International Journal of Geographical Information Science
Vol. 20, No. 10, November 2006, 1149–1171

Research Article

Reactions to geovisualization: an experience from a European project

GENNADY ANDRIENKO†, NATALIA ANDRIENKO†, RICHARD FISCHER‡, VOLKER MUES‡ and ANDREAS SCHUCK§

†Fraunhofer Institute Autonomous Intelligent Systems, Sankt Augustin, Germany
‡Federal Research Center for Forestry and Forest Products, Hamburg, Germany
§European Forest Institute, Joensuu, Finland

(*Received 3 January 2006; in final form 6 March 2006*)

The paper is written jointly by two parties, computer scientists specializing in geovisualization and experts in forestry, who cooperated within a joint project. The authors tell a story about an attempt of the geovisualizers to introduce the foresters to the concept and principles of exploratory data analysis and to the use of visualization for systematic and comprehensive data exploration. This endeavor should be considered as an informal experiment rather than a rigorous scientific study. Unlike customary tests of the usability of specific tools and techniques, the geovisualizers did not give the forestry specialists a series of tasks to carry out by applying geovisualization tools and did not try to measure how well the foresters performed. The idea of the geovisualizers was to demonstrate the principles and power of exploratory data analysis to the foresters by example. For this purpose, the geovisualizers performed an exploration of a non-trivial data set by themselves and reported the procedure, the principles, the techniques, and the findings to the foresters. The reaction of the foresters uncovered a range of fundamental issues that are relevant to geovisualization and information visualization research. The authors analyze these issues from their perspectives and formulate a set of questions which researchers in geovisualization should be asking.

Keywords: Geovisualization; Exploratory data analysis

1. Prologue

This paper is written by two different parties, which worked together in a European project NEFIS—Network for a European Forest Information Service. One party consists of computer scientists doing research in geovisualization and developing techniques and tools for exploratory analysis of spatial and temporal data; known henceforth as 'geovisualizers'. The other party consists of experts in forestry and forest data analysis being the bulk of the NEFIS project community, henceforth referred to as 'foresters'.

It may be expected from such an introduction that the paper will report the results of NEFIS or tell how the geovisualizers and the foresters cooperated to achieve the project goals. However, the paper describes a particular episode in which the two parties were involved beyond the goals of NEFIS. Nevertheless, some information about the project is necessary to understand the story.

In brief, the goal of NEFIS was to develop a framework for Web-based access for diverse users to distributed sources of forest information such as forestry statistics, forest resources assessment, and forest monitoring data. The framework includes a

International Journal of Geographical Information Science
ISSN 1365-8816 print/ISSN 1362-3087 online © 2006 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/13658810600816524

metadata-based web service for data search and retrieval, and a data processing and visualization component referred to as the Visualization Toolkit (VTK). A prototype implementation of the framework has been built on the basis of existing software. The geovisualization system CommonGIS has been used as the VTK (http://www.ais.fraunhofer.de/and/ section 'Demonstrators' and http://www.commongis.com/). Schuck *et al.* (2005) give more information concerning the background, goals and approaches of NEFIS (see also http://www.efi.fi/projects/nefis/).

Naturally, although the geovisualizers and foresters were cooperating within a common project, they had differing goals, interests, and opinions. In accord with the main objective of the project, the foresters wished to define the requirements for data visualization software intended for a broad community of users of forest data. Apparently, many of them did not consider themselves as possible users of geovisualization. As one of the foresters noted, 'At least I did not primarily aim at getting trained in geovisualization but wanted a tool to offer simplified data to the external world'. From this perspective, the foresters saw the primary function of the VTK as providing a quick and simple overview of data.

The geovisualizers had quite different ideas concerning the VTK; they believed this should be a tool for exploratory data analysis (EDA). While EDA was not a goal of NEFIS, the geovisualizers reasoned that since forest-related data are to be provided to people through the Web, these people will, naturally, wish to explore the data they find. They will appreciate the VTK not being restricted to providing a simple overview but rather enabling data exploration. Hence, EDA as a means of getting acquainted with previously unknown data is certainly relevant to the goals of the project. Moreover, the geovisualizers also believed that exploratory tools could be useful not only for the target users of forest data but also for the forest experts themselves, particularly, when they have to analyze new, unfamiliar data.

It should be noted that the geovisualizers and foresters did not initially realize that their ideas about the role and required capabilities of the VTK were not identical. Only the sequence of events described in this story revealed the difference.

The events were triggered by the geovisualizers attempting to demonstrate to the foresters how a comprehensive exploration of spatio-temporal data can be done using the VTK. The geovisualizers undertook this endeavor on their own initiative. Their aim was not just to stimulate the use of the tools they had developed. The geovisualizers saw their mission as much broader: to explain and promote the very principles of EDA (Tukey 1977) as a philosophy and discipline of unbiased and open-minded examination of data contrasting with the application of routine procedures and testing of pre-conceived hypotheses.

In order to fulfill their ambitions, the geovisualizers took a non-trivial forestry data set, which had been previously unknown to them, and tried to explore it comprehensively in order to demonstrate the goals, principles, and power of EDA to the foresters by example. The overall exploration procedure, methods applied, and observations made were described in a richly illustrated report. The report was sent to the foresters, who were asked for feedback. The geovisualizers expected the foresters to assess the validity of the observations and the appropriateness of the entire procedure and the individual methods. However, the reaction of the foresters was quite surprising for the geovisualizers. The report, apparently, did not convince the foresters that the presented exploratory tools might be useful in their work. Moreover, it became clear that they would not like to facilitate an uncontrolled exploration of (raw) forest data by non-experts.

Having deliberated about the reaction of the foresters, the geovisualizers found that it uncovers a range of fundamental issues relevant to the broad field of geovisualization and information visualization research. Therefore, they deemed it appropriate to communicate their experience to other researchers working in this field. So, the geovisualizers decided to write this paper and invited the foresters to participate in order to avoid a one-sided treatment of what had happened. As should be clear, the incident motivating this paper was not a planned experiment; otherwise, a totally neutral 'third party' observer would have been included to report the affair from the beginning and take part in the analysis.

Here are some details about the incident and its context. Before it happened, the geovisualizers had been successfully cooperating with the foresters in NEFIS for more than two years. The major goal was to define and model a European-wide forest information system, without software development. For this purpose, the project participants examined and evaluated existing forest information systems and software available for data visualization, including a methodical evaluation of the usability of CommonGIS as a VTK (Requardt and Köhl 2005). In the episode discussed here usability is not in question, however, because the foresters did not use the system by themselves, but only read the report produced by the geovisualizers. Hence, it was not poor usability of the VTK that made the foresters skeptical about EDA.

The communication between the geovisualizers and the foresters after the report had been circulated to all the NEFIS partners was mainly by e-mail with one face-to-face discussion between the geovisualizers and one representative of the data owners, which took place about a week after the distribution of the report. This was a week of intense exchange of e-mail messages concerning the report. During the personal meeting, the parties finally clarified their positions and agreed on writing a paper.

The main goal of the paper is to reveal the possible reasons for the negative reaction of the forest experts to geovisualization. Despite the lack of scientific rigor, the story may still be interesting and informative for researchers in geovisualization and information visualization. It does not deal with problems of using particular software tools or visualization techniques but rather with the understandability of the general principles of EDA and exploratory (geo)visualization to domain specialists and acceptance of these principles for practical application. The authors hope that the story can motivate thinking of (geo)visualization researchers about the general problems of visualization and EDA while they are inventing new techniques and developing ingenious tools.

The remainder of the paper is organized as follows. The next section positions the paper in relation to research on the usability of geovisualization tools and techniques. After that, the example data set is introduced and the content of the report that triggered the events is briefly described. This information is important for understanding the following discussion and the outcomes of the authors' reflection, which come at the end. The readers should not expect the paper to conclude with solutions to the problems encountered; rather it puts a number of questions that require further deliberation and discussion among researchers in visualization.

2. Usability?

Two themes dominate research in usability of geovisualization software in particular (Fuhrmann *et al.* 2005): user-centered design and evaluation of artifacts. Neither is the topic of this paper. This does not mean that the authors deny the value of such research. As noted, NEFIS included an evaluation of the usability of CommonGIS for forest data, and the geovisualizers have been involved in the evaluation of tools in their earlier projects (Andrienko *et al.* 2002). These studies are similar to those conducted by Harrower *et al.* (2000), MacEachren *et al.* (1998), or Tobón (2005).

