Abstract — The paper is focused on the temporal GIS that will be able to examine human activities under various constraints in a space-time context. The paper discusses the contribution of space-time geographica l object understanding and the possibility to analyse the complex spatial-temporal relationships to improve cognitive processes. 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. The simple time-series analysis is presented to understand consequences of spatial-temporal space of object states.

Keywords — Space-time GIS, object behavior, activities and interactions, time-series visualization, comparative point transform

I. INTRODUCTION

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 [3], [4].

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.

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.

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 [4].

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.

II. TEMPORAL GIS

A. Space-time Modeling

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.

Dynamic 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.

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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].

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].

B. Temporal Analysis

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 1937 – 1999. 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 \( I_R \), \( I_G \) and \( I_B \) to create colour image in fig. 1 with specification of 32 object states.

III. TIME-SERIES VISUALIZATION

A. Comparative Point Transform

Let us assume we have temporal layers
\[
T_k = (x, y) \quad k = 1, 2, ..., n
\]
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. 1.

We propose to define comparative point transform as follows:

\[
I_R = a_1 T_1 + a_2 T_2 \tag{1}
\]
\[
I_G = b_1 T_1 + b_2 T_3 + b_3 T_4 \tag{2}
\]
\[
I_B = c_1 T_3 + c_2 T_4 + c_3 T_5 \tag{3}
\]

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.

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 \( I_B \).

Dynamics of the forest body

Fig. 1 Colour state space of comparative temporal analysis of 5 temporal layers, describing the dynamics of the body of forest from 1937 to 1990.
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.

<table>
<thead>
<tr>
<th>( n )</th>
<th>( a_1 )</th>
<th>( a_2 )</th>
<th>( b_1 )</th>
<th>( b_2 )</th>
<th>( c_1 )</th>
<th>( c_2 )</th>
<th>( c_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.75</td>
<td>0.25</td>
<td>0.5</td>
<td>0.5</td>
<td>0.25</td>
<td>0.75</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
<td>0.6</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Fig. 1 shows the complexity of state space already for 5 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. 1) 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.

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]

\[
S(q) = S(l, t) \text{ is a function of location } l = (x, y) \text{ and time } t.
\]

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

\[
\text{Cov}(q, q^*) = E[(S(q) - \mu(q))(S(q^*) - \mu(q^*))]
\]

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 product of covariance for location and time.

B. Fuzzy Approach

In the last years, also fuzzy logic is often implemented successfully in various GIS processes [18] - [20]. Important implementations were made in the fields of classification, analysis, data collection and in remote sensing [21].

The GIS practice deals with many activities with fuzzy behavior and this is the reason why fuzzy approaches should be modeled appropriately also for temporal GIS.

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.

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.

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