IRIS: INTELLIGENT VISUALIZATION FOR DATA EXPLORATION SUPPORT IN GIS

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ABSTRACT

Our work is focused on assisting users in exploration of spatially referenced data, i.e., economical, demographic, ecological, etc. data referring to geographical objects or locations. Analysis of such data is impossible without representing them on maps. The main weakness of **G**eographic **I**nformation **S**ystems (GISes) in support of data mapping is that the user is not given any guidance in designing presentations whereas improper selection of visualization methods can impede subsequent analysis or even result in wrong conclusions. Correct map design requires special knowledge from the field of thematic cartography. One cannot presume that any GIS user has this knowledge.

We introduce the software system IRIS that incorporates the knowledge on map design in the form of generic, domain-independent rules. On this basis it automatically generates thematic maps properly presenting user's data. Another distinctive feature of IRIS is that it supports subsequent data analysis with the use of generated maps. The user can interactively manipulate the presentations, and in response they dynamically change making more salient various features of the data under analysis.

1. INTRODUCTION. KNOWLEDGE-BASED SYSTEMS FOR DATA VISUALIZATION

It is widely recognized that graphical presentation of data can significantly help in problem solving. At the same time it is non-trivial to present data adequately. The method of graphical encoding should be chosen in accord with characteristics of the data and relations among them, otherwise the presentation would be ineffective or even misleading.

There is nothing mysterious in building correct graphical presentations. The principles of doing this are formulated in the special literature [Berti83, Tufte83] and well known to professionals in statistical graphics and in cartography. However, this kind of knowledge is hardly a possession of the general public. Unfortunately, the existing commercial software used for data visualization leaves the responsibility for the selection of proper presentation methods to the users without offering them any guidance. The same applies to visualization of territory referenced data in geographical information systems (GISes) [Hearn94]. In addition, existing GISes are rather complex and difficult to operate; considerable training is required to master them. It is also a drawback that the user should think how to present available data instead of complete concentration on data analysis and problem solving.

These shortcomings can be overcome by incorporating knowledge on graphics design in data visualization software. On this basis correct and effective data presentations can be designed and rendered automatically. Research on the use of generic knowledge on data visualization for automated graphics generation has recently extensively developed (see the survey [Murra94]). The system APT developed by Mackinlay [Macki86] was among the first experiences in this direction.

According to Mackinlay's approach, the system partitions the data set to be presented into subsets with less numbers of domains (fields) so that it becomes possible to selects some *visualization primitive* for each subset. The visualization primitives used in APT include seven *visual variables* introduced by Bertin [Berti83]: *position*, *size*, *value* (the degree of darkness), *color*, *texture*, *orientation*, and *shape*, as well as some more complex graphical encoding techniques, such as bar charts, pie charts, or scatter plots. Selection of the primitives is done depending on characteristics of the data set: number of domains, cardinality (number of different values) of a domain, type of values in each domain (nominal, ordinal or quantitative), kind of dependency between domains (functional or one-to-many). It conforms to the basic principle of graphical presentation stated by Bertin: features of data components should be matched by properties of visual variables selected to represent them. For example, a quantitative data component can be represented only by a visual variable that allows quantitative perception, that is, by *position* or *size*. The visualization primitives selected for the partitions are combined by merging parts of partial designs that encode the same information (axes) or by implementing them as different visual properties (size, shape, color, etc.) of the same graphical elements.

The Mackinlay's work showed the feasibility of automated graphics design on the basis of generic principles and rules of visualization. The suggested approach was developed in further research on data visualization. In the system VISTA [Senay94] more visualization techniques and composition operators are available that allow, in particular, to build 3D graphics. In the project SAGE [Roth90] the inventory of data characteristics to be accounted for in graphics design is significantly extended. The design is sensitive to the user's information seeking goals expressed by primitive operations of the kind "accurate lookup of separate data values" or "comparison of values of two attributes". Casner [Casne91] considers information-processing tasks specified as sequences of predefined primitive ***logical operators*** such as search for an object with a given property. Casner's system BOZ receives such a sequence and substitutes logical operators by primitive ***perceptual operators*** such as ***visual search*** for a graphical object with a given graphical property. Then the system selects visualization primitives that enable these perceptual operators.