In such studies, the researchers ask the test participants to complete typical user tasks and observe their performance. The researchers usually strive to obtain quantitative data and so measure performance by the time taken, the rate of errors or the number of interactive operations, complemented by the subjective opinions of participants concerning the tools. One problem such studies face is that 'a clear specification of tasks (and sometimes of users) is often not possible due to the exploratory and interactive nature of geovisualization' (Slocum *et al.* 2001, p. 71). Therefore, some researchers give the test persons broadly stated tasks, and use 'think aloud' methods to record outcomes, i.e. the test participants are asked to verbalize their thoughts while completing the task. This provides information about the cognitive processes that occur during problem solving (Fuhrman *et al.* 2005).

The user-centered design approach means designing a tool or a system on the basis of an understanding of the potential users, in particular, their perceptual and cognitive processes and mental models (Slocum *et al.* 2001, Ware and Plumlee 2005, Edsall and Sidney 2005) and knowledge of the tasks that the users need to perform (e.g. Ahonen-Rainio and Kraak, 2005, Andrienko *et al.* 2005a). Although tasks and user characteristics need to be taken into account in design, no innovative tools and techniques would appear if researchers simply asked the users to describe the tools they want and implemented the tools according to the specifications received. When an innovative tool or technique is created, it differs from what the users have seen or utilized before and hence needs to be appropriately introduced. This raises the problem of user guidance and instruction, which is especially challenging when the developer cannot directly communicate with each and every user to explain to him/her how to operate the tool. In spite of evaluation of individual visualization tools, any toolkit, like CommonGIS used here, involves a number of different tools, which may be oriented to various data types, tasks, and users. On the one hand, having multiple tools in a single system gives clear advantages since various tools can be easily used in combination and produce synergistic effects. On the other hand, this creates the main usability problem of systems like CommonGIS: while none of the individual tools is too complex to understand or difficult to use, the entire system is. The usability tests conducted in NEFIS confirmed this (Requardt and Köhl 2005).

The foresters who participated in the tests found the system too complex as a whole but at the same time did not point out the complexity of any individual tool. They just had a feeling that the tools are too numerous. However, the foresters could not say which of the tools were excessive. For each tool, they could imagine a situation when exactly this tool is necessary or serves in the best possible way. Hence, what the users need is support in choosing appropriate tools, which would allow them to pay no attention to the size and complexity of the toolkit as a whole. This is a challenging research problem, and we shall return to it in the concluding part of the paper.

The problem that is more relevant to the topic of the paper is that users often do not know how to approach a new, previously unknown data set. Thus, various users (and not only foresters) ask the geovisualizers from time to time, 'How do you know what to do with a given data set and what tools to use? Are there any written instructions to follow?' In fact, the geovisualizers' endeavor to perform and report an example data exploration was meant to provide such instruction. Let us now describe how the geovisualizers did this.

3. The example data set

Out of a large number of data sets within the NEFIS project, forest condition data were chosen to explore within CommonGIS. These are data collected and harmonized across Europe under the International Cooperative Programme on the Assessment and Monitoring of Air Pollution Effects in Europe (ICP Forests) operating under the UNECE Convention on Long-range Transboundary Air Pollution in close cooperation with the European Commission. The programme operates *inter alia* a large-scale monitoring gridnet at which around 6000 so-called Level I plots (land parcels) are arranged on a systematic grid of mostly 16×16 km throughout Europe. The monitoring program did not start simultaneously on all the plots. This resulted in varied lengths of the observation series, the longest being 17 years starting in 1987. At each plot, forest health is annually assessed on several trees in terms of an indicator called defoliation. This is a single tree-wise estimate of leaf or needle loss in comparison to a fully foliated tree. A tree carrying a maximum of leaves or needles is rated with 0% defoliation, whereas completely defoliated trees obtain the value of 100%.

The goals of the NEFIS project supposed that various forest-related data were made accessible to the 'external world', i.e. a broad public. For this purpose, the defoliation data were aggregated as mean defoliation values per plot. Additionally, up to three dominant (most frequent) tree species were determined for each plot. This aggregation was carried out to reduce data volume and to simplify the structure, in order to make the data accessible to European citizens. Another reason for the aggregation was the fear of the data owners that inexperienced public would be prone to misinterpretations and incorrect conclusions.

In fact, the averaging over diverse species was not an absolutely valid data transformation since each particular species may react differently to the same set of interrelated factors relevant to defoliation. However, the foresters who provided the data did not consider this as a major problem since they prepared the data not for the geovisualizers to explore but for external public to view. The data providers did not expect anybody to carry out detailed data analysis, and therefore the fitness of the data for analysis was not their primary concern.

One of the people to whom we told this story has pointed out the social aspect of the communication and use of information, which is clearly relevant to this case (P. Fisher, personal communication). The foresters had processed their data to a point they felt suitable for communication to relatively uninformed users who were supposed to view the data passively. The processed data were a kind of 'boundary object' (Harvey and Chrisman 1998) between the communities of data providers and data users.

4. What the geovisualizers demonstrated to the foresters

While the data set provided by the foresters did not ideally suit the didactic purposes, the geovisualizers decided to use it anyway since they wanted to introduce EDA by means of a realistically complex example (with regard to the data volume and dimensionality) rather than a 'toy problem'. The geovisualizers did not plan to impress the foresters by great discoveries and clever conclusions resulting from the data set exploration. The geovisualizers understood very well that they lacked the necessary domain knowledge that would allow them to interpret correctly what they might see.

The geovisualizers also realized that the data were not new to the foresters. Investigations into the phenomenon of defoliation and scientific analyses of defoliation-related data constitute a part of the usual job of the foresters. For these studies, the foresters use statistical and geostatistical methods and other expert tools rather than EDA techniques (see Köhl and Gertner 1997, Seidling 2001, Fischer *et al.* 2005, Seidling and Mues 2005). Hence, the geovisualizers could not expect that the application of the EDA techniques to the defoliation data would bring any new findings which the foresters might find really interesting.

The geovisualizers wished to demonstrate how people previously unfamiliar with the data (such as the geovisualizers, for whom the defoliation data were absolutely new) could grasp the principal features of the data through a systematic application of exploratory geovisualization techniques in accord with the principles of EDA.

Grasping the principal features of the data is not equivalent to gaining a full understanding of the underlying phenomenon. The latter requires more in-depth, scientific analysis with involvement of additional data and existing knowledge from relevant domains. The principles and methods of EDA are not intended for this purpose. Their task is to promote generation of hypotheses, which then should be tested using statistics and other mathematics. Another task is to direct the choice of appropriate methods and tools for analysis, which depends on peculiarities of the data. Hence, EDA, with its primary tool being data visualization, is complementary to computation-based in-depth analysis and, ideally, should precede it. However, it is quite typical that various domain specialists are proficient in the latter but unfamiliar with the former. That is why principles and methods of EDA as well as relevant tools (in particular, geovisualization) need to be promoted among domain experts.

A brief review of the principles of data exploration the geovisualizers wanted to convey to the foresters follows next, and the way in which these principles were presented. The full set of principles the geovisualizers followed is defined by Andrienko and Andrienko (2006), and parallels the Ben Shneiderman's Information Seeking Mantra: overview first, zoom and filter, and then details-on-demand (Shneiderman 1996). The principles also incorporate ideas expressed by Jacques Bertin (1967/1983), Rudolf Arnheim (1997), and other scientists.

4.1 *'See the whole'*

This principle involves two sides, completeness and unification. Completeness means, first, that all data items should be seen at once and, second, that the data should be viewed from all possible aspects, which depends on the structure of the data set. Unification means that individual elements of the display form a coherent, holistic image (further called a 'synoptic view'). These requirements are by no means absolute since it is not always possible to fulfill them entirely, as here.

