

# Spatio-temporal modelling and simulations in GIS – The principles

**RNDr. Tomáš Hlásny, PhD.**  
**Matej Bel University, Dept. of Geography,**  
**Tajovského 40, 974 01 Banská Bystrica,**  
**SLOVAKIA**  
**E – mail: [hlasny@fpv.umb.sk](mailto:hlasny@fpv.umb.sk)**

## Abstract

*The use of computer hardware, specific software solutions, rules of system approach, and variety of analytical methods, mainly from the field of mathematics and statistics, provide qualitatively higher approach to the dealing with problems in the space and allow adopting a lot of decision daily adopted by the society, objectively. This paper outlines the principles of spatio-temporal modelling within the frame of Geographic Information Systems. The paper consists of four parts – the general introduction to modelling and simulations (1), position of System Theory in this field (2), the issues of abstraction and its consequences, (3) and to exemplify these theoretical outcomes, geostatistical and TimeGis approaches to spatio-temporal modelling and simulations were demonstrated. (4).*

*Analysis of any real world system structure or functions supposes to design its model – by definition, the abstraction or simplification of reality that helps to generate testable hypotheses, which can be used to guide field studies by exploring conditions that cannot be manipulated in the field. The benefits of that are the economy of experiments, ability to deal with unreachable, long-term response and even unreal systems, and mainly the ability to experiment with a model in order to reveal and explain specific functional, physiognomic and temporal properties of the real world systems. A simulation is the experimentation with the model in order to discover its properties. A computer simulation derives from the fact that computers enable substitution of a broad spectrum of physical abstractions (models) with their digital (analogue) equivalents and provide a virtual world within which these abstractions might be manipulated. In this way modelling and simulation techniques became an organic component of dealing with problems in the space using Geographic Information Systems.*

*The abstraction is an introductory stage of any modelling – it serves to cope with original system complexness and to exclude its properties insignificant for the purposes followed. If we consider spatial data abstraction, the term of tessellation is being used, instead. This expresses the decomposition of the space and object embedded into the set of repeatable or unrepeatable objects, the information variability within the frame of which is neglected. This, so-called controlled reduction of the informational content might be accomplished in many ways and geoobject might, during its processing, undergo this process even several times. In this way the abstraction contributes significantly to the overall uncertainty amount of a model, with often undesired consequences for practical decision-making.*

*The theoretical background of modelling (of course not only) provides the System Theory established in 1940 and consequently adopted by the majority of sciences – not except goinformatics. It investigates both the principles common to all complex entities and to models, which are used to describe them. These general rules provide the foundations for variety of particular approaches to spatio-temporal modelling and simulations.*

## Abstrakt

*Využitie počítačového hardvéru, špecifických softvérových riešení, pravidiel systémového prístupu a množstva analytických metód, najmä z oblasti matematiky a štatistiky, vytvára kvalitatívne odlišný prístup k riešeniu problémov v priestore a umožňuje objektivizáciu množstva rozhodnutí denne prijímaných spoločnosťou. Tento príspevok je venovaný princípom časovo-priestorového modelovania a simulácií v kontexte Geografických informačných systémov. Príspevok pozostáva zo štyroch častí – všeobecný úvod k modelovaniu a simuláciám (1), pozícia Systémovej teórie v tejto oblasti (2), problematika abstrakcie a jej praktických implikácií (3) a špecifiká modelovania a simulácií v rámci GIS (4).*

*Analýza štruktúry, alebo funkcií akéhokoľvek reálneho systému vyžaduje zostavenie jeho modelu – podľa definície, abstrakcie, alebo zjednodušenia reality, ktoré umožňuje tvoriť testovateľné hypotézy použiteľné pri manažmente analýz reálneho objektu skúmaním podmienok, ktoré nemôžu byť navodené v realite. Prínosom tohto konceptu je hospodárnosť experimentov, možnosť pracovať s nedosiahnuteľnými systémami, systémami s dlhou dobou odozvy, alebo dokonca nereálnymi systémami a najmä možnosť experimentovať s modelom za účelom odhalenia špecifických funkčných a fyziognomických vlastností a časového správania reálnych systémov. Simulácia vyjadruje experimentovanie s modelom. Počítačová simulácia využíva skutočnosť, že počítače umožňujú nahradiť široké spektrum fyzických abstrakcií (modelov) ich digitálnymi (analogovými) ekvivalentmi a tým vytvárajú virtuálny svet, v rámci ktorého sú tieto abstrakcie spracovávané a analyzované. Týmto spôsobom sa modelovanie a simulácie stali organickou súčasťou riešenia problémov v priestore využitím Geografických informačných systémov.*