An attempt to approach the problem of cartographic visualization is described in [Zhan 95]. The authors built the expert system that consults a GIS user what visualization technique should be selected for a given data field. The system does not plan presentations for several fields and does not perform visualization. On the basis of this work and the approach of Mackinlay the system VIZARD was created that automates the presentation of spatially referenced data on maps [Jung95]. This system designs maps on the basis of the techniques conventionally applied in cartography.

The results obtained in the research on automated design of graphical presentations refer mainly to the design algorithms and the factors that influence the selection of presentation methods. In all the created systems obtaining a graphic is seen as the final goal of the work, whereas this is only the preparatory step to data analysis and problem solving. For effective analysis the user should have an opportunity not only to view graphics. According to Bertin [Berti83] and Tufte [Tufte83], graphics designed for exploration should give the analyst the maximum possible freedom of **manipulation**. Bertin offers some techniques for building dynamic graphics on paper. Computer screen as a medium for presenting graphics gives much more opportunities for dynamic graphics and interactive manipulation. The potential of interactive manipulation is recognized in more recent literature on visual data analysis [Cleve93] and cartography [Monmo96].

An overview of existing interactive manipulation techniques can be found in [Tweed97]. Though manipulations are always connected with graphical data display, each system proposes one preset type of visualization to manipulate with. This reduces the potential power of such a system in data investigation that typically requires solution of subtasks of various types. It is known that for different tasks different presentations of the same data are useful (this is well illustrated in [Casne91]).

The project SAGE [Golds94] strives to combine the latest developments in both automated visualization design and interactive manipulation. However, in SAGE these two instruments seem to merely co-exist: supported manipulations do not depend on the presentation techniques selected for the data, on the one hand, and have effect only on the number of objects displayed, on the other hand.

We have developed the system IRIS intended to support exploration of spatially referenced data by tight integration of automated knowledge-based presentation of the data in the form of thematic maps and tools for interactive manipulation of the resulting data displays.

2. IRIS FROM THE USER'S PERSPECTIVE

IRIS operates with data stored in ***table*** (relational) format. A table is a collection of uniform records (rows) composed from fields; the latter form table columns. The data should refer to some ***geographical objects*** listed in one of the columns. For these objects there should exist a file with coordinates or outlines specified in vector format. In order to design visualizations, the system needs additional information about the data fields (meta-data): types of fields and relationships among the fields[1]. Sometimes relationships among values within a column are also important.

Having a table on the screen (Figure 1), the user can perform various operations to define the content and the scope of data to be represented graphically. S/he can select table columns or/and impose a filter on table rows (restrictions on data values). S/he can also specify an arithmetic formula over the columns and let the system do the calculations by this formula for each record with storing the results in a new column. As soon as any of these operations is finished, the system, by default, automatically activates the visualization design. Activation of the design function on user's initiative is also possible. As a result, the user receives one or more maps showing the data from the selected columns. If a filter has been set, only the rows satisfying it are presented. The maps built after a calculation present the just calculated values from the new column.

When the user selects another set of columns from the table, s/he receives another family of maps. All currently open map windows are closed to avoid screen overcrowding. Still, all the maps remain available, and the user can open any of them when needed. For this purpose the system maintains an index of all generated maps. Figure 2 shows how the map index is presented to the user. Each map is represented by a name and an icon. The icon indicates which visualization methods are employed in the map. Map names are generated automatically so as to show which data fields are represented and to give a hint concerning the possible use of this map, i.e., which analysis tasks it is suitable for.

All maps are provided with automatically generated legends. A legend is intended not only to give a key to correct map interpretation. In general, the system strives to provide more information for analysis than

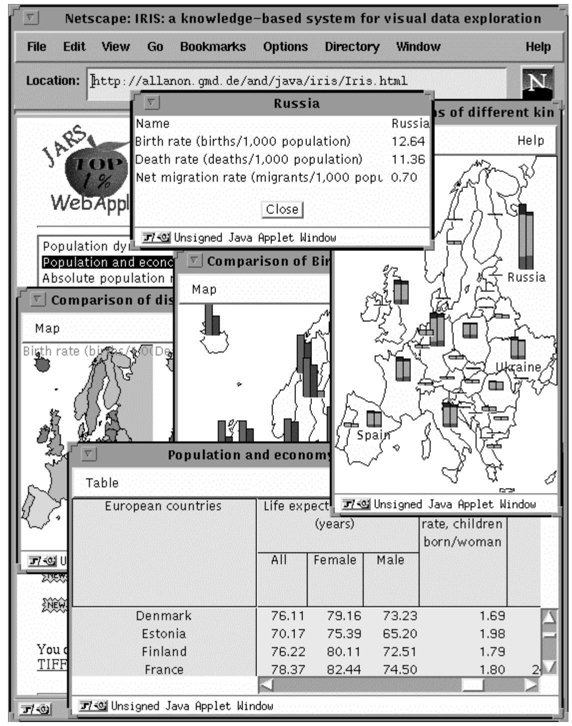

Figure 1. An example screenshot of work session with IRIS.

