monitoring system "Aqueduct" produced by SPIIRAS-HTR&DO Ltd.:

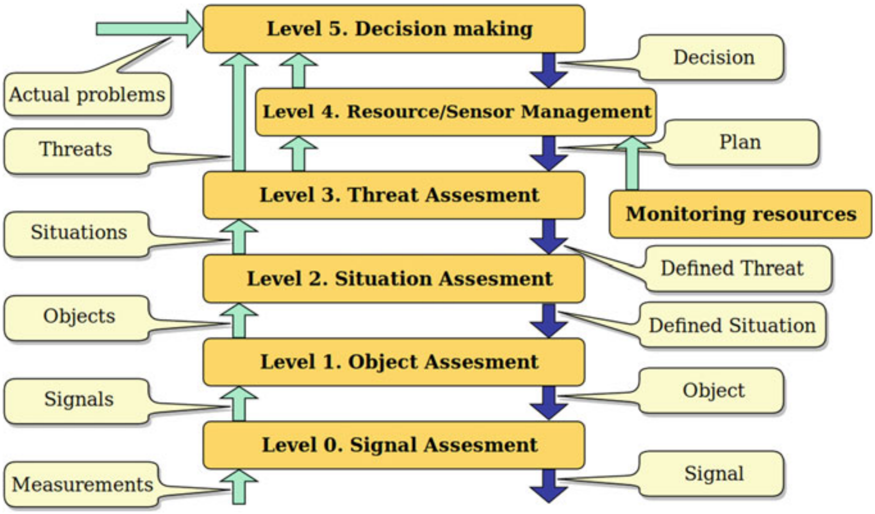

Fig. 1 JDL model for "Aqueduct"

(a) Zero or first level, space of measurements in one or several physical spaces (atmosphere, ocean, etc.).
(b) Second level, space of objects and their tracks.
(c) Third level, space of tactical situations (TSs). Tactical situation is a time sample of a state of the full range of spaces (subspaces): environment (atmosphere, ocean, etc.), available resources, challenges or problems, goals to be achieved. As a rule, TS space is specified beforehand and is based on scientific and/or expert knowledge, but it can be dynamically formed and/or added to using various mathematical and computer techniques.
(d) Fourth level, space of threats, challenges and hazards with their quantitative (preferably) assessment.
(e) Fifth level, space of available resources that can be used and applied.
(f) Decision space as a reaction to space of threats. It is also specified beforehand in the form of typical scenarios and templates; however, it can be crated dynamically in case of emergence of untypical threats and upon decision-maker's (DM) demand.

The example of maritime monitoring system illustrates that for the given subject area there exists a rather complex combination of various spaces that are closely interconnected with each other but have a fundamental difference which is a notion of "point in space" as initial abstraction with regard to GIS [10]. In short, the "point" abstraction can be specified as a measurement (of a signal), an object (physical or abstract), a tactical situation, threat, resource and decision [11]. Bearing in mind the fact that application aspect of research is of the most importance and interest for geoinformatics, a valid aspect arises regarding the concept of "measure" as the basis for creation of business analytics.

3 Specification of Measure on a Space

As was noted before [4], measure in philosophical aspect is a philosophical category and indicates uniqueness of qualitative and quantitative properties of some object. However, analysis of measure should be performed while taking into account the time interval in which the measured values are saved. "Measure" category is related to a certain number of philosophical definitions connected to ethics and aesthetics. In mathematics, measure is a common notion for various types of generalisations like Euclidean length, area and n-dimensional volume.

There are various specifications to the notion of measure (mathematical point of view):

(a) Jordan measure is an example of finitely additive measure or one of the ways of formalising notions of length, area and n-dimensional volume in Euclidean space.
(b) Lebesgue measure is an example of denumerable additive measure and is a continuation of Jordan measure on more vast class of sets.
(c) Riemann measure (Riemann integral) is an area of region under a curve (a figure between graph of function and abscissa).
(d) Hausdorff measure is a special mathematical measure. Necessity of introduction of such measure derived from the need to calculate length, area and volume of nonspecific figures that can be not specified analytically.

Along with the "usual" concept of "measure", application of Hausdorff measure in GIS opens new opportunities to expand business analytics in GIS applications and particularly in complex, multidimensional spaces. As an example, one may take calculation of a volume of acoustic field in two-dimensional (Fig. 2) and three-dimensional (Fig. 3) representation. This task cannot be solved analytically since it cannot be represented as one of the known analytical functions. There exists only a set of algorithms that executes this particular calculation.