*Abstrakcia je úvodnou fázou akéhokoľvek prístupu k modelovaniu – slúži pre vyrovnanie sa s komplexnosťou originálneho systému a k eliminácii vlastností nevýznamných z hľadiska cieľov, ktorým má model slúžiť. V prípade abstrakcie priestorových údajov, sa používa termín teselácia. Vyjadruje dekompozíciu priestoru a objektov v ňom vložených do množiny opakovateľných, alebo neopakovateľných objektov. Toto tzv. kontrolované zníženie informačného obsahu môže byť realizované množstvom spôsobom a geoobjekt dokonca môže túto abstrakciu podstúpiť opakovanie niekoľko krát. Dôležitou skutočnosťou je, že tento proces významne prispieva k celkovej miere neurčitosti daného modelu, s často nežiadúcim vplyvom pre jeho využiteľnosť v praxi.*

*Teoretické pozadie modelovania (popri množstve ďalších oblastí) tvorí Systémová teória sformulovaná v roku 1940 a následne akceptovaná množstvom vedných odborov, pričom geoinformatika nie je výnimkou. Systémová teória sa zaoberá princípmi, ktoré sú spoločné pre všetky komplexné entity a modely použité pre ich popis. Pochopenie týchto pravidiel tvorí východisko pre množstvo čiastkových prístupov k časovo-priestorovému modelovaniu a simuláciám.*

## Introduction

The purpose of geosciences is to understand the complexness of the real world, reveal natural relations of its behaviour and, on these bases, to state its expected development. In practice, these tasks are hindered by, on one side, the imperfectness of human senses, which allow us perceiving only rough surficial features and dominant processes around, and, on the other side, by the complexness and certain randomness of the real world itself. To cope with these factors, real world systems are to be simplified and the models with controlled accuracy decrease that comprise all the information needed to reach the purposes followed are to be constituted. The benefits of using the models are the economy of experiments, ability to deal with unreachable, long-term response and even unreal systems, and mainly an ability to experiment with a model in order to reveal and explain respective functional, physiognomic and temporal properties of the real world systems. From the GIS point of view models of crime, economic models, models of disease and varmits spreading, or land allocation optimisation models are the results of a variety of spatial analyses supported by the abilities of structures for digital geodata storage.

## Spatial modelling in the view of System Theory

During the last decades, the majority of sciences, not except geoinformatics, have adopted the principles of System Theory as proposed in the 1940's by the biologist Ludwig von Bertalanffy (Bertalanffy, 1968) and furthered by the cybernetician Ross Ashby (Ashby, 1956). By definition, this is the "... transdisciplinary study of the abstract organization of phenomena independent of their substance, type, or spatial or temporal scale of existence. It investigates both *the principles common to all complex entities, and to models, which are used to describe them*. Rather than reducing an entity to the properties of its parts or elements, systems theory focuses on the arrangement of and relations between the parts, which connect them into a whole. Thus, the same concepts and principles of organization underlie the different disciplines (physics, biology, technology, sociology, etc.), providing a basis for their unification ...” (Heylighen, Joslyn, 1992).

Designing and analysing any spatial model is based on the *definition of the system on this model*, definition of its components, subsystems, its environment, mutual relations of the system and its environment, and the ways in which the system changes the environment and vice versa. Typical example of that provides the set network analyses (according to DaSilva et al. 1998ab, 1999) such as location-allocation problem, traffic optimisation problem or Chinese postman problem. The case of traffic system, or system of streets composed of subsystems of individual trails, and components such as houses, or sources/demands locations, prerequisites the system approach to be employed necessarily. Another example is the constitution of an erosion model – there is a basin defined as the system, individual watersheds as subsystems, and small abiotical areal units with homogenous runoff parameters as system components. The relations between individual components and subsystems are based on the gravity flows, exchange of water and material, etc. The system relations with the environment and environment itself are defined in line with the structure of underlying algorithm. Just breaking original system apart and processing its illogical portions could result in striking unbalances in the results of simulations. Namely the examples above (erosion and network modelling), and many others of this kind, could result in unrealistic outcomes of

respective simulations, mainly in the cases when the system environment or flows of material exchange are defined incorrectly.

As can be seen this approach is particularly important when dealing with functional dynamic systems, where the topology of geoelements, and the directions and ways of matter, energy and information flows play a crucial rule. On the other side, static, descriptive or strictly structural models do not need these principles to be employed, necessarily. Unfortunately, in practice we often meet the fact that study areas are being delimited regardless the structure of systems analysed, thus a model constituted does not reflect the fundamental natural relations of the original.

The definition of the system on the model we are dealing with, prerequisites the use of the rules of **system analysis**. According to Heylighen and Joslyn (1992) ...

