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A NEW CONCEPT OF MULTI-SCENARIO, MULTI-COMPONENT ANIMATED MAPS FOR THE VISUALIZATION OF SPATIO-TEMPORAL LANDSCAPE EVOLUTION

Abstract: In this paper, we propose a new approach to the presentation of the spatio-temporal evolution of landscape using a multi-component multi-scenario animated map system. The concept of multi-scenario map was introduced with a few conceptual level objectives. Firstly, to facilitate understanding of geographic spatio-temporal changeability (especially landscape changeability) by the use of complex cartographic animations. Secondly, to investigate factors which influence an intuitive and effective use of multi-component cartographic applications. In relation to understanding processes, the overriding purpose was to build up a generic approach that allows users to recognize features of complex geographic phenomena. Finally, since the implementation of the concept was of importance, a prototype has been prepared.

Keywords: animated map, cartographic animation, cartographic visualization, the Kampinos Forest

1. INTRODUCTION

Cartographic visualization of spatio-temporal changeability is a task that requires extensive knowledge and experience. This kind of visualization is one of the biggest cartographic challenges (Plit, 1998), in addition to such issues as cartographic generalization or effective use of interactivity. Spatio-temporal visualization focuses on various geographic phenomena and needs to be accurate to allow a broad range of potential applications. It can be used for simple cartographic communication as well as an interactive tool for analysing spatio-temporal processes. Such visualization can be also treated as a sophisticated analysis and inference instrument for the exploration of spatio-temporal patterns.

The need to represent series of time stages that show the sequence of states or events is a fundamental problem associated with visualization of spatio-temporal geographic changeability. Different strategies can be used to address that issue (Monmonier, 1990; Meksuła, 2003); they may also include static and dynamic/animated methods. However, when visualizing spatio-temporal geographic changeability, it is sometimes not enough to display a simple sequence of static maps or one cartographic animation. In some cases a standard map component needs to be combined with other graphical components (modules) to identify the associations between different variables (Monmonier, 1992). These extra components can be both interactive and non-interactive. Climate studies and natural hazards monitoring are examples of domains where such a "multi-component" approach could be useful. For example, while representing changes of the Arctic Ocean ice coverage, series of maps could be presented together with a global overview map, diagrams and plots describing climate conditions for selected weather stations. In another example, when the volcano activity is visualized on the animated map, characteristics of the temperatures of spring waters could be presented by means of charts or diagrams. Such an approach was implemented in the Geo-Spatial Warning System described by Jenny et al. (2006).

Multi-component visualizations – maps linked with other visualization techniques – seem to be ineffective in case of static elaborations (due to the lack of interactivity and limited space). It leads to some conclusions concerning the superiority of animated interactive interfaces to static cartographic displays, even if the results of comparative studies on animated and static maps are inconclusive (Fabrikant *et al.,* 2008) and even if animations do not conform to the "apprehension principle" (Tversky *et al*., 2002). Moreover, we agree with the suggestion of Fabrikant *et al.* (2008) that the usefulness of cartographic animations depends on individual human differences, and therefore it is difficult to be conclusive about the usefulness of such visualizations.

Although our research challenges are manifold, the main goal is to offer a proposal of a generic methodology of multi-component, multi-scenario animated maps presenting spatio-temporal geographic changeability with a focus on the changeability of geographic landscape. It is also noteworthy that we intend to propose a solution that could be applicable to any region and any type of landscape. The aim is not only to meet the specific functional requirements of the case study presented in this paper, but also to define a general cartographic methodology for any visualization that requires different sets of components.

2. COMPLEX CARTOGRAPHIC ANIMATIONS PRESENTING THE SPATIO-TEMPORAL CHANGEABILITY

Over the past two decades cartographic animations have grown into various forms – data exploration tools (Ogao and Kraak, 2002), helpful didactic instruments (Harrower *et al.*, 2000), means of communication of information, etc. Due to the animations' particular ability to "congruently" represent the passage of time (Tversky *et al.*, 2002), these seem to be well suited for visualizing geographic spatio-temporal changeability. Because of their ability to represent temporal continuity, they facilitate understanding of entire processes rather than discrete states (Harrower *et al.*, 2000). In other words, events are shown directly in real time, therefore geographic changeability may be shown generically and immediately (Oberholzer and Hurni, 2000).