Quite possibly, the same level of complexity occurs when calculating the volume of network filed coverage (3G, 4G, Wi-Fi, etc.) for the end-user with consideration of his real location in the environment (buildings, metal plating, etc.). Numerical values of such fields in space can be calculated (often only theoretically) if one knows environment's transfer function (Green's function). To do so, one must specify the Hausdorff measure and apply step-by-step calculation. It is possible to apply simulation modelling when the field is already known in the form of some data set.

Similar tasks are common in radiolocation. Our last research illustrates that radio wave propagation medium has almost the same stratification as sea water. Moreover, the period of changes and the scale of these changes are even more considerable in the atmosphere than in the ocean. Calculation of radar field for heterogeneous atmosphere is shown in Fig. 3.

All calculations shown in Figs. 2, 3 and 4 illustrate one major difficulty. A unified function or a system of such functions for execution of these calculations does not exist. It means that no inversion can be made for this calculation task. And for

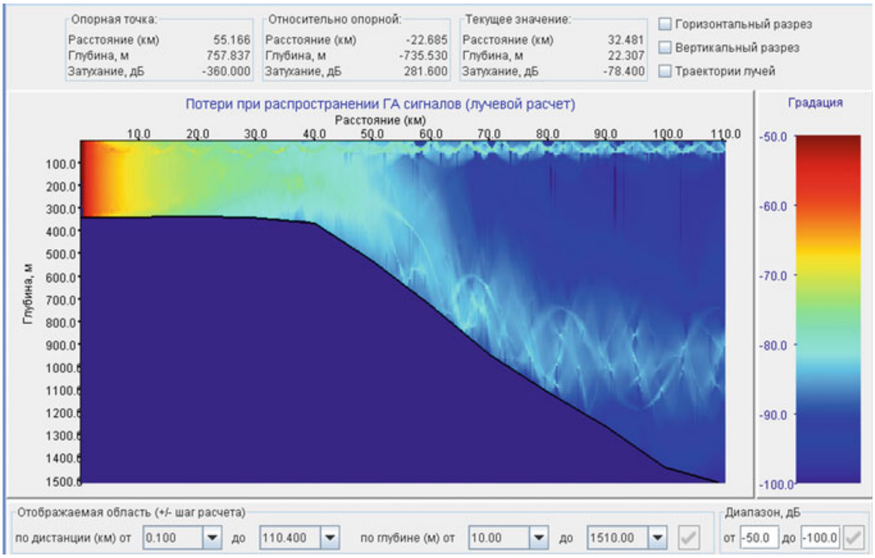

Fig. 2 Example of calculation of two-dimensional acoustic field

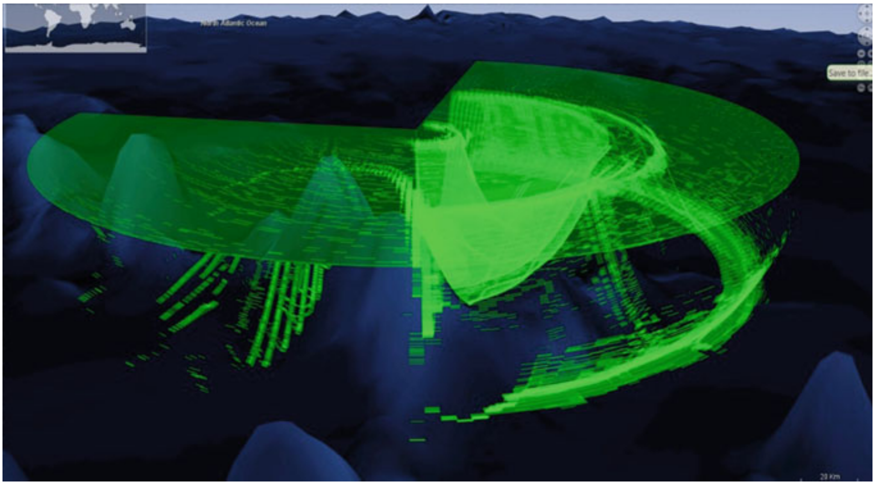

Fig. 3 Three-dimensional model of the acoustic field of acoustic source in the ocean