Spatial-temporal modeling and visualisation

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Abstract **—**This paper considers a number of properties of space-time covariance functions and how these relate to the spatial-temporal interactions of the process. The processing of five temporal series is presented to show the difficulties to determine and visualize recognized space of object states. This work is focused on the temporal GIS that will be able to examine human activities under various constraints in a space–time context. The contribution of space-time geographical object understanding and the possibility to analyse the complex spatial-temporal relationships to improve cognitive processes is discussed. The object oriented approaches are inherently connected with object dynamics and activities resulting in interactions and this point of view can help us to understand space of states that could have significant implications to our everyday life.

Keywords **—** Activities and interactions, comparative point transform, object behavior (dynamics), space-time GIS.

I. INTRODUCTION

A. Decision Making

The quality of decision making is always dependent on the quality and quantity of information about issues and for this reason certain properties of objects are observed, which are important from the decision-making process aspect [1], [2]. And our decisions are becoming increasingly dependent on understanding of complex relations, deep context and dynamics of phenomena in the world around.

Information requirement rapidly increase, namely information that is related to previously obtained results and theirs interpretation, type of used context and trends evaluation, project-related experiences and know-how [3].

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The changing society needs changing approaches to real world observation, modelling, analysis and evaluation. The concept of the time plays the significant role in our life and all our thoughts about the history, present time as well as about the future is not relevant enough without accounting the temporal axe, without state transition modelling and interactions understanding. The current development of computers contributes to the investigation of dynamical features of our world.

B. Geographical Information Systems

GIS technology is becoming an integral part of the information infrastructure in many organizations. The unique integration capabilities of a GIS allow using information layers to create a complete picture of a situation.

GIS technology illustrates relationships, connections, and patterns that are not necessarily obvious in any one data set, enabling organizations to make better decisions based on all relevant factors.

This technology is also being used via the Internet and Web services, open new to manage the business of government. GIS is demonstrating real business value.

For the future the static GIS is ineffective at spatial-temporal data processing and temporal information is useful in answering many questions and to understand better the dynamic world. Dynamics involves a state that can be observed and modified.

This way of complex solving and problem understanding is very important for losses minimization.

The approach allows us to create significant geographic knowledge by organizing data, analyzing and modelling various processes with using of relationships and interactions in spatial temporal space.

In order to evaluate and visualize spatial-temporal data, it is usually necessary to develop a specific temporal model for given type of the task [5].

C. Spatial-temporal Data

Because of the complexity of spatial-temporal data we usually need in fact to work with spatial-temporal data represented in different data models [5]. For example, temporal data of population, public health, environment and climate, public security as well as public safety, land use or transportation are able to answer many interesting questions and of cause may be represented in different data models. Therefore, there is a need for temporal GIS which will be able to work with spatial-temporal data represented in different models [6], [7].

On the other hand, working with temporal information and provide it can contribute to the temporal GIS formation as well as to the temporal oriented spatial databases. Temporal GIS it includes: to store, manage, process and visualize time-varying spatial data.

This technology of data processing and spatial analysis, together with modern decision analysis techniques promote new styles of knowledge communication and utilization. This requires complex communication and collaboration by many people with different educational backgrounds.

D. Requirements

The different requirements of the sophisticated methods can be described by the set of factors and coefficients, but these factors are often connected to the critical characteristics coming from the selected area and surrounding objects that can influence the estimation quality.

The great part of parameters can be successfully put more precisely with the aid of expert knowledge. But the current trends are oriented on knowledge-based databases, the use of previous project results, application reuse and creating of picture of human activities and possible impacts.

II. TEMPORAL GIS

A. Space-time Modeling

The temporal and contextual design of spatial data and further development of geo-information technologies, image processing techniques and the possibilities of object history modelling together with the geographical networks environment will provide quite new and considerably wider possibilities of using GIS.

GIS architecture is open to incorporate new requirements of temporal and knowledge-based analysis and modelling, namely in connection with web designed spatial databases and temporal oriented approaches. This type of geo-information processing it is the resource, tool and means. It is modelling in most common sense.

Structural approach connected with spatial data arrangement in GIS using spatial reference system – localized information layers is not enough in many disciplines that can benefit from temporal GIS [8], [9].