*... the system analysis was developed independently of systems theory and applies system principles to aid a decision-maker with problems of identifying, reconstructing, optimising, and controlling a system, taking into account multiple objectives, constraints and resources. It aims to specify possible courses of action, together with their risks, costs and benefits.*

From the spatial modelling point of view, system analysis focuses either on system spatial structure, its functions or on the analysis of relationships rising from this approach – how the structure influences the functions and how the functions form the structure. If we consider the analysis of system functions and structure as two fundamental points of system analysis, this might be summarized into the following steps:

Analysis and synthesis of system structure consists of

- The analyses of the relations between individual system components, their character and intensity and their contribution to the stability and compactness of the whole
- The analyses of the system topology, evaluation of its complicatedness and character of relations (cyclic, acyclic, positive, negative, etc.)
- The decomposition of the system into its parts able to fulfil autonomous functions
- The composition of the system to reconstruct it from its autonomous subsystems, components and relations, inclusive the homogenisation of its heterogeneous properties

Analyses of system behaviour consists of

- The analyses of the system behaviour as a whole, i.e. the definition of the only class of its behaviour, as a resultant of mutual relations between functions of its parts, inclusive system environment
- The analyses of the system processes, i.e. the definition of the all stages of the processes employed (initial, intermediate, final), inclusive underlying mechanisms
- The analyses of extended system behaviour, i.e. the determination of qualitative and quantitative characteristics of respective processes as the parameters of functions of system components and relations (according to Mitášová et al. 1990)

System analysis and synthesis allow understanding system structure and behaviour, determining its weak parts and optimising its functions. If we consider spatial systems, this concept appears outstandingly important in, for example, land exploitation optimisation, designing ecological networks, flows modelling, etc.

## Modelling and simulations

Spatial analyses, modelling and simulations are undoubtedly the most interested and appealing parts of GIS being a “climax” after time consuming and tedious data input and processing. In this part we focused on the foundations of spatio-temporal modelling within the realm of GIS terminology and concepts. To make this field clearer, the terminology according to several authors will be introduced.

By definition, a **modelling** is the process of discovering certain object properties by means of its projection that contains some of the properties important for the purposes followed (Šutek, Varga 1981). A **model** is the abstraction or simplification of reality that helps to generate testable hypotheses, which can be used to guide field studies by exploring conditions that cannot be manipulated in the field (Turner 2001). A **simulation** is the experimentation with a model in order to discover its properties. The prominence of **computer simulations** derives from the fact that computers enable substitution of a broad spectrum of physical abstractions with their digital (analogue) equivalents and provides a virtual world within which these abstractions might be manipulated. In this sense, a **system modelling** is one of the basic knowledge-building processes, and **simulation** is a knowledge-evaluation technique, which enables inquiry into the possibility of knowledge and the limits of this possibility (Bargiela 2004). By geostatistical definition, a **model** is the best approximation of the phenomenon considered, while **simulations** describe all the possible states taken on by individual model variables. This will be explained in more details below.

Important concepts of modelling are the **isomorphic** and **homeomorphic** approaches. In the case of isomorphic model, each model component corresponds to one component of the original system and vice versa. These are mostly the models of simpler and smaller real systems. On the contrary, in the case of homeomorphic models, each model component corresponds to one component of original system, but *not* vice versa. It means, that some of real world components are not considered. In the case of cartographic maps it touches the concept of generalisation.

According to Bargiela (2000), the essence of simulation and modelling is the characterisation of real-world objects by:

- set of abstract entities,
- relationships between these entities and
- set of unique mappings that give the abstract entities a real-world interpretation.

In this sense, positional, temporal and attribute real world properties correspond to their model counterparts by means of so-called reference frames – spatial, temporal and attribute. In fact, these are a set of parameters (e.g. equations) assigning to each position in time and space, or to certain property of a real world object its simplified counterpart in the model. From the more general point of view, this might be any mechanism assigning to any real world entity its model counterpart – satellite scanner technical parameters, various laboratory methods for data evaluation, etc. Logically, in geoinformatics the spatial models, i.e. the projections of spatial properties of real world components play a crucial rule, thus the problematic of spatial reference frames belongs to those best developed.

According to Turner et al. (2001), Goodchild et al. (1993), Mitášová et al. (1991), Isaaks and Srivastava (1989) and others, there are to be distinguished several groups of models. Theoretically, the most comprehensive one is the real world model, in GIS literature often referred to as **conceptual world** (Lauriny and Thompson, 1982). This comprises, after the abstraction, all the real world components – information on the spatial characteristics of

the objects considered, their functions, temporal behaviour, attributes and respective relationships. Practically, such a complex model is unreachable and if, a great deal of abstraction is required, so it serves for the academic purposes, only. To meet the needs of practice, this concept is to be narrowed and partial, more specialized models are to be used.

If discarding temporal and functional components, it might be spoken about *spatial descriptive and static model* – for example a map. *Structural models* describe primarily the spatial distribution of model components and relationships. These are for example aircraft model or urbanistic plans. On the contrary, *functional models* could discard the structural component and depict primarily the mechanisms of model behaviour. *Dynamic models* comprise the information on the temporal behaviour of its components – it might be a model of insolation describing spatially the intensity of relief insolation during certain period, intelligent traffic system models or fluid propagation model. If discarding the spatial component, a *set of numerical time series* might express the phenomenon considered, effectively. In these cases also the *mathematical dynamic model* might be used, which uses for example the systems or differential equations to describe model dynamics.