While the main advantages of cartographic animations have been described in the literature of the subject, potential areas of practical use of animated maps are still to be discovered. In prior studies, considerable efforts have been devoted to the usability aspects as well as investigating the usefulness of animations for knowledge extraction. The problem of accurate presentation of geographic changeability by means of multi-component animated maps has not as yet been tackled directly. Some projects dealt with this idea partially, e.g. dynamic cartographic sequences called "graphic scripts" presented by Monmonier in 1992. These sequences were composed of maps juxtaposed with statistical diagrams and blocks of text to explore the temporal patterns and geographic correlations. A partial continuation of the Monmonier's concept can be noticed in the GeoVISTA project – a visualization tool for knowledge extraction. In that project, several applications were invented, also with animations (Hardisty *et al.*, 2001). However, first of all they are multicomponents (Takatsuka and Gahegan, 2002; Hardisty, 2009) and their main purpose is to support spatial data exploration. Another project which should be mentioned here it is the concept of the *Atlas Information System* (Jenny *et al.*, 2006) or the concept of the *Multimedia Atlas Information System – MAIS* (Hurni, 2008), a kind of multi-component cartographic product with predefined themes in the form of maps connected with other presentations that may include animations (Oberholzer and Hurni, 2000). Finally, the multicomponent "nature" that links various visualization techniques is visible in the map of the Gruben Glacier prepared by Isakowski (2003). This suggestive and well-designed cartographic animation comprises an animated map and selectable diagrams.

Our concept of multi-component animations presenting geographic changeability should be placed close to the Monmonier's idea, somewhere between the MAIS concept and the GeoVISTA concept. Various tools and solutions also have to be borrowed from GIS applications. However, to make the best possible multi-component visualization, predefined components and map functionality should be based on a thorough study of the presented topic.

In case of cartographic visualization of spatio-temporal changeability by means of multi-component animated maps, the palaeogeographic changes can be recognized as a particularly interesting theme. The understanding of landscape genesis is in fact one of the fundamental issues when investigating contemporary landscape processes.

There are surprisingly few examples of animated maps that visualize landscape evolution. Cartographic animations that present the movement of tectonic plates are the most frequent in this group, while palaeogeographic reconstructions by means of animations are rather occasional. Why is it so? Cartographic reconstruction of landscape genesis is a challenging and extremely time-consuming task which requires cartographic skills and broad knowledge about the contemporary processes that shape the landscapes. Moreover, the lack of animated maps' methodology, especially with the multi-component approach, is noticeable here.

The preparation of temporal multi-component animated maps requires a generic methodology with workflow instructions. Thus, the following questions are of great concern: What components (maps, animations, timelines, controllers, etc.) are needed and in what cases they should be included when composing visualisations on landscape evolution? In what way should the interface be arranged? Which interactive tools could ensure the best contribution in the process of knowledge acquisition? How could continuous animation be prepared on the basis of discrete data?

3. MULTI-SCENARIO AND MULTI-COMPONENT ANIMATED MAPS PRESENTING SPATIO-TEMPORAL CHANGEABILITY OF LANDSCAPE

When preparing an animated cartographic visualization, e.g. a complex map presenting landscape evolution, the basic question always refers to the reason for the use of the animation. In other words, the use of animation or of multiple components (equipped with various interactive tools) or arrangement of interface elements and cartographic design are factors which depend on the purpose of the map. They all rely on the inference tasks the map should support. In turn, these tasks are closely connected with the nature of the depicted area.

3.1. Map components

The range of the content depends not only on the goals of the animated map. It also – first and foremost – depends on the nature of the region presented on the map. The content and components of maps presenting e.g. the evolution of the swamp area are different from the content and components of maps depicting coastal dunes. A similar difference can be noticed between maps of permafrost regions and these that illustrate U-shape valleys;

between maps of volcano genesis and those concerning the genesis of a mountain chain. The components also depend on the spatial and temporal scale. For example, the design of the timeline component as well as its level of details depends on the temporal scale. It means that the timeline component should be more detailed when the visualization of the landscape's evolution (the more key events) is more precise.

The variety of used components depends on the topics and areas presented on animated maps illustrating landscape evolution. In general, two kinds of components can be distinguished: fixed and variable.