Temporal GIS is an important tool for disaster management and the development of recovery strategies. Analysis of spatial-temporal data can be a useful technique for the prediction of the aftereffects of natural disaster, such as flooding, fires, earthquakes. By evaluating of historical data, we can help to evaluate the risk of events associated with natural disasters.

Especially environmental science can use the wide-range applications of this technology to monitor the regional resource use, water resource monitoring, the evaluation of the effects of climate change [10]. Spatial temporal analysis has great potential to advance the understanding of environmental trends and the impact of change.

B. Temporal GIS

Dynamical GIS, space-time context, should be based on common spatial and temporal reference systems to be able working with spatial-temporal data represented in different data models and supplemented appropriate links with possibility to aggregate, separate and generalize parts and wholes in **temporal dependence.**

However, the specific introduction of the term dynamic GIS creates a different viewpoint and allows more sophisticated ways of the use [11] - [13]. We will need new methods including those for discovering activities and interactions (co-locations, co-occurrences, decomposition).

Every state of object can be decomposed if we need to describe more exactly object behavior (having adequate temporal data in disposal). There are still many aspects that must be resolved including spatial as well as temporal data resolution.

Dealing with this approach we are facing also the difficulties in generating spatial-temporal space of quality data for analysis, the necessity of interpolation or integration of observational data [14].

C. Object Dynamics

Object dynamics it means be able to model object behavior, identify object states and understand the activities influencing the transitions into states along temporal axe.

We have to take into consideration the interactions between objects they affect object behavior. Moreover, we need time-series visualization technique in disposal to describe the space of temporal states [15], [16].

As the complexity of systems increase, so does the importance of good modelling techniques. To describe object dynamics we have to identify **states** and **events** that result in a change of the state.

And to be successful in dynamics modeling we can use well known modeling tool like UML (The Unified Modelling Language) is. Moreover UML is now the standard notation for modelling.

The state is a set of attribute values and links of the object at any given time. It represents a stage in the lifecycle of object it has name, attributes and operations (activities) that are related to the state.

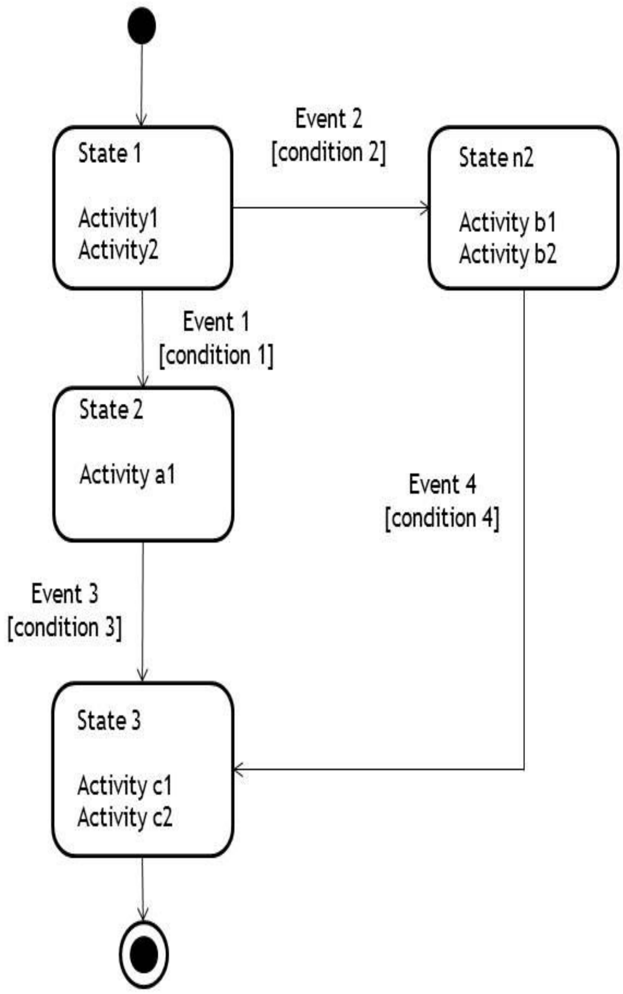

Fig. 1 Graph shows the state space of the object of a given context, the events that cause the transition from one state to another and the actions that results.