Besides, the mathematic, schematic, inductive, deductive, substancial, normative, mechanistic, process-based and many other kinds of models might be distinguished. Many of them might coincide with the category of spatial models, thus their use in a GIS environment is straightforward.

Important concept related to spatial modelling is **probabilistic modelling** that expresses the statistical probability of occurrence certain phenomenon or action. Into this group belong for example geostatistical modelling, which follows the statistical description of source data set, or Bayesian modelling, which derives the probability of occurrence different phenomena by means of a set of indirect proofs, etc. The comparison of these approaches for the ecological purposes elaborated Hlásny (2005). Probabilistic modelling is a counterpart of **deterministic modelling** based on the exact knowledge of the most desirable information brought to bear on the problem of modelling (Olea 1999). The stochastic model is often referred to as a counterpart of deterministic model.

Different, technical view on this problematic, introduced Pequet (1984), who proposed three steps of constituting a model within the frame of GIS. These are the following:

- Real world is to be expressed in the form of appropriate data model
- Appropriate data structure is defined to describe the data model
- Appropriate data format is defined to store the data structure

An example of that is to express the relief by means of digital elevation model, raster structure with appropriate spatial parameters are defined, and *USGS DEM* format is used to store the data.

## Abstraction, discretisation, tessellation

Abstraction is a key point of any approach to modelling. In this regard Harvey (1969) stated that

*“In reality any system is infinitely complex and we can only analyse some system after we abstracted from the real system“.*

Abstraction is based on the definition of a system on the object of interest, coping with its complicatedness and exclusion of its insignificant properties. According to Mitášová et al. (1990), the abstraction grounds in the assignment of source objects (in the case of spatial data, the space and objects embedded) into the classes, thus the model comprises only the information of classes defined, instead of the information of original objects features. The most common example of that is the use of raster structure, where the class is defined as the smallest spatial element. Logically, the information variability within this unit is discarded and only a representative value is being used, instead. This so-called controlled decrease of the informational content is a key issue of modelling - just keeping this process under control facilitates the modelling and the restrictions of a model are easily defined.

Discretisation of the space is the simplest way of abstraction due to its feasible algorithmisation, and the fact that individual objects, such as houses or parts of road and river network, are implicitly defined as independent uniquely identified objects. The concept of discretisation, in a GIS literature often referred to as tessellation, appears problematic when dealing with continuous phenomena such as elevation or pollution. In this case the discretisation is based on the decomposition of the phenomenon treated into the set of regularly or irregularly distributed points, and missing values are being interpolated (Kemp 1993). Openshaw (1983) stated that this process pose a threat of the transformation of naturally heterogeneous units into homogeneous region with possibility of discontinuous transition on the edges of regions delineated.

Laurini and Thompson (1994), Robinson et al. (1995) and Worboys (1995) introduced several basic approaches to the tessellation. The authors distinguished regular tessellations, where belong space decomposition into the squares, pentagons, octagons and other regular geometric object. The group of irregular tessellations comprises building of triangular irregular networks, Dirichlet's (Voronoi's) tessellation (building of Thiessen polygons), decomposition of space into parcel, soil units, or other natural or artificial spatial units (Fig.1).

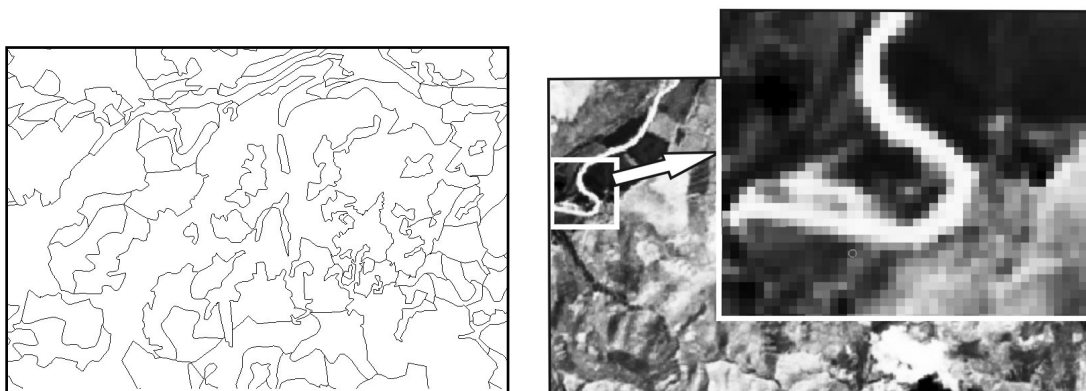


Fig. 1. Irregular tessellation by means of natural objects (soil units) and regular tessellation by means of artificial units – pixels (satellite imagery).

All these approaches might be employed in the plane or in the sphere, and some of them might be carried out recursively, i.e. a basic element is decomposable into the elements of the same form.