The most important fixed component is the main map window comprising the animation of landscape changes. It is of great importance to place this component in a strong point of the interface and to supplement it with a legend. In addition to the main map window, in order to be useful, every animated map illustrating landscape evolution should contain the following fixed elements:

– control panel with basic functions for displaying animation,
– time display panel,
– panel which displays names of periods (phases, cycles, etc.),
– timeline panel with movable slider for temporal navigation.

The second group of components is hard to clearly define. The list of possible components should be developed with the support of experts representing disciplines linked with the theme presented on the map. Apart from nuances and sophisticated components for which specialized knowledge is required, the following "common" components can be listed (in random order):

– *Additional animated map,* the content of which can be watched simultaneously with the main animated map. The visual complexity of the main animated map negatively influences the efficiency of human perception. Therefore, in some cases the content of the main map may be split into separate animated maps. For example, while visualizing changes of the land cover, changes of climatic conditions may be displayed on the additional animated map.
– *Map with a settable time stage* that allows to display, in a static form, the most suitable time step or event. This component may be useful while comparing events or facts from different time stages.
– *Overview animated map covering broader geographic context.* Very often, the area presented on the main map is not enough to precisely interpret the presented phenomenon (e.g. landscape evolution). Therefore, a wider geographic area should be visualized together with the region visible on the main map. Obviously, the area has to be visualized on a smaller scale and in a more generalized way. Owing to this, the user is able to analyze the detailed information about the most important part of the landscape and to compare it in parallel with a broader region. For instance, the main animated map of the visualization of the evolution of a volcanic island arc can be juxtaposed with the small animated map of the whole subduction zone.

- *Overview animated map with extra thematic information*. While interpreting the main map, sometimes supplementary information about broader thematic characteristics is required. An interesting solution is to include a small animated map providing specific content. For example, the genesis of the Namib Desert (the main animated map) can be displayed, accompanied by a small animated map illustrating the cold Benguela ocean current along the west coast of Africa.
- *Set of static thematic maps*. An interpretation of the main animated map may even better serve the knowledge acquisition process, if the static thematic maps of the same region are displayed beside the main map. Of course, there is no way of predicting what set of thematic maps is the most suitable because it depends on the general theme of visualization.
- *Static or animated cross-sections*. The main animated map can be supplemented by various cross-sections: through the atmosphere, water bodies or rocks. For example, an animated cross-section through the rocks can help to understand the animated map that illustrates the landform evolution in the karst environment.
- *Static or dynamic profiles*. For example, static soil profiles of selected points may provide valuable information as to when ecological succession is presented on the main map.
- *Static or dynamic graphs, diagrams, scatter plots, parallel plots, etc.*, describing various geographic characteristics of the whole area (e.g. climate trends throughout the presented periods) or of selected measurement points.

The list described above encompasses only the most basic components. There are also other examples, such as static or animated block diagrams, commentaries, photos or movies, which facilitate understanding landscape changeability. Due to their obvious nature, no additional explanation is required here.

Not all components are needed on the map interface at one time. For instance, some themes might be portrayed more effectively when the complex visualization is composed only of two or three modules – e.g. the main animated map juxtaposed with one static thematic map. Others themes for good performance require more components. According to this, if restraining the group of components can bring any benefits to inference making, this should be done. The simplest way for achieving that is to predefine the most suitable sets of components – “map scenarios”, with well-considered components and their limited amount.

3.2. Map scenarios

In order to be useful, multi-component animated maps should be structured around two aspects: content and a functional point of view. This is the cartographer’s task to investigate the presented theme and the possible ways of using the complex animated map, and to predefine the most suitable sets of components. We termed these specific sets “map scenarios”.

Not all available components should be included in the map’s interface at once. Furthermore, not all available components are relevant and suitable for visualizing the evolution of various landscapes. Thus, not all components are simultaneously required by potential map users. For example, while preparing the complex animated map that illustrates the evolution of a fictitious forest area in the period between the 12th and 19th century, the following sets of components (scenarios) might be planned:

1. Scenario aimed to provide a general insight into the land cover changes (presented on the main animated map linked with a static relief map) in the broader geographic context (presented by means of the animated small map presenting geographic context).
2. Scenario for investigating physical features of the region (the main animated map, selectable geologic cross-sections and selectable soil profiles).
3. Scenario for investigating the relationship between land cover changes (the main animated map) and general changes of climate conditions (static graphs and charts).
4. Scenario targeted at getting a deeper insight into geomorphologic processes that might influence the land cover changes (the main map juxtaposed with animated graphs presenting geomorphologic processes in selected points, e.g. accumulation, erosion).