In our case, the data consist of values of two attributes (the mean defoliation and the dominant tree species) referring to places in the geographical space (forest plots) and to moments in time (years). The space and time can be viewed as dimensions

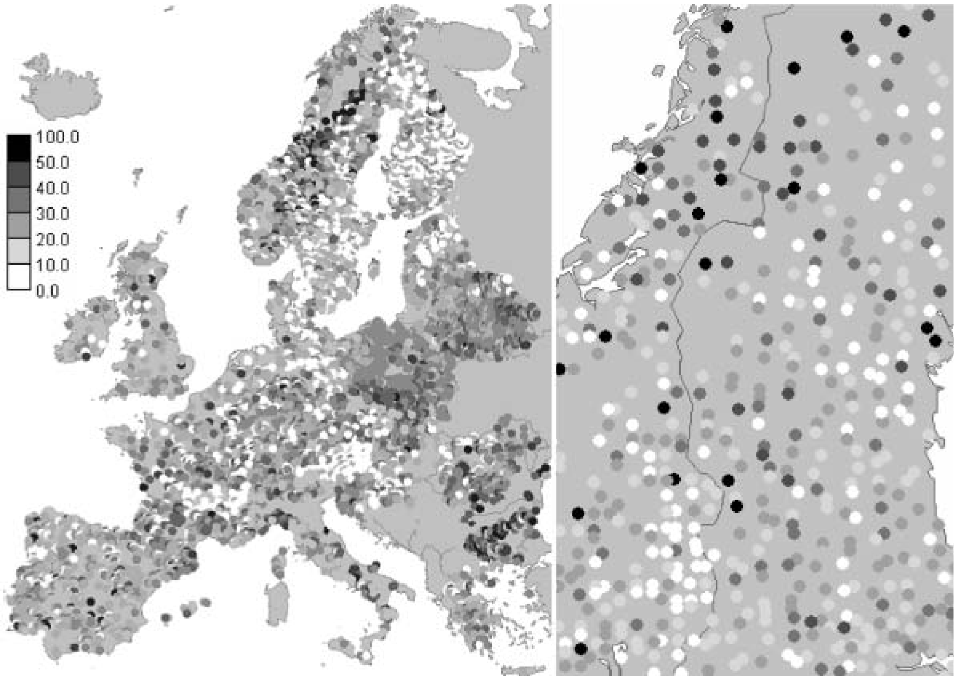

Figure 1. On the left, the values of the defoliation index (i.e. the mean percentage of the leaves or needles lost by the trees on a plot) in a single year are represented on a map by shaded circles. Due to symbol overlapping, the characteristic features of the spatial distribution of the values are hard to grasp. An attempt to show the data for more than one year would further aggravate the problem. The use of zooming (right) reduces overlapping but precludes the overall view.

forming a reference framework for the attribute values. These two dimensions entail two possible aspects:[1]

1. Changes in the spatial distribution of the attribute values from year to year.
2. The distribution of local temporal behaviors over space.

For completeness, the data referring to all 6000 plots should be represented in a visual display. However, an attempt to represent all the plots, for example, on a map results in overlap of many map symbols that makes the display completely illegible (figure 1). While zooming reduces the overlapping, it precludes visibility of the entire territory, and so handling large data volumes requires special measures some of which are mentioned in the following sections.

4.2 *'Simplify and abstract'*

The geovisualizers demonstrated the problems arising from the large data volume and suggested some approaches to solve or at least diminish the problems, based on data aggregation. Because of the high spatial density of the plots, it was judged

[1] In general, a data set with N dimensions entails $N!$ (N-factorial, i.e. $N \times (N-1) \times (N-2) \times \ldots \times 2 \times 1$) possible aspects. Adding a single dimension can tremendously increase the number of aspects. Thus, adding a third dimension to a two-dimensional data set yields 6 possible aspects. Therefore, multi-dimensional data are generally very difficult to explore and analyze.

reasonable to apply spatial aggregation. The general idea of spatial aggregation is to use some division of the territory and group together locations within a unit of the division. Attributes of the divisions are then derived by computing summary statistics of the original attribute values associated with the locations: the mean, the minimum, the maximum, the median, the mode, etc. Here the geovisualisers achieved the spatial aggregation by dividing the territory into equal-sized squares.

Aggregation was performed separately for each dominant species owing to warnings of the incompatibility of defoliation data for different species. This means that the entire set of plots was divided into subsets according to the dominant tree species (birch, oak, pine, etc.), and the aggregation was applied individually to each subset.

The geovisualizers noted a high variability of the data and advised that not only should the average attribute values in the aggregates be considered in such cases but also at least the minimum and maximum values. The geovisualizers also explained the impact of the granularity of the aggregation:

> When constructing a grid for spatial aggregation, different granularity (i.e. cell size) can be chosen. The larger the cells are, the higher the degree of data aggregation. Our grid is rather fine. In general, it is appropriate to try several different degrees of aggregation and check whether a change of the granularity substantially affects the spatial distribution of properties being observed.

The spatial aggregation allowed the geovisualizers to get a synoptic view of the spatial distribution of the values of the defoliation index (i.e. the percentage of the leaves or needles lost by the trees) in each year and observe the changes of the spatial distribution pattern from year to year. For this purpose, the geovisualizers used animated maps and map series, i.e. temporally or spatially arranged sequences of maps showing the distribution in individual years (see figure 2). In each map, cell shading represented the corresponding index values (average, minimum, or maximum). The visualization was applied separately to the data subsets referring to different dominant species.

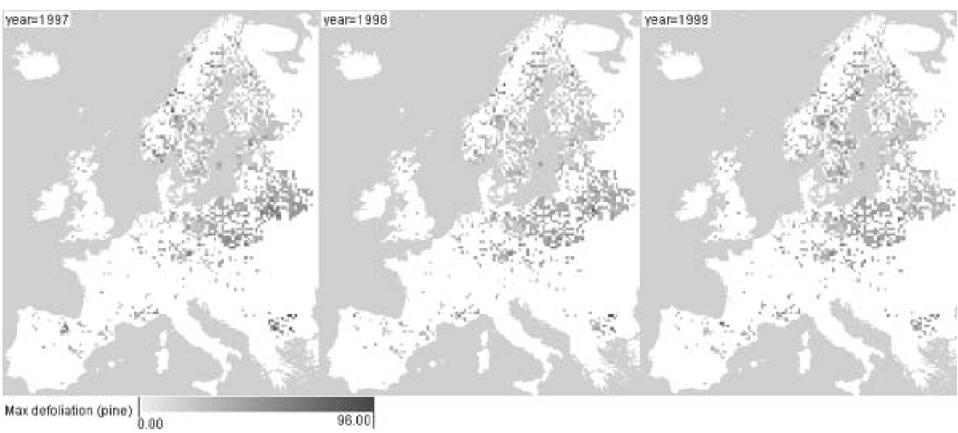

Figure 2. Changes of the spatial pattern of the index value distribution from year to year can be explored using a series of maps where each map represents the distribution in one year. Only three years from the 17-year series are shown here.

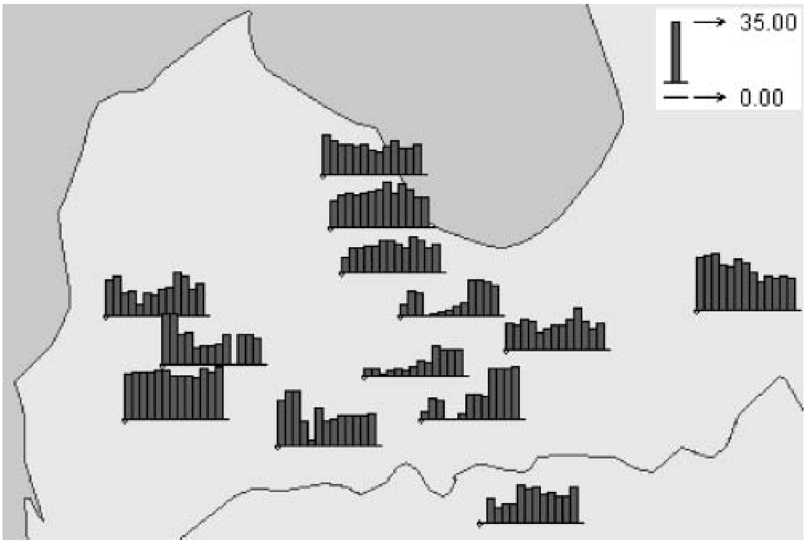

Figure 3. The bar charts represent the temporal behaviors of the defoliation index over the period 1991–2003 in individual forest plots with a common dominant species. The bar charts are placed on a map according to the locations of the plots. The map has been zoomed so that only a small part of the territory under study is visible.