As far as non-spatial (attributal, temporal) data abstraction, this is given primarily by their acquirement (accuracy of measuring instrument, sampling design, etc.) and by their further processing (rounding, outliers removal, classification, etc.). In these cases, the uncertainty analysis is much simpler, since a variety of statistical analysis might be used, even in the case of multiple information aggregation procedures.

## **Uncertainty – natural consequence of modelling**

Recently, a great deal of attention of the GIS community has been paid to the phenomenon of uncertainty and to the uncertainty management. Important works from this field have been published by Foody and Atkinson (2002, eds.), Zhu (1997), Brown (1998), Agumya and Hunter (1999) and others. The abstraction is one of the fundamental contributors to the overall model uncertainty contributing to all the “difficulties” with consequent model handling and to the interpretation of the results of simulations. In this regard, the extreme case might be term as the over-abstraction (Eastman, 1999).

As stated above the abstraction is a *controlled decrease of the informational content*. This means that we know the errors and insufficiencies that appeared in this process and the restrictions of a model are exactly known. In general, there are two ways in which the uncertainty due to the abstraction steps in – the first one is simple omission of some real world elements (homeomorphic models, might be a matter of generalisation) and is easy to be evaluated. The second one, a little bit trickier, comes from the simplification of real world object either by generalisation of aerial and linear object, by discretisation of continuous phenomena, or, on the contrary, by inferring population data from sample data set, for example by means of spatial interpolation. In the last case, the abstraction and consequent uncertainty are define by rules of statistical inference, straightforwardly.

The problem is that a model is often derived from several (many) data sources that could underwent various levels and kinds of abstraction, thus to asses such a complex restrictions is rather problematic. This issue became much more complicated, if we consider that the datum often undergo the abstraction several times repeatedly – the contours are first time simplified when being drawn on paper map, second time when being redrawn by tablet, to derive a DEM the TIN model is to be derived, to overlay TIN model with satellite imagery, TIN is to be transformed to raster structure, etc. In this way the uncertainty propagates through all the stages of the constituting of a model, what is to be considered when using a model and interpreting results of simulations.

Besides, the abstraction is not the only uncertainty source – extra portion of uncertainty comes from algorithms used, individual analyses and, specifically, from the temporal predictions. These areas go beyond the scope of this article.

## Particular approaches

Dealing with time and space within the frame of digital geodatabases might be considered as the spirit of GIS. Spatial modelling and particular analyses are facilitated by both the set of mathematical and statistical methods and analytical tools typical of and belonging to GIS. Just the methods such as relief morphometry computation, comprehensive set of network analyses, or spatial interpolation belong to those significantly extending the abilities of standard methods (in fact, the references on these all might be found many decades before the age of GIS, but just the commence of this technology popularised them widely). All these methods provide the underlying algorithms for comprehensive modelling capabilities described above. The field of applications is extremely wide, touching all the areas of spatial science. This part is to introduce two modelling and simulation concepts bringing certain specifics in terminology and methods into the spatial science – geostatistical and TimeGIS approaches. Besides, these provide unique look just at both spatial and temporal dimensions of modelling.

### The specifics of geostatistical approach

Geostatistics, as the science using database and visualisation techniques of GIS, has brought a specific terminology and modelling capabilities into this field. Since this approach differs, in many aspects, from those described above, we introduce its concept and the way in which the modelling and simulation are being perceived.

By geostatistical definition, a **model** is an optimal (or most probable) approximation of the phenomenon that is being modelled (to avoid confusing, in geostatistics the term of model often refers to the variogram or other function describing the spatial variability of the phenomenon considered). On the contrary, **simulations** express all the possible states, not just optimal ones, which are to be taken on by respective location with regard to certain probabilistic mechanism. These are of a great importance when assessing the uncertainty due to the estimation procedure.

To step deeper, the probabilistic background of geostatistics according to Matheron (1971), Journel and Huijbregts (1978), Olea (1999), and others should be outlined. In this realm, we consider the phenomenon treated as a result of stationary random function  $Z(x)$  that is an infinite family of random variables constructed at all points  $x$  of a given region  $D$ . The advantage of this approach is that we shall only try to characterize simple features of the random function and not those of particular realisations  $z(x)$  (Wackernagel, 1998). Since the random function is stationary (second order stationary), it has a covariance and its mean and variance are constant over all given spatial domain. In this way, the modelling might be based on the assessing the residuals from the constant mean (either known or unknown) by means of weighted linear combination of the available samples with regard to the random function covariance (but also different approaches have been developed). In this way, a model might be constituted. For more details see Matheron (1971), Isaaks and Srivastava (1989), Wackernagel (1998) and others.

The simulation uses these bases, and following known probability distribution function and variogram (covariance function), all other states, inclusive those with the smallest probability, are estimated. This might be of a **conditional** form, if the random function coincides with the source point data set, or unconditional, where only the density distribution function and variogram are honoured. This results in a discrete structure expressing the actual variability at a location, instead of the most probable value.