Initiative from one object to another is an event and response of the object to the event depends on its condition.

The state has time duration while the event is instantaneous and of course we model states in the direction of temporal axe and consider **the start** and **the end.** Decision is used to extend a simple transition to describe multiple output transition. It is possible include **condition** – fig.2.

When an event occurs, the next state depends on this event and current state. Change of the state caused by events is the transition.

Each transition can be specified with an event that triggers the transition together with condition that is evaluated before transition and possibly with action that is done during the transition – see fig. 1.

To describe the behaviour it means to show the sequence of states that an object goes through during its life in response to received stimuli, together with its responses and actions.

D. Object Interactions

Special type of object behavior modeling using so called action states where the transitions are triggered by completion of actions enables investigate interactions between objects.

A pattern of interactions among objects is arranged in time sequence and shows the objects participating in the phenomenon and maps the interactions between them.

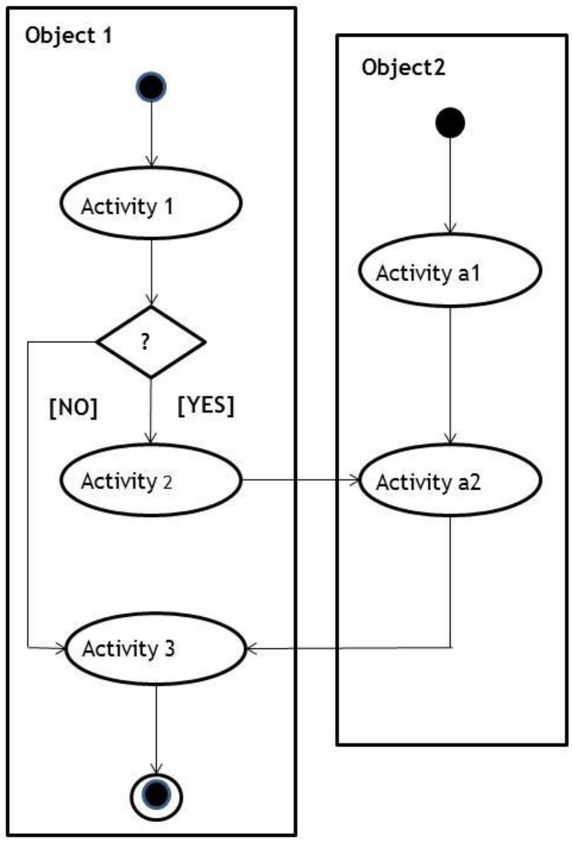

Fig. 2 Graph shows an example of interactions between Object1 and Object2.

E. Temporal Analysis

One of the new aspects will be the temporal context investigation, which can stay on different levels of application. There is no life without the time consideration.

There is no past and no future. And the natural process connected with time accounting is real analysis of changes. Further development it is the question of accessible information, knowledge-based decision making and context sensitive analysis applying.

Spatial-temporal investigation can be used to monitor fire situation, seasonal and flash floods, construction activities, forest management, environmental and navigation situation, urban management, agricultural activities, municipal field services, investment, and etc.

Usually the goal is to get very good and well-founded estimate of the object or phenomenon development in the context of the dynamics of the surrounding.

Spatial-temporal and contextual modeling is to locate the area or areas where the given criteria apply and eventually calculate the measure of exposure to hazard, find the optimal routes and submit different complex scenarios. Together with the expert knowledge we can set the ranges and find the areas with defined ways of protection.

As an example we can present simple way of time- series processing. We have five temporal layers – the results of textural classification of aerial data from the period of fifty years. It means our object is forest body in the selected area.

To evaluate and effectively describe object or phenomenon dynamics we propose the simple way how to describe and visualize the state space of the object (without interactions) using *Comparative Point Transform* which is designed for 3 – 8 temporal layers – binary images. The method is based on RGB colour system. We will compute components I_R, I_G, I_B to create colour image in fig. 3 with specification of 32 object states.