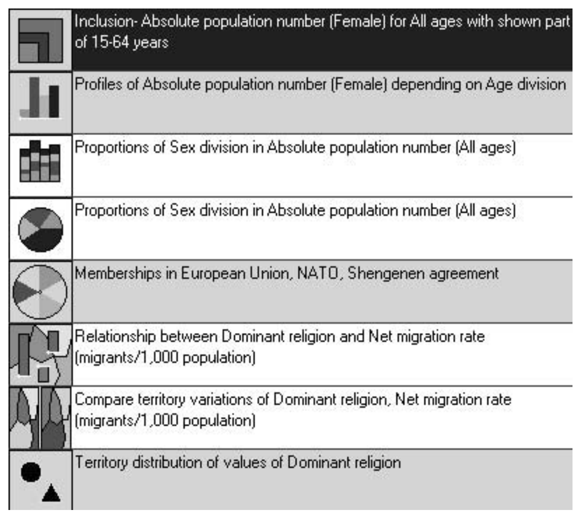

Figure 2. An index of generated maps.

can be read directly from the map. For example, in Figure 3 the legend shows what data are presented in the map and how data values are mapped into color intensity scale. It contains also Tukey's box plot [Tukey77] that depicts statistical characteristics of data values variation (minimum, maximum, quartiles, and median). When a map represents several numeric data components (table columns), its legend shows variation of each of them. If the components are comparable, the corresponding box plots are also shown together in a row to enable comparison of variations.

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[1] When meta-data are not available, the system assumes table columns and values to be unrelated. In visualization design only the techniques applicable to unrelated data are used.

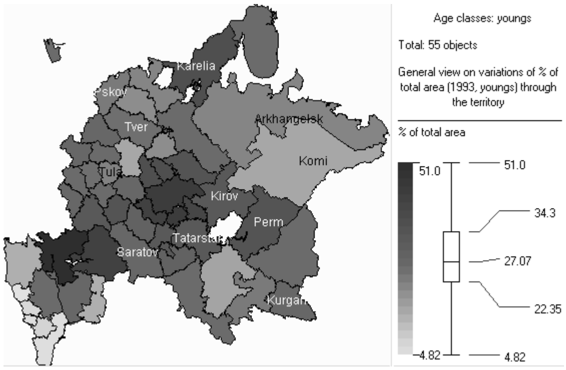

Figure 3. An example map with a legend showing summary statistics of values variation.

When IRIS visualizes one or more columns with numeric values together with a column with qualitative information, it assumes the qualitative column to suggest grouping of geographical objects and calculates summary statistics for the groups as well as for the whole set of objects. For example, the map in Figure 4 presents qualitative information about dominant religions in the countries of Europe together with quantitative data, percentages of children and old people in population. Different dominant religions are encoded by colors. The quantitative data are shown by bar charts. Attached to the map is a supplementary window that shows the averaged "portraits", with respect to percentages of children and old people, of the groups of countries according to religions. Differences among groups are apparent. Below the averaged bar charts Tukey's box plots characterize variations of values for each numeric data component. Exact values of extremes, medians, and quartiles can be received by clicking on the rectangles representing groups.