Theoretically, the average of a large number of simulations gives a model. This can be seen in Fig. 2. For these purposes a number of simulation techniques was developed such as Gaussian Sequential Simulation, Turning Band Simulation, etc. The simulations are useful in models classification taking into regard the uncertainty due to the estimation, volumetric calculation, etc.

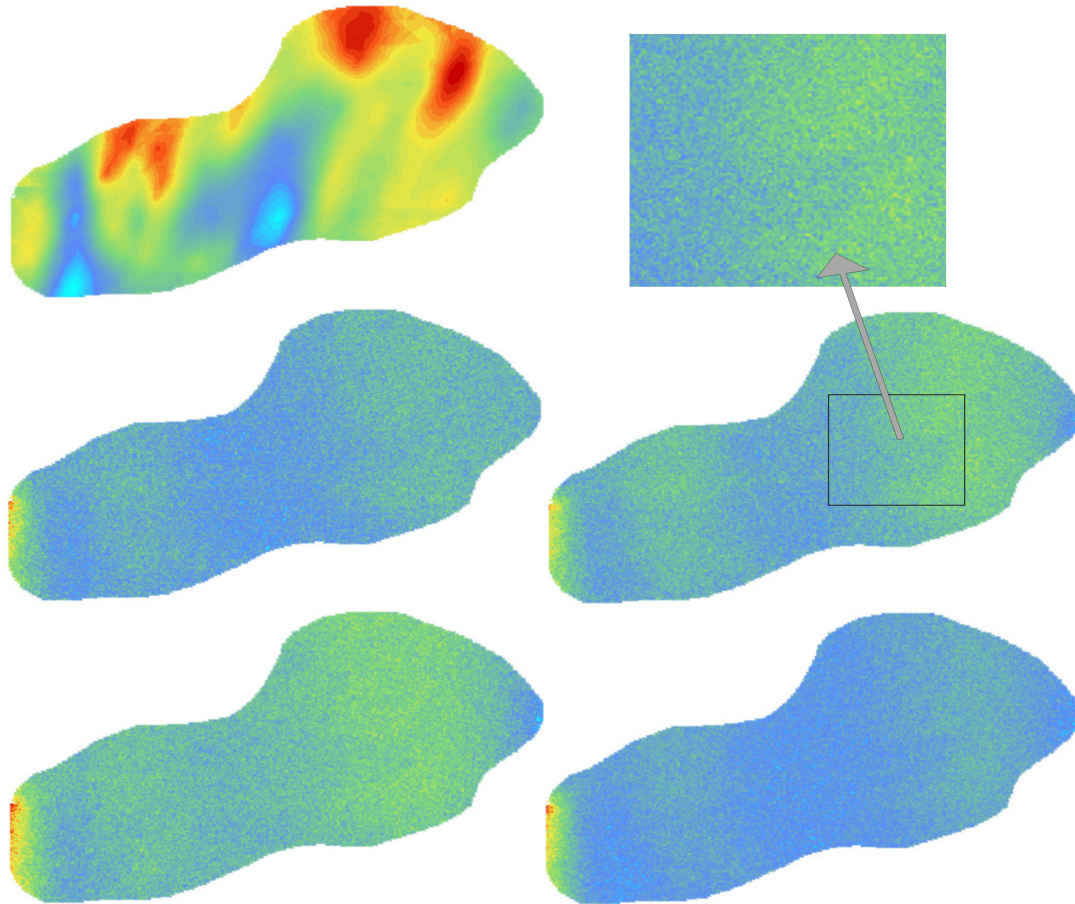


Fig. 2. The model derived by means of ordinary kriging procedure (upper left) and the result of four simulations derived from the same sample data set by means of Sequential Gaussian Method / Simulation.

### **TimeGIS approach**

As stated above, the analyses of spatial and temporal phenomena and processes are those, which are the focus of geoscientists. Analytically, these two components are being processed separately, since the time of integrated spatio-temporal geodatabases has not come, yet. While the concepts of spatial data processing are well known in the GIS community, the concept of temporal modelling lays in the less known field of Time GIS terminology, data structures, and statistical time series analyses. (Worboys 1992, Yuan 1997, Ott and Swiaczny 2001, Hlásny 2003, and others). In general, it is still quite rare to integrate complex spatial and temporal geodata in one database, following the TimeGIS concepts and principles, as specified recently. Besides, the difficulties with complex spatio-temporal modelling come from the lack of GIS software solutions providing convenient tools. In this regard, the users

are thrown back on statistical packages or on specialized Time Series Analyses softwares, although the data exchange is not just straightforward.