This sort of visualization is suitable for looking at the temporal variation of the spatial distribution pattern. However, it does not expose the other aspect of the spatio-temporal variation, specifically, the spatial distribution of the patterns of the local temporal behaviors. For the latter purpose, one needs a visualization that places a suitable representation of temporal behavior in the spatial context, for example, a map with superimposed bar charts showing changes in values in consecutive years. However, a bar chart map of the whole territory of Europe cannot be used because of overlap of the bar chart symbols. One can zoom in to rather small areas like the one in figure 3 and explore the distribution of the temporal behaviors over these areas. A synoptic view of the entire distribution of the behaviors cannot be achieved in this way.

From figure 3, it may be seen that the temporal behaviors (perceived from the bar chart profiles) in spatially close locations substantially differ and do not necessarily show any common features. The same can be observed in other arbitrarily selected parts of the territory. It might be natural to conclude that the overall spatial distribution of the temporal behaviors throughout the territory of Europe is not characterized by any consistent patterns.

While it is useful to have local temporal behaviors represented in the spatial context whenever there is a reasonable way to do this, such a representation alone is not sufficiently powerful. One of the problems is that it does not support a synoptic view of the spatial distribution of the temporal behaviors since the symbols or diagrams representing the individual behaviors, as in figure 3, do not stick together or produce a coherent image in a human's perception. Moreover, even elementary tasks (i.e. tasks that do not require a synoptic view) such as the search for behaviors with particular features or comparison of behaviors in various places are quite difficult to perform since the explorer would need to scan the map and attend to each and every diagram on it.

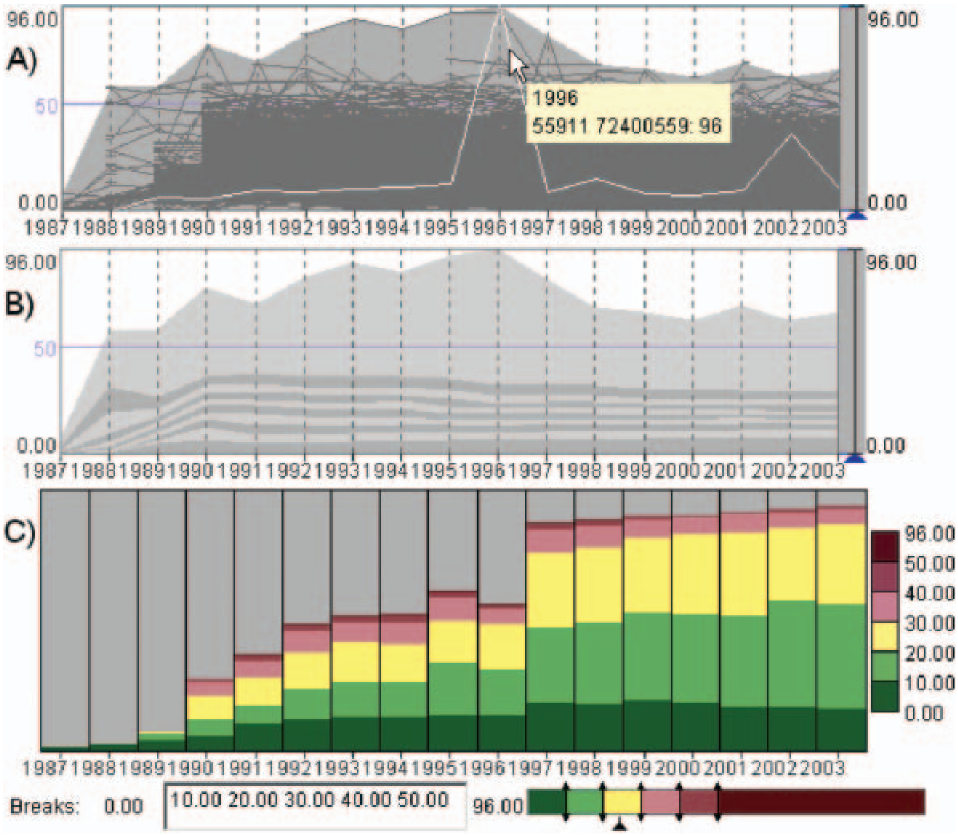

Figure 4. (A) A time graph represents the temporal behaviors of the mean defoliation index in the 2085 plots where the dominant species is Scots pine. The maximum among the values in all years was 96%. (B) Instead of the individual lines, the positions of the yearly deciles are indicated: for a given year, each segment (distinguished from the neighboring segments by shading) contains 10% of the available yearly values. (C) Another method of aggregation: for each year, the proportions of the yearly values fitting into specified intervals are shown. While the full height of a bar corresponds to the total number of plots (i.e. 2085) the colored part shows the number of plots where the values were available in the respective year.

For these reasons other ways to visualize the temporal behaviors were examined, including techniques that represent the behaviors irrespective of the space. For example, the behaviors can be represented as overlaid lines on a time graph (figure 4A) where each line corresponds to one of the plots. However, because of overplotting only selected individual behaviors can be seen in this visualization, not the desired synoptic view. A kind of synoptic view can only be achieved by aggregation.

The geovisualizers used two methods of aggregation that can be applied to multiple time series like the temporal behaviors of the defoliation index (Andrienko and Andrienko 2005).

The first method is based on the use of deciles in each year, and illustrated in figure 4B. The lines showing the change of decile values are removed from the time graph, and the graph area is divided into shaded stripes alternating between light gray and dark gray. Hence, the boundary between a dark gray area and an adjacent light gray area corresponds to one of the deciles and shows the dynamics of this decile over time. Therefore, figure 4B gives an idea of the statistical distribution of the values in each year and shows how the distribution changes over time although the varying number of available yearly values complicates the task. In general, one can observe that, despite the variation of the sample size, the statistical distribution of the yearly values is rather stable.

The second method of aggregation is shown in figure 4C. The idea is that the user divides the value range of the attribute into intervals, and the tool counts how many values fall in each year into each of the intervals. The counts are represented by the heights of the colored segments of the bars where each bar corresponds to one year. Although this display is also somewhat difficult to use because of the differing number of available values in the various years, it still allows one to extract useful general information. Thus, it may be seen that the number of very high values (more specifically, values greater than 50) was larger in the period 1991–1998 than in the last five years. The number of values falling in the interval from 40 to 50 tended to decrease during the period from 1997 to 2003. At the same time, the number of small values (below 10) also decreased.

Hence, by examining the aggregated displays of the temporal variation of the index values, the geovisualizers obtained some general-level knowledge about the underlying phenomenon. This knowledge does not account for the spatial aspect of the phenomenon since the displays that were used represent the data out of their spatial context. Therefore, the time graph and its derivatives cannot substitute for maps but should be used as a complement to maps.

4.3 *'Divide and group'*

As the geovisualizers explained in their report, after gaining a general understanding of the variation of the attribute values with respect to the dimensions of the data (i.e. space and time in the case of the example forest data), an explorer should look at various subsets of data in a search for distinctive patterns, anomalies, or other structures that may be of interest. Potentially interesting subsets to look for are often defined in the course of examining the data set as a whole, when the explorer not only tries to find commonalities and generalities but also notes the existing differences. Another scenario is dividing the data on the basis of the explorer's background knowledge: the explorer may expect in advance that certain subsets may notably differ from other data.

In the case of the forest condition data, the background knowledge (available to the geovisualizers in the form of explanations received from the foresters) suggested that the data be divided by the dominant species, as discussed in the foregoing. Here, the geovisualizers grouped the forest plots according to the dominant species and considered each group separately since they had been advised of the incomparability of the data referring to different species.

The next useful division, according to the foresters, is by the age of the trees in a plot. This information was available in the form of the age classes defined with a 20-year interval: up to 20 years (class 1), from 20 to 40 (class 2), and so on. Class 7 corresponded to the trees older than 120 years, and class 8 signified irregular stands. Partitioning according to the age class was applied to the subsets of the forest plots defined earlier on the basis of the dominant species.