The examples cited in this session give an idea about the variety of presentation techniques employed in IRIS for map generation. The next section explains

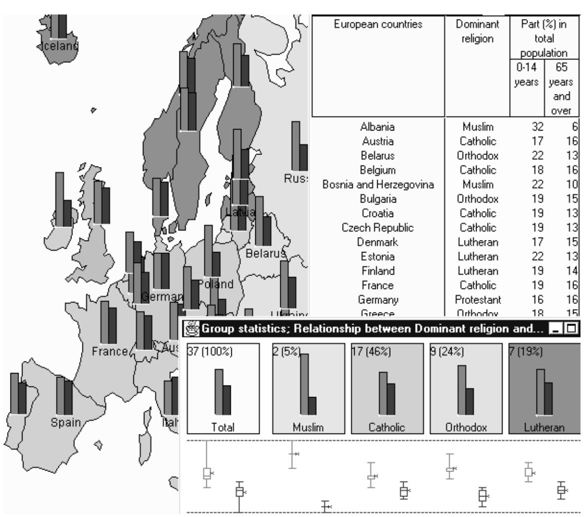

Figure 4. Averaged "portraits" of groups of European countries according to dominant religions.

how data characteristics and conceptual relationships among data components govern the selection of the presentation techniques.

3. KNOWLEDGE-BASED VISUALIZATION IN IRIS.

Implementing knowledge-based data mapping in IRIS, we were aware that the general principles of graphics design are certainly valid for maps but the latter have their own peculiarities. Geographical objects must be depicted on a map so as to reflect actual geographical positions, relative sizes and geometry of these objects. This requirement prescribes the way of organizing other kinds of information in a map: graphical elements selected to represent spatially referenced data should be placed at the points of locations of the geographical objects the data refer to or inside their outlines. The visual variable *position* cannot be used to encode data. Good visibility of graphical elements against the background should be ensured. The background includes outlines of the referred geographical objects and, possibly, other geographical layers such as rivers, forests, mountains, and so on. All this provides familiar appearance of the territory and easy identification and location of the objects under analysis.

An arsenal of methods appropriate for data visualization on maps has been developed in cartography. Most of these methods were included into IRIS. Among the visualization methods we distinguish those based on painting and those based on the use of signs. Signs may be either simple or structured. Painting can be applied when outlines of geographical objects are given to the system (the outlines are specified as polygons by co-ordinates of each vertex). In this case we have *area* objects. Another variant is when geographical objects are specified by pairs of co-ordinates (*point* objects). Signs may be applied both to area and to point objects.

Each visualization method exploits some visual variable. In painting *color hue* or *color value* are used (further referred to as hue and value). Simple signs may vary in *size*, *shape*, *hue*, and *value*; combinations of these variables are limited to *size + hue*, *size + value*, *shape + hue*, *shape + value*. Size and shape are not combined because of the difficulties in comparing sizes when shapes differ. The variable *size* is used in two forms: *length* (bars) and *area* (circles). Area is better in case of large differences in data values. Structured signs (further called *diagrams*) are composed from graphical elements varying in *size* (length, area, angle), *hue*, or *value*; combinations of variables are not used. To ensure that graphical elements are distinguished within a diagram, they are given different colors or textures or/and fixed positions.

Consistency of perceptual properties of visual variables (summarized in the table below) with data characteristics is the main principle governing selection of visualization methods [Berti83]. According to this principle, quantitative data can be shown by *size* or *value*, ordered qualitative data - by *value*, unordered qualitative data - by *shape* or *hue*.

Level of perception	**Size**	**Value**	**Hue** *red green blue*	**Shape**
quantitative	⊕			
ordered	⊕	⊕		
selective	⊕	⊕	⊕	
associative			⊕	⊕

When several data components are to be visualized, presentation of each of them should be consistent with its type, and these presentations should be in some way combined. The opportunities for technique combination in cartography are severely restricted: one can overlay signs upon painting but is not encouraged to place signs of different types on the same map. Simple signs may combine two visual variables each assigned to a distinct data component. Structured signs themselves are means for combining several data components in one presentation. They can be classified according the methods of their construction from basic graphical elements: *juxtaposition*, *divergence*, *segmentation*, and *inclusion* (Figure 5).

a) b) c) d) e)

Figure 5. Examples of techniques of diagram construction: juxtaposition (a), divergence (b), segmentation (c, d), inclusion (e).

The basic rule of diagram type selection is the following: the construction method must be consistent with relationships among the components of data to be presented. Thus, juxtaposition encourages comparisons between elements of a diagram and therefore may be chosen for *comparable* data components, such as numbers of births and deaths per 10000 population in countries of Europe. Parallel bars, as in Fig.5 (a), give a good opportunity to estimate differences between birth and death rates. But this feature is undesirable when we wish to analyze together birth rates and sizes of national product per capita: differences of values of these two attributes have no sense. For *incomparable* data components diagrams based on divergence are used (Fig.5 b). In this case direct comparisons are impeded but variations of the shapes of the resulting signs (whether the signs are symmetric or not) allow judging about relatedness of the attributes.