In general, spatio-temporal modelling in the frame of GIS might be approached in two ways. The first one, which this paper focuses on, is that using Time Series Analyses techniques capabilities, system approach and TimeGIS principles. This focuses mainly on providing time series compact description, estimating model parameters, checking/validating a model, and on understanding the underlying processes generating the data. The objective is also predicting one time series based on other one, forecasting and simulation studies (Sahu, 2003). TimeGIS theory, according to Worboys (1992), Yuan (1997) or Ott and Swiaczny (2001) define both the concepts of spatio-temporal geodatabases and physical structures for spatio-temporal data storage. In practice, spatio-temporal models are mostly restricted to the use of so-called *snapshot structure*, i.e. a set of horizontally overlaid temporally stable layers. This, however, provides very weak modelling and simulation abilities. This might be effectively extended into some of more sophisticated forms, such as *Temporal Map Set Model*, *Spatio Temporal Object Model*, *Event Based Spatial Temporal Data Model*, etc. (described by the authors above), but, for the time being, these remain in theoretical position, mostly. Despite these facts, growing demands for accurate spatio-temporal data will force these areas develop rapidly. Contradictory, one reason of the stagnation of this field is less-demanding users community, where the projects requiring complex spatio-temporal analyses are still quite rare.

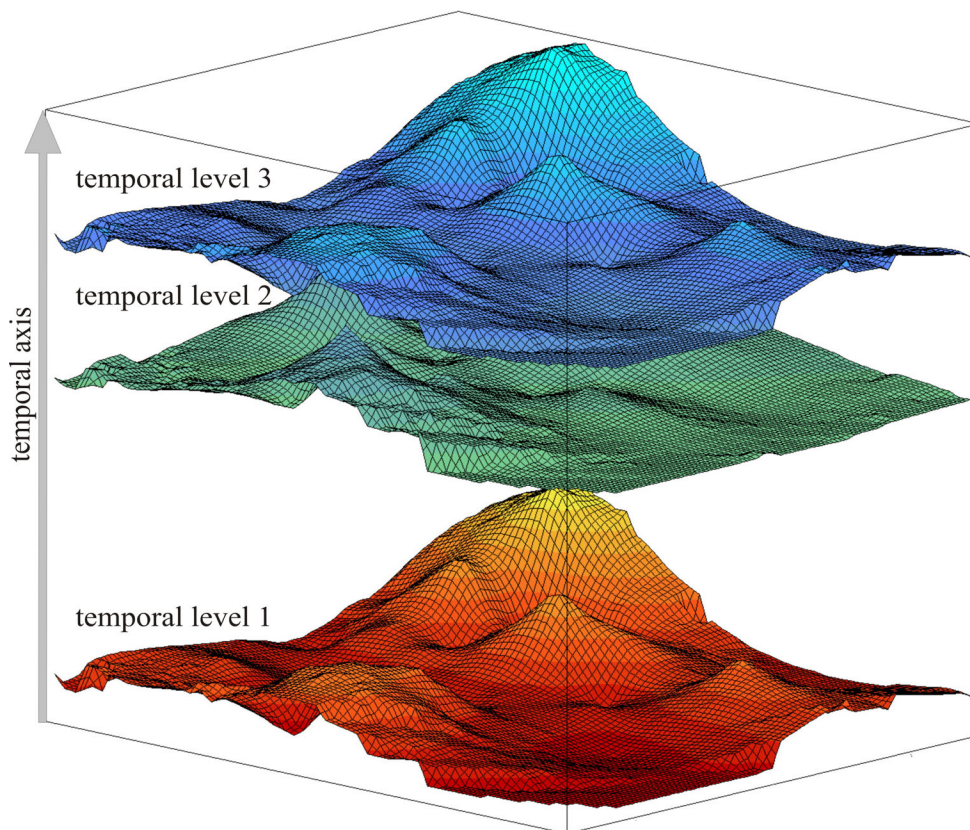


Fig. 3. The example of snapshot model storing three temporal levels (ground radon concentration, unequal time step between measurements).

The second, much more “practically” oriented stream is that providing (near) real time services, often combined with specific technologies for wireless data transfer. This, unambiguously, represents the main course of recent spatio-temporal applications. Mentioned *(Near) Real Time Systems*, focus mainly on the monitoring dynamic phenomena such as traffic, pollution, or weather and on providing real-time responses. In general, simulations, or more specific spatio-temporal analysis are of a smaller importance. Might be just the connection of these two streams responds the needs of future.

## **Conclusion**

This paper was to bring general outlines of modelling and simulation techniques from the GIS perspective. The width of this area doesn't allow elaborating complex overview within the extent of several pages, thus we focused on certain foundations of modelling and simulation techniques, useful regardless the area of application. Stepping deeper, this field definitively requires the study of System Theory and some parts of cybernetics, along with particular fields of application, such as geostatistics, Time Series Analysis, hydrology, economics, forestry, etc. Just this connection supported by the technology of GIS provide effective tool of complex spatio-temporal modelling and simulation.