As already mentioned above, the mapmaker should examine the presented theme and try to point out components which are important for knowledge acquisition and task solving. It means that it is the mapmaker who, by collaborating with specialists from other domains, should predict possible ways of map use. As a result, the multi-component and multi-scenario map with a specific content, components, functionality, layout and design, should be intuitive and useful.

However, not only one scenario may be possible in a complex animated map of landscape evolution. On the basis of the accumulated knowledge, experience and suggestions from specialists, the cartographer may propose more scenarios. Consequently, significant components can be captured in several different scenarios, selectable by the user (Figure 1). Each scenario should provide essential content and functionality to answer specific tasks. These tasks can benefit different users, both specialists as well as amateurs. Using metaphor and, similarly to the Monmonier’s (1992) concept of “graphic scripts”, the cartographer’s role could be compared to that of a film director. The cartographer should direct the whole sequence of scenarios that “tell the story” about landscape changeability. It is a prerequisite for an intuitive use of map interfaces, that differences among the parts of the sequence should be fully understood. Therefore, an important role is played by the “opening window”, whereby the user is introduced to the map content and selects the scenario for the first time.

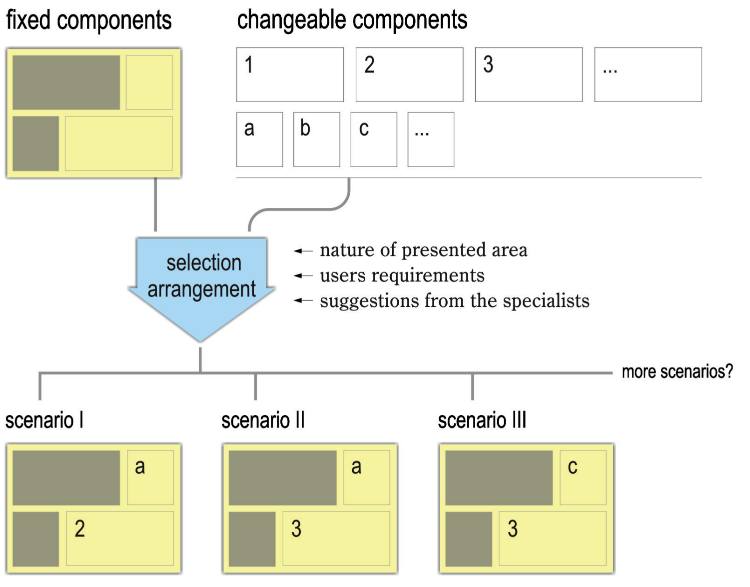

Figure 1. Defining of scenarios of complex animated map. While arranging the sequence of map scenarios fixed components are juxtaposed with extra, changeable components taking into account the nature of presented area and users requirements

When using the multi-component and multi-scenario animated map of landscape evolution, at the beginning the user should obtain the basic information about the available content. A GUI module that appears when the visualization is running for the first time and which is accessible during the use of the visualization, could be a convenient way for providing that information. We called this idea the “opening window”.

It is of great importance to structure this module in a clear manner, with emphasis put on the scenario selector. The “opening window” may be divided into several parts. However, the following aspects seem to be the most important: 1) the selection part with buttons, and 2) the information part with schedules and scenarios’ descriptions (Figure 2). While designing the opening window, the main objective is to accomplish an intelligible visual effect. Consequently, this will allow to acquire precise information about the scenarios and easily choose the most appropriate one. The available scenarios might be ordered with a progression from primitive to more sophisticated visualizations.

Moreover, to easily change the map scenario when using/viewing visualization, the button: “set/change scenario” should be placed in a visible part of the map’s interface. The perceptibility of this button can be reinforced in various ways. However, a useful visual result, and not a stylish effect, is crucial.