Segmentation is applicable when data components added together make some meaningful whole, for example, numbers of young, middle-aged and old people in country population. Well-known segmentation-based diagrams are pies and segmented bars. The latter may, in their turn, be juxtaposed or diverge. Diagrams based on inclusion are applied when there are inclusion relationships among data components, for example, number of population in total, number of students, and number of university students.

In general, in visualization design IRIS significantly exploits limitations of the map form of data presentation, on the one hand, and relies upon meta-information about relationships among data components, on the other hand. The limitations make impractical the design on the basis of *visualization primitives* considered by Mackinlay and his followers. Instead, IRIS designs maps using whole *visualization methods* developed in cartography. This makes the design rather efficient: the user receives maps almost at the same moment when s/he finished data selection.

The availability of meta-information allows *partitioning* of selected data components *by comparability*. For each group of comparable components the system performs inference over knowledge base on map presentation to find appropriate visualization methods. For groups with two or more components the system selects juxtaposition-, segmentation-, or inclusion-based diagrams, according to *relationships* among components. In the case of one group nothing else is needed. For two groups the system applies permissible combination operators (area painting + signs or combining visual variables within simple signs), and for more than two groups the system tries to apply divergence-based diagrams that can be combined with qualitative area painting. Of course, presentation of arbitrarily selected data components within a single map is not always possible.

According to [Berti83] and [Tufte83], a powerful instrument to examine relationships between two or more data components is comparison of several maps each presenting one of the components. Our experiments with the earlier versions of IRIS showed that this way of data analysis was much easier for the users and gave larger number of interesting findings than that with presentation of the same information in one map by complicated diagrams. Area painting method proved to be especially good for these purposes. This observation inspired adding presentation by multiple maps to the arsenal of combination techniques used in IRIS. Each of the multiple maps presents one of the selected data components by area painting (for contour objects) or by simple signs (for point objects). These maps are united within a single panel, and the system supports their simultaneous scaling so that they always have the same size and show the same territory. This simplifies their joint analysis.

Unlike other systems for automated visualization design, IRIS does not strive to select the "best" presentation from all permissible designs. Instead, it aims to supply the user with **multiple different presentations** of the same data whenever possible. The reason for this is that each presentation method gives different opportunities for analysis. For example, pie charts allow seeing proportions while bar charts make differences more easily estimated. In the course of data exploration the user needs to perform tasks of different types. It is impossible to determine beforehand which tasks and in what sequence will emerge. According to [MacEa94], "the concept of selecting an optimal map, although possibly relevant for presentation, becomes less relevant (and perhaps even counter-productive) as we approach the exploration end of the continuum" (here the author means the continuum of possible map applications from communication to data exploration). For this reason it is very important to give the analyst the opportunity to work with several complementary presentations of the same data that could support the variety of subtasks emerging during the analysis.

4. EXPLORATION BY INTERACTIVE MANIPULATION OF MAPS

Presentation of spatially referenced data on a map is a necessary prerequisite for the analysis of such data, but this is just a prerequisite. The real work of an analyst begins only at this moment. The conventional GISes do not support this work. Our goal has been to create an environment for visual data exploration rather than mere data mapping. Therefore we develop in IRIS dynamic manipulation facilities intended to support map exploitation.

Our approach to the support of visual data exploration consists in the design of **specialized** manipulation tools. It differs, on the one hand, from the approach adopted in other systems exploiting interactive manipulation [Tweed97]: we combine interactivity with automatic knowledge-based design of different types of visualization depending on data characteristics rather than exploit one pre-selected presentation. On the other hand, our interactive tools differ from those offered in [Golds94] that are designed to control the scope of data presented and do not account for peculiarities of different visualization techniques.

Our approach can be explained as follows. As is commonly recognized, each presentation method offers its own means for analysis, i.e., due to certain properties of a given presentation type, some analytical tasks can be done with it easier and more effectively than with others. Our idea is to **reinforce** these potential capabilities by adding dynamics to data displays employing this presentation method. The dynamic changes to be enabled **depend on the properties** of this type of presentation. Hence, the tools allowing such dynamics need to be specialized, i.e. designed individually for each method. Given below are some examples of interactive manipulation facilities offered in IRIS.