Often forgotten point is that the technical managing of spatial analyses, without understanding the geographic reality and concept of space itself, remain an empty tool. The result of correctly carried analyses might be ripped off the reality without the knowledge of structure, functions and behaviour of respective natural or social-economic systems. In this view, just the preservation of traditional “non-computer” approach along with the theory of spatial analyses move the frontiers of knowledge forward. Understanding the relief does not mean the knowledge of goniometric function, but the knowledge of its genesis and ways in which it influences the processes around. Understanding the city does not mean to know its size and number of habitants, or the ability to extract the data from municipal database, but to know natural relations of its inner structure, development, function, and relations with its surroundings. On the other side, recent trends of research head towards the narrow specialisation of individuals and problems are handled within the teams of specialists, hence the need of wide horizon of knowledge is fading. Undoubtedly, this brought much more effective research environment.

## **Acknowledgement**

This study is supported by grant VEGA No. 1/1368/04

## References

- Agumya, A. and Hunter, G. J., 1999: Translating uncertainty in geographical data into risk in decisions. In *Proceedings of the International Symposium on Spatial Data Quality* (Hong Kong: Hong Kong Polytechnic University), pp. 574–584.
- Ashby, R., 1956: Introduction to Cybernetics, 1956
- Bargiela, A., 2004: Specialist Physics Book, Computer Simulation and Modelling Series, <http://www.doc.ntu.ac.uk/RTTS/rsp-sm.jpg>
- Bargiela, A., 2000: Strategic Directions in Simulation and Modelling, (paper invited by the Conference of Professors and Heads of Computing as a contribution to the UK Computing Research Strategy CPHC Meeting, Manchester, 6-7 January 2000), 5 s.
- Bertalanffy L., 1968: General Systems Theory,
- Brown, D. G., 1998: Classification and boundary vagueness in mapping presettlement forest types, *International Journal of Geographical Information Science*, 12, 105-129.
- Da Silva, A. N. R.; R. S. Lima, A. A. Raia Jr and P. Van der Waerden, 1998: Urban Transportation Accessibility and Social Inequity in a Developing Country. In: Freeman, P. and C. Jamet (eds.) *Urban Transport Policy: A Sustainable Development Tool*. Proceedings of the International Conference CODATU VIII, 709-714, Cape Town, South Africa.
- Da Silva, A. N. R.; R. S. Lima and P. Van der Waerden, 1999: The Evaluation of Urban Network Patterns with a Global Accessibility Index in a GIS Environment. Paper accepted for the 6th International Conference on Computers in Urban Planning and Urban Management, Venice, Italy.
- Da Silva, A. N. R.; P. Van der Waerden and H. Timmermans, 1998: Intra-Urban Accessibility and Land Values in Developing Countries. Paper presented at the 8th World Conference on Transportation Research, Antwerp, Belgium. Davidson, K. B. (1977) Accessibility in Transport
- Footy, G.M., and Atkinson P.M. (eds.), 2002: *Uncertainty in Remote Sensing and GIS*, John Wiley and Sons Ltd.
- Heylighen, F., Joslyn, C., 1992: What is System Theory, Principia Cybernetica Web, <http://pespmc1.vub.ac.be/SYSTHEOR.html>
- Hlásny, T., 2003: TimeGIS – časový aspekt digitálnych geoúdajov, In: *GIS Ostrava 2003*, Růžička, J.(ed.), on CD
- Hlásny, T., 2005: Probabilistic approaches to ecological modelling, In: *Ekológia* (Bratislava), accepted
- Isaaks, H.E., Srivastava, R.M., 1989: *Introduction to Applied Geostatistics*, Oxford University Press

- Journel, A.G., Huijbregts, CH.J, 1978: Mining Geostatistics, Academic Press London
- Laurini, R. & Thompson, D., 1982: Fundamentals of Spatial Information Systems, Academic Press, San Diego
- Olea R.A., 1999: Geostatistics for Engineers & Earth Scientists, Kluwer Publishers
- Turner M., Gardner H.R., and O'Neill V.R., 2001: Landscape Ecology in Theory and Practice, Patterns and Process, Springer-Verlag, New York
- Worboys, M. F., 1992: A model for spatio-temporal information. Proceedings: the 5th International Symposium on Spatial Data Handling, 2, pp. 602-611
- Matheron, G., 1971: The theory of regionalized variables and its application, Les Cahiers du Centre de Morphologie Mathématique de Fontainebleau
- Ott, T., Swiaczny, F., 2001: Time-Integrative Geographic Information Systems, Springer, Berlin/Heidelberg/New York
- Sahu, B. K., 2003: Time Series Modelling in Earth Sciences, A. A. Balkema Publishers Lisse/Exton (Pa)/Tokyo
- Wackernagel, H., 1998: Multivariate Geostatistics, Springer - Verlag, Berlin
- Yuan, M., 1997: Temporal GIS and Spatio-Temporal Modeling, The University of Oklahoma, [http://www.ncgia.ucsb.edu/conf/SANTA\\_FE\\_CD-ROM/sf\\_papers/yuan\\_may/may.html](http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/yuan_may/may.html)
- Zhu, A.X., 1997: Measuring Uncertainty in Class Assignment for Natural Resource Maps under Fuzzy Logic, Photogrammetric Engineering and Remote Sensing, Vol. 63, No. 10, pp.1195-1202