III. TIME-SERIES VISUALIZATION

A. Comparative Point Transform (CPT)

Let us assume we have temporal layers

$$T_k = (x,\ y) \qquad k = 1,\ 2,\ ...,\ n$$

classified with respect to selected object or phenomenon the dynamics of which we are going to investigate. The reasonable range of temporal layers used in one comparative analysis is about 3-8, taking into consideration that the result has to be distinguished for human perception of possible temporal states.

In case n = 4 layers it means 16 temporal states of object but for n = 5 layers it is 32 states to express – see fig. 3, 4.

We propose to define comparative point transform as follows:

$$I_R = a_1 T_1 + a_2 T_2 \tag{1}$$

$$I_G = b_1 T_2 + b_2 T_3 + b_3 T_4 \tag{2}$$

$$I_B = c_1 T_3 + c_2 T_4 + c_3 T_5 \tag{3}$$

where T_1, T_2, T_3, T_4, T_5 are values of one pixel in each of the layer we suppose the binary images (object is found , object does not occur).

I_R, I_G and I_B are values of the same pixel of the red, green and blue component of the result colour synthesis.

Coefficients a, b and c for $n = 4,5$ are presented in Table I.

B. CPT – More Temporal Layers

On the basis of the preceding considerations, it is possible to achieve the set of equations for *n* = 6, 7, 8. When 6 - 8 temporal layers are analysed we must compose each component separately.

It actually means:

$$I_C = \frac{1}{3} T_k + \frac{2}{3} T_{k+1}, \tag{4}$$

where $k = 1,\ 2,\ ...,\ 7$ for two layers per component and

$$I_C = \frac{1}{7} T_k + \frac{2}{7} T_{k+1} + \frac{4}{7} T_{k+2} \tag{5}$$

where $k = 1,\ 2,\ ...,\ 7$ in the case of three layers per component and I_C stands for I_R, I_G or I_B .

The result shows the complexity of state space already for 5 temporal layers. But it would be possible before the analysis more exactly specify what the subject of our interest is.

The result is without considering interactions with other objects that may influence forest dynamics. This means that the model will be necessary to ensure the specifications and conditions of their control, define and evaluate the extent of interactions and find a way of problem decomposition.

In case of long term temporal analysis (fig. 3) we can see and understand the forest in historical development. Before the Second World War forest disappeared because of fortress building on the border, after world war the new roads have been constructed and later new forest domains occurred.

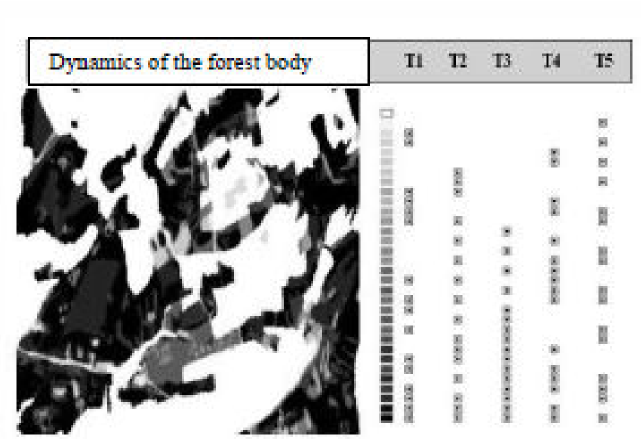

Fig. 3 Colour state space of comparative temporal analysis of 5 temporal layers, describing the dynamics of the body of forest.

Construction of power plants has resulted in severe pollution and forests on the windward side were heavily damaged.

TABLE 1

Coefficients of equations for n = 4, 5. The computerized process using comparative point transform enables to evaluate qualitative as well as quantitative the development of temporal object or phenomenon along the selected temporal layers.

n	a_1	a_2	b_1	b_2	b_3	c_1	c_2	c_3
4	0,75	0,25	0,5	0,5	0	0,25	0,75	0
5	0,6	0,4	0,2	0,6	0,2	0	0,4	0,6

We can also recognized and evaluate the effectiveness of interventions carried out in connection with the operation of power plant.

We expect that the proposed method can be used for many different purposes such as analyses of urban growth, environmental impacts, transportation and others.

IV. SPATIAL-TEMPORAL VARIABILITY

A. Spatial-temporal Models

We are working with spatial-temporal random field [17]

$S(q) = S(l, t)$ is a function of location $l = (x, y)$ and time t.