Besides these divisions, the geovisualizers also looked at geographically defined data subsets. They considered the dynamics of the index in various countries and in broader geographical regions such as northern or central Europe. In the report, the

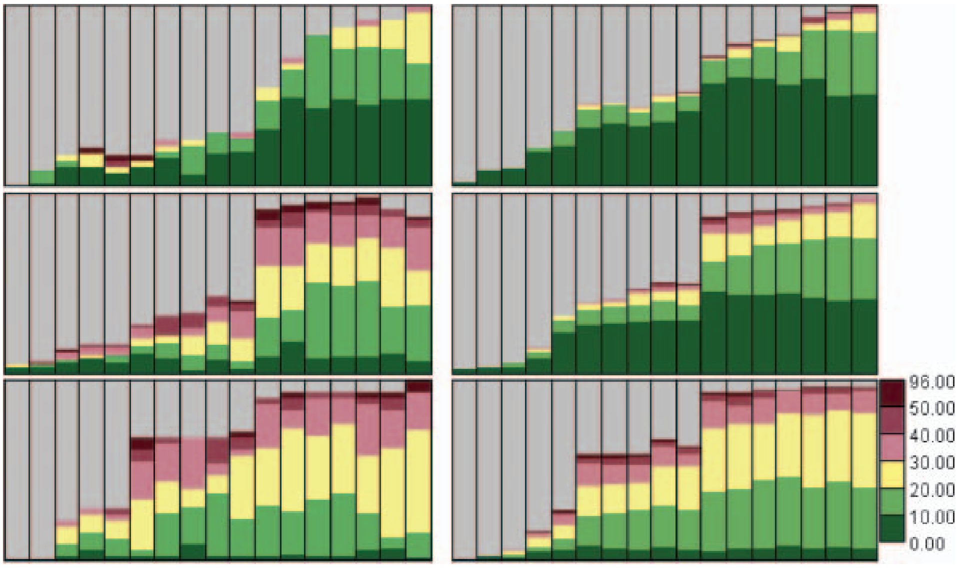

Figure 5. The dynamics of the defoliation index in various subsets of the forest plots are compared using displays where time-series data are aggregated by value intervals. The diagrams on the left correspond to the plots where the dominant species is oak. On the right, the plots are dominated by Scots pine. From top to bottom, the diagrams represent the age classes 1 (up to 20 years), 2 (from 20 to 40 years), and 7 (more than 120 years).

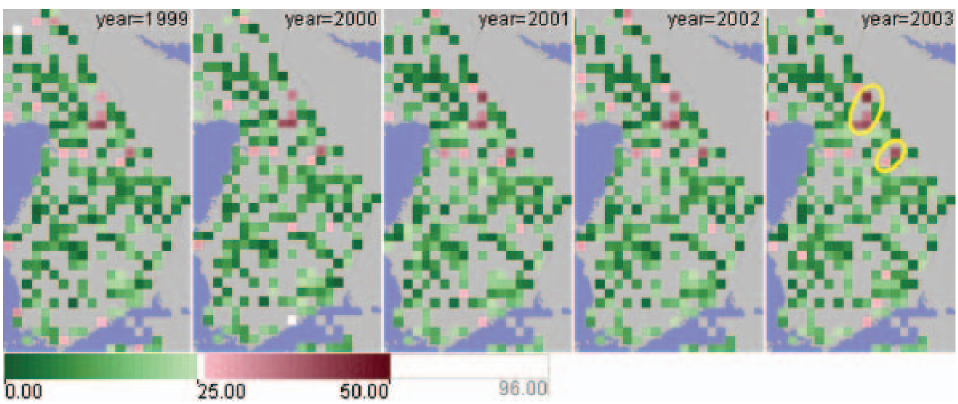

Figure 6. An example of spatial 'particulars': persistent small clusters of high values (marked on the rightmost image) interfere with mostly low values throughout the territory under consideration. Since the values higher than 50 do not occur in this part, the color scale has been adjusted to represent only the range from 0 to 50. The values below 25 are shown in green and the values above 25 in red.

geovisualizers demonstrated to the foresters the existing tools and methods for dividing and grouping the data on the basis of various criteria.

4.4 *'See in relation'*

'See-in-Relation' complements 'Divide-and-Group', and says that any subset of data must not be analyzed in isolation but must be compared with the remaining data, with the data set as a whole, and with other subsets. The geovisualizers demonstrated how such comparisons could be done using various visualization techniques. Thus, figure 5 allows one to compare how the defoliation index behaves in the plots dominated by oaks (left) and in locations where Scots pine prevails (right). The comparison can be done separately for subgroups of plots with various ages of the trees. Besides the cross-species comparisons, one can also compare the index behaviors in the plots with the same dominant species but differing age classes of the trees.

The ‘See-in-Relation’ principle also involves an explorer in looking for possible relations between attributes of the phenomenon under study and between this phenomenon and other phenomena. Such an investigation, however, requires a rich data set. Since various environmental factors may contribute to defoliation, information concerning these factors is necessary for a proper investigation into the existing relations. Such information was not available in the particular data set that was explored. Besides the defoliation index, there were only a few additional attributes.

Nevertheless, in order to introduce the principle ‘See-in-Relation’, the geovisualizers used what was available, i.e. the attributes characterizing the age of the trees and the soil properties. They demonstrated how to search for relations between attributes using various visual and interactive tools such as scatterplots, linked histograms, dynamic selection, and dynamic filtering. The geovisualizers also explained that, whenever a correlation between some attributes is noted, the explorer should also pay attention to the instances that contradict it and try to explain the discrepancy by involving other attributes or background knowledge. This touches upon the principle ‘Attend-to-Particulars’, which is discussed next.

4.5 *‘Attend to particulars’*

Data aggregation is used as a means to handle a large data volume and get a synoptic view of the major features of the data. However, it should be borne in mind that aggregation involves substantial information loss. Therefore, it is inappropriate to look only at aggregated data. Individual data items should be given proper regard. While it is impossible to consider each individual data item, various ‘particulars’ such as abnormal attribute values, atypical temporal behaviors, or incongruities encountered in a spatial distribution require the explorer’s attention.

When non-aggregated data are visualized, ‘particulars’ often ‘pop up’ and do not require additional effort in order to be detected. However, any extraordinary thing can be lost completely in a mass of overlapping graphical marks, as in figure 4A. In such cases, an explorer has to use displays of aggregated data. Since aggregation usually hides particulars, special techniques are needed to allow them to be detected.

Such particulars as atypically high or atypically low values can be spotted when the explorer looks at maximum and minimum values in the aggregates in addition to the average values. In figure 6, for example, where the series of images corresponds to five consecutive years, color encoding represents the maximum values in the grid cells. Green shades are used for values below 25 and red shades represent values above 25. Owing to the chosen parameters of the color encoding (a diverging color scale with a suitable midpoint value), high values appear as salient red spots contrasting with the mostly green surrounding. A viewer can easily notice not only occasional rises of values in particular years and particular places but also detect persistent presence of high values in some places, which, probably deserve additional examination.

The time series visualization tool shown in figure 4 can be enhanced with special techniques that allow the user to segregate temporal behaviors with various characteristic features for specific consideration. The features that can be looked for include extreme changes, high or low fluctuation, stable increasing or decreasing trends, etc. For example, figure 7 shows how extreme changes can be detected by means of a particular transformation of the time graph; instead of the original values, the graph shows the differences between the values in successive years (for additional examples, with different data, see Andrienko and Andrienko 2005, 2006).

As it was previously stated, the exploration reported to the foresters was meant primarily to demonstrate the goals, principles, and tools of EDA, by example. The geovisualizers did not want their report to appear excessively didactic to the foresters; it was rather conceived as a story about the 'detective work' (Tukey 1977, p. 1) of people exploring a data set previously unfamiliar to them.