The arrangement of components (layout of each scenario) also seems to be important. It may be said that the scenarios’ layouts, the same as in the

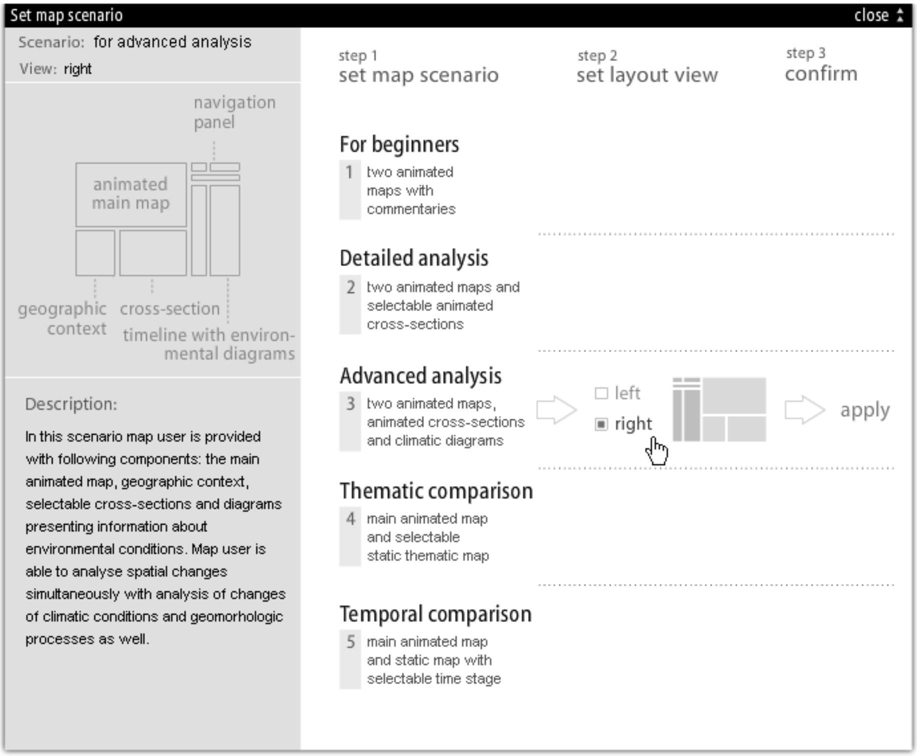

Figure 2. The "opening window" implemented in the prototype of the Kampinos Forest animated map (http://www.geomatikk.ntnu.no/prosjekt/KampinosForest/). It is divided into two parts: the selection part with white background and the information part with gray background

MAIS conception (Hurni, 2008), should be prearranged, without any possibility of flexible change. This is an important difference in comparison to the GeoVISTA software, in which the user can customize the interface (Takatsuka and Gahegan, 2002; Hardisty, 2009). For an expert user, full flexibility of the interface's composition might be a useful advantage. On the other hand, for a lay user, this feature can generate unforeseen difficulties. In general, the layout of the map should be closed, although sometimes the possibility of making small changes in the settings should be available.

3.3. Functionality aspects

An appropriate use of interactive functions in the multi-component animated map is a result of an in-depth study of the tasks which the animated map should support. Making a multi-component animated map interactive raises several fundamental questions. How much interaction should be allowed? Which tools might be suitable to enable the user to extract knowledge from a complex cartographic animation? Or to enable a correct, effective understanding of landscape changeability?

These questions reflect a very common dilemma associated with interactive maps. This dilemma has been aptly described by Monmonier (1992), by two competing metaphors for information retrieval. The first metaphor (the navigation approach) states that the user is free in his activity. The second (the narrative approach) says that user is limited by a system. However, there seems to be a lack of clear boundaries between these metaphors/approaches. Additionally, it is of great concern to try to adapt both of them in one presentation. Thus, a useful multi-scenario visualisation should include two strategies. For example, in the initial scenarios, the narrative approach can be applied (as an introductory scenario), whilst for further, more advanced scenarios, the navigation approach can be preferable.

Interactive functions that determine the use of interactive tools have been thoroughly described by Hurni (2008) in the context of concept of the *Multimedia Atlas Information System*. As mentioned above, this concept is close to the multi-scenario proposal due to its multi-component nature, predefined and limited content, structure and interactivity. Hurni divided interactive functions into 5 groups and 11 subgroups (Hurni, 2008). Almost all of them are applicable in a multi-scenario animated map. However, they should be incorporated in a slightly different manner and the general level of interactivity should be lower. For example, temporal navigation and map navigation functions seems to be common, while analysis functions with such tools as buffering, intersection or overlapping might be regarded as less popular.

In case of multi-scenario animated maps presenting landscape changeability, the following functions may be considered as the most important:

– scenario selection (thematic navigation),
– temporal and spatial navigation with the positioning of timeline, displaying of animation (start/stop, etc.),
– explanatory functions with displaying legends, info-windows, etc.,
– manipulation of map content with switching on/off layers or legend categories,
– basic analysis functions with at least temporal and thematic comparison.