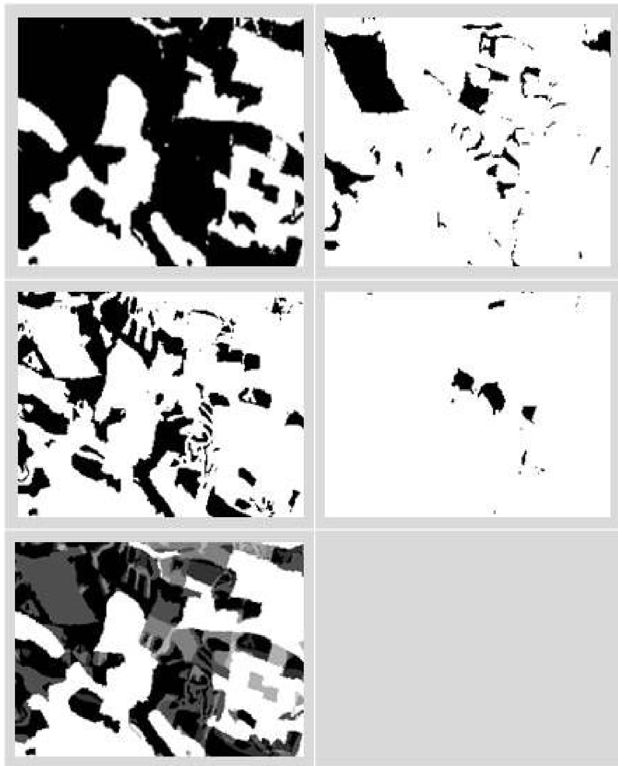

Fig. 4 Complex and temporal states of the object are shown.

To express covariance between spatial-temporal points q and q^* we can use formula as follows:

$$Cov(q, q^*) = E[(S(q) - \mu(q)).(S(q^*) - \mu(q^*))] \quad (6)$$

Spatial-temporal processes and the difficulties connected with modeling of spatial-temporal data structures can be overcome using separable processes. This subclass of spatial-temporal processes has several advantages namely simple extensions of developed techniques.

Major advantage of these processes is that covariance function can be express as the sum of covariance for location and time.

In terms of type of the spatial temporal process, sometimes is assumed to be stationary to simplify computation but in fact most of processes from practice are non-stationary.

B. Spatial Temporal Covariance Functions

This part concentrates on space-time covariance functions and on the way how this covariance functions describe space-time interactions [18] – [20].

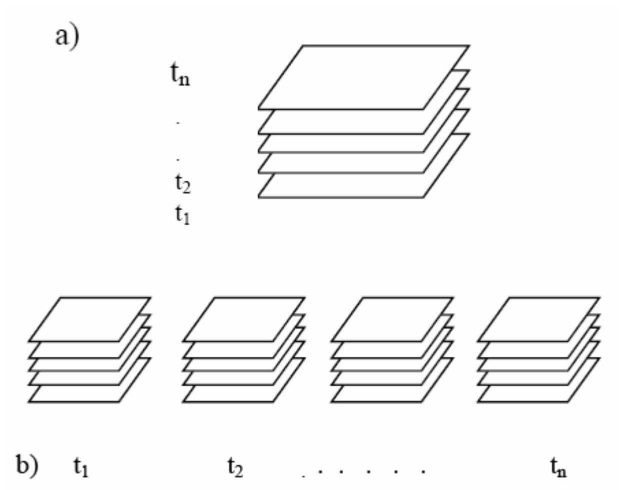

Fig. 5 Two main types of S-T models a) the model for one type of temporal object b) model for temporal object with selected interactions.

Different classes of spatial-temporal covariance functions (spatial-temporal interactions):

- Separable covariance functions
- Totally symmetric covariance functions
- Asymmetric covariance functions
- Compactly supported covariance functions
- Stationary covariance functions (in time, in space, in time and space)
- Non-stationary covariance functions [17], [21].

The last named class of functions gives the best description of covariance function of the processes but it is not easy to estimate it.