5. How the foresters reacted

Prior to the NEFIS project, the reporting activities within the ICP Forests monitoring program mainly relied on scientific evaluations and publications in various media ranging from Internet pages and printed reports to scientific publications. Modern visualization techniques that allow for user-driven data compilation had never been applied before. Therefore, the foresters greatly appreciated the variety of opportunities provided by the diverse visualization tools and interactive techniques. However, their ideas concerning the purposes for which such tools and techniques could and should be used differed from those of the geovisualizers. As mentioned in the introduction, the foresters thought about effective visual communication of information from forest experts to end users while

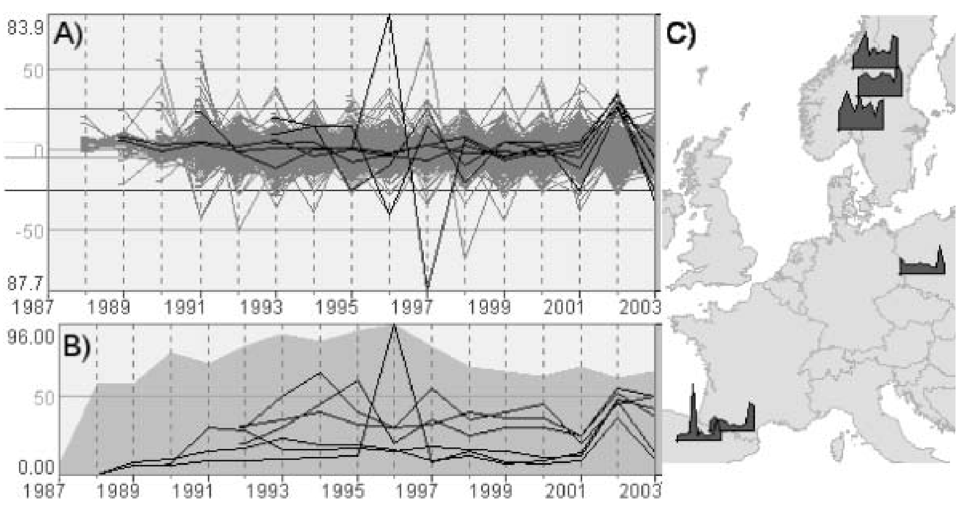

Figure 7. (A) The transformed time graph represents the differences between the values in successive years instead of the original yearly values. Using this display, the behaviors with extremely high value increase (more than 25%) in 2002 are selected. (B) The selected behaviors can be observed on a time graph without transformation. (C) The selected behaviors are shown on a map at the locations where they occurred.

the geovisualizers were sure that the principal need of both the experts and the end users was tools for data exploration.

Surprisingly, this discrepancy remained unnoticed by both sides until the geovisualizers undertook and reported their example exploration. This does not mean that the collaboration between the foresters and the geovisualizers throughout the project was insufficient or ineffective. The partners not only communicated via e-mail but also met regularly. At the meetings, the geovisualizers demonstrated the application of various visualization techniques to examples of forest data, and gained an understanding of the data from explanations given by the domain experts. This allowed the geovisualizers to choose appropriate tools and appropriate ways to apply the tools and indicated directions for improvement and further enhancement of existing techniques. So the partners exchanged their knowledge and experiences for the mutual benefit and for the success of the project.

At the same time, people tend to interpret what they see according to their expectations and mental schemata. Therefore, the foresters interpreted what the geovisualizers showed them as novel approaches to information communication, and the geovisualizers did not realize this being led by their own expectations and schemata. They were preoccupied with the ideas of EDA and exploratory visualization, and it did not come to their minds that these ideas were not evident to the foresters.

Hence, the demonstration of the capabilities of individual geovisualization tools could not properly convey the ideas of EDA. Only the example of a more systematic data exploration helped the foresters to notice a contradiction between their expectations and the intended purposes of the geovisualization techniques. Likewise, only the foresters' reaction helped the geovisualizers to broaden their vision of what potential users might really need.

An immediate response of the foresters was that the data used for this experiment were not meant for 'digging so deep'. As was explained at the beginning, these were secondary data resulting from a severe aggregation of original measurements. The aggregation was done intentionally in order to prevent the uncontrolled distribution of the original data for fear of possible misinterpretation and misuse. Besides, the foresters did not consider providing the original data to the geovisualizers as they did not expect that the geovisualizers would attempt to undertake such a systematic investigation.

Further comments of the foresters indicated that the demonstration of the capabilities of the exploratory approaches and tools was not sufficiently convincing to them. The foresters noted that the exploration performed by the geovisualizers could not compete with what they called an in-depth scientific evaluation. In particular, they mentioned: 'e.g. multivariate statistical evaluations would be necessary, kriging is more advanced than just adding values into grid cells …'. However, the foresters did not recommend enhancing the VTK with techniques for multivariate statistical analyses and for kriging. They pointed out that the experts in forestry already have their specific software and do not need any additional analytical facilities.

Rather than a powerful toolkit for 'visual analytics' the foresters would prefer to have 'a tool to offer simplified data to the external world'. This corresponds to what is stated in the NEFIS evaluation report (Requardt and Köhl 2005). It should be explained that the geovisualizers had not been involved in the evaluation study (to preclude their influence on the users' opinions) and received the report about the study a few days after sending their exploration report to the foresters.

The conclusions from the evaluation study say that the VTK requires improvements to provide better support of reporting. This can be understood in two ways: (i) either that the time needed for the foresters themselves to prepare high-quality presentations should be reduced, or (ii) that the broader audience such as internet users can extract relevant information themselves. In the foresters' opinion, the current VTK has a clear potential to develop into a good reporting tool. However, besides optimizing the system for the purposes of reporting, the usability issues must be solved.

The foresters saw the key problem in the complexity of the toolkit that makes it difficult to use. The complexity results from the variety of visual and interactive techniques and numerous possibilities for combining them. However, the foresters believe that this variety is superfluous, as the VTK cannot substitute the statistical packages, GIS, and domain-specific tools already used by domain experts for genuine scientific analyses. Therefore, the VTK should be seen as 'a tool for a broader audience and for that reason it should rather be easily applicable than fully exhaustive' (Requardt and Köhl 2005, p. 60). In the case of providing access to forest data through the Web an extensive training of the users seems to be unrealistic.

On the other hand, most of the foresters that cooperated in the project liked the tools of the VTK. For example, one of the foresters appreciated the possibility of uncovering various 'particulars' and admitted that finding such things using a GIS would take much time. None of the present features was recommended for removal from the system.

As a solution to this contradiction, the foresters suggested creating two versions of the system: a simple version for new users and for those who do not need sophisticated functions and an advanced version for experienced users. It may be expected that, as a user becomes more experienced with the simple version, he/she will want more features, and then it should be possible to switch to a more advanced version.

User friendliness is a crucial requirement to both simple and advanced versions. For this purpose, not only the user interface of the current VTK needs to be improved but also appropriate guidance to the user should be provided. As is stated in the user study report, 'better guidance for getting started as a new user is much more important than to delete available features to a minimum' (Requardt and Köhl 2005, p. 60).

To summarize, the foresters clearly indicated that they do not need a comprehensive toolkit for EDA. What they do need is a simple and user-friendly tool for reporting, which may optionally include, in addition to the basic functions, some fancy facilities for advanced users.

6. Reflections of the geovisualizers

The reaction of the foresters showed that the geovisualizers failed to convince them of the utility of the principles and techniques of geovisualisation. While it cannot be claimed that the teaching was perfect, it was definitely not the only problem. Contemplating the reaction of the foresters uncovers a range of issues that appear quite fundamental and relevant to the state of the art and the directions of the further research in (geo)visualization.

6.1 *'The data were not meant for digging so deep'*

The forest experts worried that the data they provide to others could be misinterpreted and misused. Therefore, they would prefer to preclude the possibility of uncontrolled analysis of the data. The geovisualizers demonstrated how people unfamiliar with the data and having no background in forestry could apply exploratory tools to make their own observations and come to their own conclusions. This did not make the foresters happy. In this connection, the question arises: should (geo)visualization scientists pay attention to worries of experts about possible misinterpretations of data or can they treat this problem as irrelevant to their research?

The following considerations show that the problem should not be ignored. Application of the traditional tools for data analysis such as statistical methods and GIS functions requires specific knowledge and skills. Since only educated specialists can perform reliable data analysis, the possibility of misinterpreting results and reaching incorrect conclusions may be deemed quite small. The data visualization tools, on the contrary, are oriented to a broad community of users, which are not specifically educated. Any computer-literate user can relatively easily obtain some (default) data visualization. Although the visualization systems typically provide more facilities for analysis than a single display, many users may feel comfortable with the first visualization they get and may not even bother to try to look at the data from a different perspective, as pointed out in Chen (2005). On the basis of this single display, which is not necessarily correct, the users may try to make their judgments and draw conclusions about the data.

The relative ease of using data visualization tools, on the one hand, and the general ignorance of the principles underlying the use of these tools for data analysis, on the other, make a fertile ground for various misinterpretations and misuses. Hence, the fears of the experts are justified as well as their opinion that developers of visualization tools should not sell these tools as instruments for analysis, but rather should focus on reporting.

6.2 *'We have our own tools'*

The foresters are right in saying that the geovisualization tools cannot compete with the traditional tools for in-depth scientific analysis. What they do not realize is that the exploratory geovisualization tools are not at all intended to compete with these tools and methods since exploratory data analysis is meant to complement rather than substitute for in-depth analysis. The purpose of EDA is to discover patterns and arrive at hypotheses; statistics and various domain-specific methods should then be applied to verify discoveries, elaborate patterns, and test hypotheses.