When designing interactive functions for a multi-component and multi-scenario visualization, particular attention should be paid to the temporal navigation tools. These tools, as temporal coordinators, play a key role in connecting all the dynamic elements: maps, diagrams, cross-sections and others. Temporal navigation tools, together with juxtaposition of map components, enable simultaneous reading and interpretation of the dynamic visualization.

4. IMPLEMENTATION: MAP OF THE KAMPINOS FOREST LANDSCAPE'S GENESIS

The objective of the prototyping was to prepare a proof-of-concept implementation in order to show what the multi-scenario and multi-component visualization can look like and how it can work.

Due to the geographic specificity, the Kampinos Forest has been chosen as the study area. Cartographic presentation of its genesis is crucial for understanding the high environmental importance of this site. An extensive literature survey (Kobendzina, 1966; Galon and Dylik, 1967; Różycki, 1972a, 1972b; Dylikowa, 1973, Starkel, 1977; Baraniecka and Konecka-Betley, 1987; Wiśniewski, 1987, 1990; Starkel, 1991; Lindner, 1992; Starkel, 2001; Andrzejewski, 2003; Mojski, 2005) has enabled us to indicate the crucial facts of the genesis of the Kampinos Forest. In general, the Kampinos Forest landscape was created during and after the last glacial period, between 20 000 and 10 000 years BP. At that time, this region was a part of a glacial drainage system, and a bigger part of the Kampinos Forest was situated within the Vistula River valley. The unique character of the landscape comprising parallel zones of dunes, divided by parallel zones of swamps, is the most valuable and specific feature of the Kampinos Forest.

Taking into account the collected information, 5 map scenarios have been proposed for the visualization of the Kampinos Forest genesis (Figure 3). *Scenario 1 – For beginners* was established as an introductory scenario. Its objective is to provide the outline of the Kampinos Forest genesis with textual explanations. It consists of the main animated map, the small animated map with geographic context (the northern Poland) and the component with commentaries. Naturally, the necessary navigation components have been included as well: date component, phase name component, controller and timeline. *Scenario 2 – Detailed analysis* is the next step of the visualization. Its most characteristic part is the component with selectable cross-sections, which makes it possible to investigate geomorphologic processes within the Vistula River valley. *Scenario 3 – Advanced analysis* provides users with the main animated map, geographic context and selectable animated cross-sections. There are also fixed temporal navigation components, but instead of a typical timeline, graphs presenting information about environmental conditions are used (Figure 4). Thanks to this the map, users are able to examine spatio-temporal landscape changes and simultaneously investigate changes of climatic conditions and geomorphologic processes.

The recognition of potential users' requirements provided the basis for predefining two extra scenarios: *Scenario 4 – For thematic comparison,* makes it possible to compare the main animated map with static thematic maps (only 3 static maps have been proposed in the prototype). *Scenario 5 – For temporal comparison,* enables comparing any time stage presented on the main animated map with any time stage illustrated by the selectable static map.