Separable covariance functions, although not describe the covariance function as well as non-separable like, but this approach is far more flexible for estimating and modelling of covariance functions and gives the possibility to estimate covariance function more precisely from the data – see fig. 6.

C. Stationary covariance function

Stationary covariance function can be distinguished as:

- **Separable** - spatial and temporal component can be separated as follows:

$$Cov(l,t) = Cov(l) + Cov(t) \qquad (7)$$

$Cov(l,t)$ is covariance function assuming that functions are positive semi definite.

The sum or product of spatial and temporal covariance functions is the simplest way to estimate spatiotemporal covariance function.

$$Cov(l,t) = a1\,Cov(l).Cov(t) + a2\,Cov(l) + a3\,Cov(t)$$

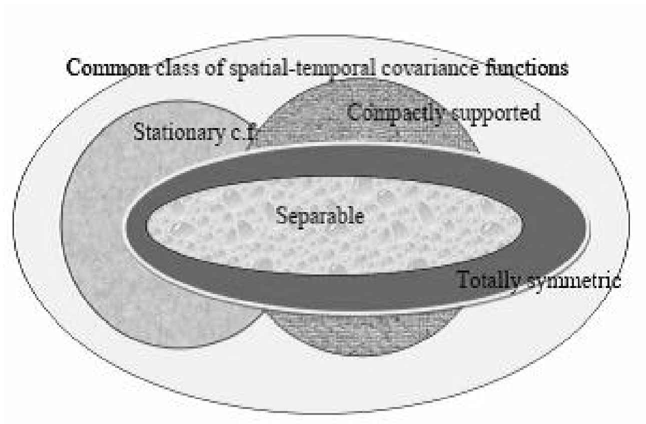

Fig. 6 Classes of spatial-temporal covariance functions

C. Stationary covariance function

Stationary covariance function can be distinguished as:

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Although separable covariance functions are not the best mean of modelling of interactions, but they can be used to derive from them non-separable covariance functions using different types of **mixture** methods [22] – [24].

These methods are based on purely spatial and purely temporal covariance functions and using specialized approaches we can mix spatial temporal covariance function (for example - positive power mixture).

Also the cosine transform can be used to create non separable covariance function from purely spatial and temporal covariance functions.

Under certain assumptions we can create covariance function using methods like: Fourier transform, stochastic differential equations, stochastic representation …

D. Covariance function Parameterization

To be able to set up different parameters of covariance function to estimate spatial temporal covariance function as well as possible we take into account other possible properties of covariance functions.

- **Totally symmetric covariance function**

$$Cov\left(S\left(l_1,t_1\right), S\left(l_2,t_2\right)\right) = Cov\left(S\left(l_2,t_1\right), S\left(l_1,t_2\right)\right) \quad (9)$$

is usually used when interaction with significant influence is taken into account, but did not show up. For example to describe the spread of pollution in case of no wind or no predominant wind direction.

Convex combinations of fully symmetric space-time covariance functions might well provide improved fits and improved prediction skill for environmental space-time datasets.

- **Compactly supported covariance function**

It means that for sufficiently large distances in space and in time or just in space or just in time, is zero.

We can use also isotropy – it is the characteristic of natural processes or data where the spatial dependence varies only with distance, direction is irrelevant (isotropic covariance function).

Many spatial covariance functions are isotropic if they are not non-stationary and many spatial-temporal covariance functions are isotropic in space if they are not non-stationary in space [24], [25].

V. CONCLUSION

In this paper, the problem of spatial temporal GIS is addressed and the different ways of future development is discussed as well as the problem of wide spatial and temporal context. This work considers a number of properties of space-time covariance functions and how these relate to the spatial-temporal interactions of the process.

There is a real and motivating need of good statistical models. Each model is affected by data so that there is no model that best fits to all the data.

The processing of five temporal series is presented to show the difficulties to determine and visualize recognized space of object states. It shows the complexity of state space without considering interactions with other objects that may influence object dynamics.

Our decisions are becoming increasingly dependent on understanding of complex relations, deep context and dynamics of phenomena in the world around and geographic information technology is able to incorporate these new requirements and produce more valuable results. Well-founded strategies for spatial temporal modelling are still great demand of geo-statistics and GIS.

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