We admit that there is a tendency to skip the exploratory stage of data analysis and start immediately with computational methods according to customary approaches and procedures. This tendency entails significant dangers, however. First, without knowing the features of a data set to be analyzed, the analyst may apply unsuitable methods and come to incorrect conclusions. Thus, the methods involving data smoothing are not applicable to highly variable data lacking spatial and/or temporal continuity. In general, most statistical methods are based on specific assumptions about the data, and EDA is one way of for checking whether these assumptions are fulfilled. Second, computational methods often have specific features that make particular types of results more likely to occur than others, and analysts are not always aware of this or they do not always try to compensate for the bias by applying other methods. For example, Brimicombe (2005) notes the popularity of the kernel density estimation approach in crime analysis, which unfortunately tends to conceal localized peaks of criminality in favor of regional patterns and is subject to boundary effects around the edge of a data set, which causes a failure to reveal concentrations of crime incidents at boundaries. As a result, 'police analysts tend not to find "hot spots" at the edge of their jurisdictions' (Brimicombe 2005, p. 4). Looking at appropriate visualizations of the data prior to applying the computations could be helpful in such circumstances.

The exploratory stage of analysis is neglected not only because experts are insufficiently familiar with the concept of EDA, but also because the developers of exploratory visualization tools often imply that they can serve as standalone software systems without a bridge between hypothesis generation and hypothesis testing. This produces an impression of assumed self-sufficiency, which may irritate experienced data analysts and mislead inexperienced people, who may tend to draw hasty conclusions just from what they see, without verification.

6.3 *'Give us a convenient tool for reporting'*

One of the problems encountered by the users of geovisualization tools is that the observations and discoveries they make cannot be conveniently captured for later recall and for communication to others. Results of data exploration with the use of visual displays come in the form of visual impressions, which are hard to verbalize or express in any other form without referring to the images from which they originate. Thus, in order to report to the foresters about their data exploration, the geovisualizers used numerous screenshots incorporated in the text since there was no other way to communicate what they had observed. It was a laborious and time-consuming job to make the screenshots, post-process them in a graphical editor in order to cut off unnecessary parts or arrange several images in a single figure, and then comment on the figures in the text of the report. When a comment referred to a specific part of an image, it was not always clear how to indicate this part verbally. It was necessary to draw marks on top of the image, as in figure 6, and the geovisualizers had to use a graphical editor for this purpose.

The difficulty of recording and reporting the findings may be a serious obstacle to wide recognition and use of geovisualization tools. Time is a precious commodity for data analysts; they cannot afford to spend a great deal of their time producing reports similar to the one made by the geovisualizers for didactic purposes. Hence, it is the duty of geovisualizers to support properly the capture of observations and reporting of findings.

6.4 *'It is too complex'*

Complexity is a factor limiting the use of geovisualization toolkits. This is a multifaceted problem. It certainly relates to user interface issues such as ill-organized menus, intricate GUI controls, and inadequate help, but another aspect is the variety of techniques and the multitude of possibilities to combine them. The users seem to like the idea of having the minimum tool combination covering their needs. The problem is that both data and user needs vary (even the needs of one and the same user at different times vary), and what is sufficient in one case may be insufficient or even inappropriate in another case.

Exploratory data analysis as such is a further aspect of complexity. It requires an analyst to look at data from various perspectives and at various scales, from 'See-the-Whole' to 'Attend-to-Particulars'. The analyst is also supposed to 'See-in-Relation', i.e. make numerous comparisons. This complexity is multiplied by aspects of the data that is explored and analyzed. The complex, multi-dimensional structure and heterogeneous components of most contemporary data sets necessitate a combined use of multiple techniques and approaches. No single visualization can be used to show 'the whole'. The analyst has to decompose this whole into parts, examine these parts, and then try to synthesize the whole picture from the partial views, analogous to reconstructing a complex three-dimensional shape from a set of projections and slices. Because of large data volumes, no visualization is simultaneously capable of providing an overall view and exposing various 'particulars'. Looking for 'particulars' requires therefore different techniques than 'seeing the whole', and so the multitude and variety of techniques is indispensable for comprehensive EDA.

Thus even a perfect user interface and extreme ease of use of every technique separately and of several techniques jointly would not solve the complexity problem. Complexity remains in:

- remembering which techniques are available, for what purpose they are suitable and to what data each can be applied;
- decomposing a data exploration problem into subproblems and understanding how to do this properly and effectively in any particular case; and
- merging fragmentary knowledge resulting from the application of multiple tools into a consistent conception of the data and underlying phenomena.

What seems clear is the need to educate people to do exploratory data analysis and to use visualization and other exploratory techniques. It seems desirable that researchers in geovisualization and information visualization propose adequate educational materials for various user categories. This may be insufficient, however. Thus, the 54-page report with 56 figures that the geovisualizers produced for educating their partners in the NEFIS project might not seem sufficiently encouraging to the addressees. A reader of such an instructive text may be overwhelmed by the multitude of aspects that must be cared of, irrespective of whether complex or simple tools are used.

Therefore, the researchers should also try to find ways to alleviate the complexities. For example, is it possible to build a geovisualization system that is sufficiently powerful and flexible but appears light and simple to the user? Is it possible to find the principles and develop the methods of building 'sufficient minimum' tool configurations complying with data specifics and user demands? Can geovisualization systems configure themselves automatically (once being connected to a particular data collection) to propose only the minimum, but sufficient, number of techniques and functions to the user? Can geovisualization systems guide inexperienced users through the process of data exploration and analysis: help them to examine the structure of the data and decompose the problem, suggest the correct tools at the right moments, attract attention to potentially important or 'strange' things? Can geovisualization systems simplify and advance the work of experienced users, for example, by learning typical scenarios of data exploration and re-playing these scenarios when appropriate? Can geovisualization systems support not only analytical but also synthetic activities, i.e. uniting fragmentary knowledge into an overall model?

These questions are put here because of their direct relation to the complexity problem, which is discussed above. At the same time, they also fit in the context of the following section where a broader list of questions is proposed to geovisualization and information visualization scientists for reflection and discussion.

7. Questions for discussion

We believe that the problems indicated in this paper are not specific to the NEFIS project, or to the particular groups of foresters and geovisualizers that carried out this project, or to the whole community of forestry specialists, or to CommonGIS, or to any other particular software system. Still, our observations and conclusions from them may appear quite subjective. Therefore, we would like to engage the visualization-related research community in a discussion concerning the problems touched upon. We propose the following list of questions:

1. Do apparent simplicity and visual appeal of graphical tools promote incompetent use? Can this harm the reputation of these tools among domain experts and contribute to their reluctance to use visualization? If so, can researchers find ways to minimize misuses of graphics as well as one-sided and superficial investigations? Can (and should) a visualization system actively promote comprehensive exploration?
2. Should users of visualization tools be prompted to verify the observations they make and hypotheses they arrive at by means of confirmatory techniques? If so, how do we accomplish this in such a way that the user can appreciate it but not feel offended or annoyed? How can exploratory and confirmatory tools be integrated?
3. Does visualization require as much expertise to use effectively as statistics and other 'genuinely scientific' methods of data analysis? If so, how can this expertise be effectively conveyed to users?
4. Is data exploration inherently complex irrespective of the tools being used? If so, can scientists find ways to alleviate this complexity?
5. Is it possible to conceal the indispensable complexity of software for EDA behind a well-designed user interface with intelligent behavior? In particular, can a software system recognize which instruments make a minimum combination appropriate to analyze a specific data collection and simplify itself by hiding unnecessary tools and arranging the necessary ones in a way convenient for the user? (See also section 6.4.)
6. How do we enable users to record, comment, organize, browse, and report the findings they obtain while using visualization? How do we support the capture of observations so that the user is not distracted from the process of data exploration?
7. Do domain experts really need exploratory tools as a complement to their customary tools for data analysis? If so, what are the right ways to promote EDA and visualization as the primary instrument for exploration among domain specialists?