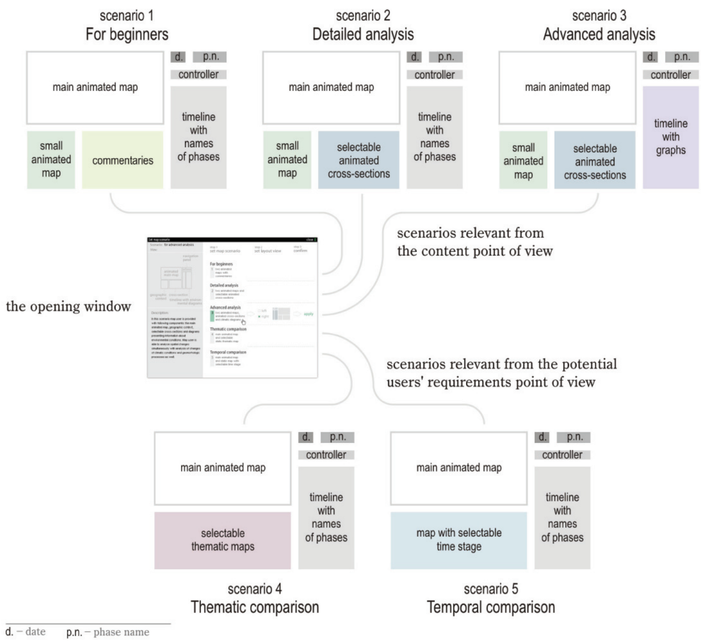

Figure 3. Scenarios relevant for the map content and for the potential tasks

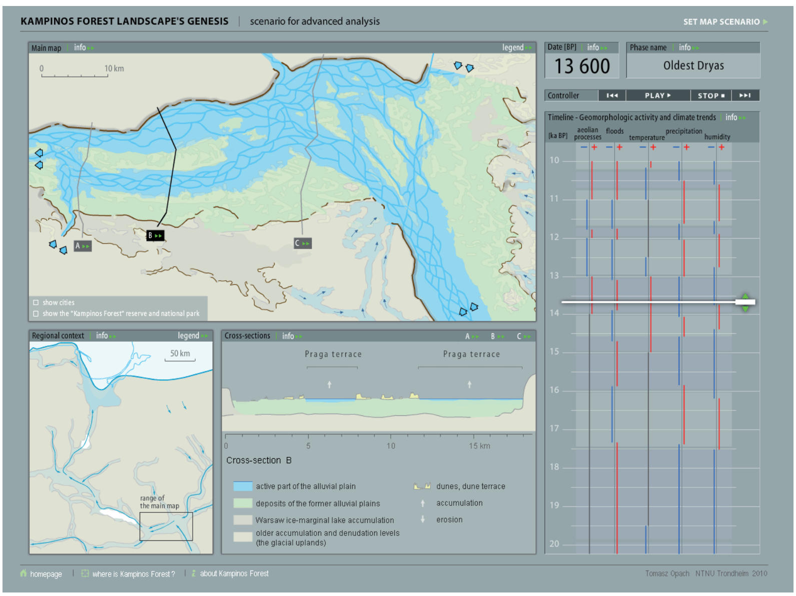

Figure 4. Screen snapshot captured for the most complex 3rd scenario (for advanced analysis) shows juxtaposed the main animated map, the small animated map, animated cross-section and fixed temporal navigation components with set of graphs (attention: in the set of graphs a fictitious data has been used!)

For this project, the Flash technology has been found the most suitable since high cartographic quality could be achieved in a relatively easy way. The prototype was implemented, but further evaluation and improvement should be conducted. It should be noted that not everything was completed and fully equipped in the prototype. All the described tools were implemented but, for example, only one animated cross-section was prepared and the fictitious data were used in the set of graphs illustrating the geomorphologic activity and climate trends (scenario no. 3).

6. CONCLUSIONS

Animated maps of various landscapes are not popular. The continental drift is an exception in this group. It is presented quite often by means of successful animated visualizations. Nevertheless, the lack of proper graphic tools and animation techniques can hardly be regarded as the reason for the low popularity of animations on landscape changeability. The following facts may be considered as the main reasons:

– shortage of proper data with detailed description of phenomena,
– lack of experienced and broadly educated mapmakers, and
– labour-consuming nature of preparing of animated maps.

Multimodal (multi-component) cartographic presentations, such as for example geographic atlases consisting of maps, statistical visualizations, textual explanations, illustrated with images, cross-sections, sketches, etc., have long been used to communicate spatial information about the characteristics and structure of the environment. Among this group, along with the development of the Internet technology and graphic software, dynamic cartographic visualizations have become more common. The simultaneous juxtaposition of various visualization techniques has the potential for increasing the power of all these techniques, but the role of multi-component animations should be investigated more thoroughly. The range of their reasonable use has to be specified in a more precise way.

It is hoped that our concept will offer a new insight into the cartographic visualization of spatio-temporal data. However, introducing the concept is not enough to achieve success. Therefore, a prototype has been introduced. We are currently in the process of conducting a more comprehensive evaluation which will be presented and discussed in detail in further papers.

New areas of use of the multi-component and multi-scenario maps should be proposed and investigated. Thus, the next step of the research on multi-scenario visualizations will be to seek new possibilities of its use. Arctic shrinkage, urban sprawl, desertification as well as deforestation processes – all of these phenomena may be presented by the use of the multi-scenario approach. It would be expedient to examine the user and usability issues as well. Split attention is of concern as the multi-components may be encouraging this effect. Further research on the effectiveness of such solutions is required.

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