8. Epilogue

From the episode that occurred in NEFIS, the geovisualizers have learned that the foresters are primarily interested in the use of visualization for communication purposes, that is, for exhibiting data to a public (so that the exhibitor can be sure that the public will interpret the data exactly as supposed and will not obtain anything extra beyond what the exhibitor wants to convey) and for reporting. While visual communication of information is an interesting and important area of research, the geovisualization and information visualization communities are traditionally focused on visualization as an 'instrument for ideation' (Andrienko *et al.* 2005b). It seems that the scientists (at least some of them) tend to believe that the value of exploratory techniques is self-evident to everyone; hence, the major task is to supply people with convenient, well-designed exploratory tools and properly instruct them in using these tools.

Accordingly, the geovisualizers who worked in NEFIS wanted to demonstrate to their project partners how to use visualization for ideation and in this way encourage them to utilize exploratory visual techniques in their own work. However, the foresters' comments indicated that they have not been fully convinced of the usefulness of these techniques. The problems revealed and discussed in this paper include the high probability of improper use of visualization tools by uneducated people, the insufficiency of visualization for a full analysis and the absence of links to complementary methods, the difficulty of recording and reporting observations and related ideas, and the complexity of the toolkits for EDA, which apparently reflects the inherent complexity of EDA as such. The paper does not propose any solutions to these problems. However, the authors believe that appropriate solutions can be found through focused joint efforts of multiple researchers.

The incident with the demonstrative data exploration has been very consequential for the geovisualizers. They have better understood the needs and problems of potential users and started to reflect on issues they had never considered before. The experience has also been useful to the foresters. They have recognized that visualizing data does not end at producing images for illustrative purposes. They have better understood the intended purposes of exploratory tools. However, further steps are required to make these tools completely acceptable and appreciated. Data providers should recognize EDA techniques as an important means by which data users can gain an understanding of the data and build trust in the data and its potentials. Moreover, the use of EDA tools can stimulate the interaction of the end users with the data providers, who may utilize users' feedback for improving the data and broadening the user base.

It is very encouraging for the geovisualizers that the foresters are willing to work together with them on finding the best approaches to promote a wider acceptance and use of exploratory geovisualization. The foresters acknowledge that this will depend on the use of exploratory tools by the forest experts themselves. Only if the domain experts are using the VTK and only if they themselves rely on it, will they have a sustained interest in maintaining the system and in keeping it updated. On this basis, a simplified version could be open to the broad public.

The foresters want to communicate more closely and regularly with the geovisualization experts so that they can have an influence upon the further development of the portfolio of geovisualization tools moving towards comprehensive exploration opportunities and, at the same time, improved usability. However, the foresters would like the geovisualizers not to forget how important it is to support information presentation and communication and to do research and development work also in this direction.

Acknowledgements
We are grateful to the anonymous reviewers for their helpful comments and suggestions and to the editor for his hearty support.

References

Ahonen-Rainio, P. and Kraak, M.-J., 2005, Towards multivariate visualization of metadata describing geographic information. In *Exploring Geovisualization*, pp. 611–626 (Oxford: Elsevier Science).

Andrienko, G. and Andrienko, N., 2005, Visual exploration of the spatial distribution of temporal behaviours. In *Proceedings of the 9th International Conference on Information Visualization*, pp. 799–806 (Los Alamitos: IEEE Computer Society Press).

Andrienko, N. and Andrienko, G., 2006, *Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach* (Berlin: Springer).

Andrienko, N., Andrienko, G., Voss, H., Bernardo, F., Hipolito, J. and Kretchmer, U., 2002, Testing the usability of interactive maps in CommonGIS. *Cartography and Geographic Information Science*, **29**(4), pp. 325–342.

Andrienko, N., Andrienko, G. and Gatalsky, P., 2005a, Impact of data and task characteristics on design of spatio-temporal data visualization tools. In *Exploring Geovisualization*, pp. 103–125 (Oxford: Elsevier Science).

Andrienko, G., Andrienko, N., Dykes, J., Gahegan, M., Mountain, D., Noy, P., Roberts, J., Rodgers, P. and Theus, M., 2005b, Creating instruments for ideation: software approaches to geovisualization. In *Exploring Geovisualization*, pp. 103–125 (Oxford: Elsevier Science).

Arnheim, R., 1997, *Visual Thinking* (Berkeley: University of California Press).

Bertin, J., 1967–1983, *Semiology of Graphics. Diagrams, Networks, Maps* (Madison: The University of Wisconsin Press).

Brimicombe, A.J., 2005, Detecting clusters in spatially repetitive point event data sets. In *Proceedings of International Conference on Spatial Analysis and Geomatics SAGEO'2005* (CD-ROM).

Chen, C., 2005, Top 10 unsolved information visualization problems. *IEEE Computer Graphics and Applications*, **25**(4), pp. 12–16.

Edsall, R.M. and Sidney, L.R., 2005, Applications of a cognitively informed framework for the design of interactive spatio-temporal representations. In *Exploring Geovisualization*, pp. 577–590 (Oxford: Elsevier Science).

Fischer, R., Bastrup-Birk, A., Becker, R., Catalayud, V., Dietrich, H.-P., Diese, N., Dobbertin, M., Graf-Pannatier, E., Gundersen, P., Haussmann, T., Hildingsson, A., Lorenz, M., Müller, J., Mues, V., Pavlenda, P., Petriccione, B., Raspe, S., Sanchez-Peña, S., Sanz, M., Ulrich, E., Volz, R. and Wijk, S., 2005, *The Condition of Forests in Europe. 2005 Executive Report* (Geneva: UNECE).

Fuhrmann, S., Ahonen-Rainio, P., Edsall, R.M., Fabrikant, S.I., Koua, E.L., Tobón, C., Ware, C. and Wilson, S., 2005, Making useful and useable geovisualization: design and evaluation issues. In *Exploring Geovisualization*, pp. 553–566 (Oxford: Elsevier Science).

Harrower, M., MacEachren, A.M. and Griffin, A.L., 2000, Developing a geographic visualization tool to support Earth science learning. *Cartography and Geographic Information Science*, **27**(4), pp. 279–293.

Harvey, H. and Chrisman, N., 1998, Boundary objects and the social construction of GIS technology. *Environment and Planning*, **30**, pp. 1683–1694.

Köhl, M. and Gertner, G., 1997, Geostatistics in evaluating forest damage surveys: considerations on methods for describing spatial distributions. *Forest Ecology and Management*, **95**, pp. 131–140.

MacEachren, A.M., Boscoe, F.P., Haug, D. and Pickle, L.W., 1998, Geographic visualization: designing manipulable maps for exploring temporally varying georeferenced statistics. In *Proceedings IEEE InfoVis'98*, pp. 87–94 (Los Alamitos: IEEE Computer Society Press).

Requardt, A. and Köhl, M., 2005, NEFIS Evaluation Report, EFI-NEFIS-WP5-D10-2005. Available online at: http://www.efi.fi/projects/nefis/deliverable.html.

Schuck, A., Andrienko, G., Andrienko, N., Folving, S., Kohl, M., Miina, S., Paivinen, R., Richards, T. and Voss, H., 2005, The European Forest Information System—an internet based interface between information providers and the user community. *Computers and Electronics in Agriculture*, **47**(3), pp. 185–206.

Seidling, W., 2001, *Integrative Studies on Forest Ecosystem Conditions. Multivariate Evaluations on Tree Crown Condition for two Areas with distinct Deposition Gradients* (Geneva, Brussels, Gent: UN/ECE & European Commission & Flemish Community).

Seidling, W. and Mues, V., 2005, Statistical and geostatistical modelling of preliminarily adjusted defoliation on an European scale. *Environmental Monitoring and Assessment*, **101**(1–3), pp. 223–247.

Shneiderman, B., 1996, The eyes have it: a task by data type taxonomy for information visualizations. In *Proceedings of the 1996 IEEE Symposium on Visual Languages*, pp. 336–343 (Piscataway: IEEE Computer Society Press).

Slocum, T.A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D.R., Fuhrmann, S. and Hedley, N.R., 2001, Cognitive and usability issues in geovisualization. *Cartography and Geographic Information Science*, **28**(1), pp. 61–75.

Tobón, C., 2005, Evaluating geographic visualization tools and methods: an approach and experiment based upon user tasks. In *Exploring Geovisualization*, pp. 645–666 (Oxford: Elsevier Science).

Tukey, J.W., 1977, *Exploratory Data Analysis* (Reading, MA: Addison-Wesley).

Ware, C. and Plumlee, M., 2005, 3D geovisualization and the structure of visual space. In *Exploring Geovisualization*, pp. 567–576 (Oxford: Elsevier Science).