Interactive visual comparison with a number. This tool is designed for choropleth maps representing values of a numeric attribute by the visual variable *value*, i.e., by shades in which objects are painted: the greater is the value of the attribute, the darker is the shade. Choropleth map is good to study spatial distribution of attribute values: shades are promptly perceived by a human; similarly painted adjacent spots tend to be perceived together as larger figures (images), and this favors finding interesting spatial patterns and trends.

The visual comparison tool allows selection of some number N between minimum and maximum values of the shown attribute. In response the map is repainted so that values grater than N are depicted by shades of green and those less than N are shown by shades of cyan. The greater is the difference between some value and N, the darker is the shade used to represent it. The values exactly equal to N are shown in light yellow. The map is immediately repainted after any change of the reference value. There are several ways to control N: entering an exact number, moving the slider, selecting an object in the map or in the list (the attribute value associated with this object becomes the new reference value for the comparison), automatically locating the object with the previous or with the next value of the attribute.

Visual comparison adds *color hue* to the expressive means used in the map. This encourages visual grouping of objects: neighboring objects painted in the same color tone tend, despite differences in shades, to be visually united in a single figure. This evidently favors revealing spatial patterns.

A similar tool is applied to maps encoding values of a numeric attribute by heights of bars. In this case bar heights are changed so as to be proportional to the differences between values of the attribute and the basis for comparison N. So, this tool operates with the visual variable *size* on which the presentation method is based. For better legibility, positive differences are shown by green bars and negative by cyan ones.

To illustrate better the idea of *specialization*, we would like to give here an example of a completely different dynamic manipulation tool.

Dynamic separation of qualitative values. This tool works with a map presenting values of a qualitative attribute by colors or shapes. It allows the user to temporarily switch off depiction of some values. Corresponding colors or shapes are removed from the map. This helps to concentrate the attention on the remaining values and see their distribution more easily. With shifting the focus from one group of values to another, the user changes the selection of values to be depicted, and the map is immediately redrawn.

Dynamic separation facilitates study of groups and their spatial distributions with presentations based on the use of associative visual variables (*hue* or *shape*). This is especially important for *shape* that is, according to Bertin, only associative but not selective. Dynamic separation helps to visually isolate particular qualitative categories or groups of categories. After this has been done, the associative potential of shape or color promotes seeing the geographical distribution of these selected categories as a single image. In opposite, when all categories are shown in a map, it is difficult to focus on some of them and disregard the others.

An interesting group of dynamic techniques is based on **data generalization and summarization**. Thus, IRIS includes tools for interactive classification combined with dynamic re-calculation of class statistics. Some techniques are being designed to control minimum values shown by structured signs and to detect dominant component in each sign. A detailed consideration of all interactive techniques offered in IRIS is beyond the scope of the paper.

5. REALIZATION NOTES

The system was implemented so as to run in the World Wide Web (WWW). It consists of two communicating parts: the core working on a WWW server and the user's interface part implemented in Java running on a WWW page under an appropriate web browser. The core performs all operations over data and presentation design. A result of map design has the form of map specification that is sent to the interface part for rendering and displaying on the screen. This approach differentiates IRIS from the tools providing cartographic presentations in the WWW [Gross96] on the basis of CGI interface; that is, static raster pictures are built on a server and transferred via the Internet to a client site. The latter approach cannot provide such wide range of interactive actions that we considered essential to implement in IRIS. More interactivity can be provided by the use of the Tcl/Tk plug-in software working with WWW browsers [Dykes97]. However, this approach is applied to previously prepared maps, whereas in IRIS the maps are dynamically generated on demand.

Implementation of the user's interface in Java and providing an access to the system via WWW[2] allowed wide testing the system by people from all over the world. The actions of people that tried to work with IRIS were registered by the server. This gave us interesting material that allowed us to improve the user's interface of the system. The independent Java applet rating service (http://www.jars.com/) included our system into the top 1% of Java applets.

6. CONCLUSIONS

IRIS is designed as an intelligent environment for visual exploration of spatially referenced data. Two complementary instruments are employed to achieve this goal: **automatic data visualization** and **dynamic manipulation** of produced displays.

Data visualization is done on the basis of a knowledge base on map design. Due to this the maps being generated conform to the principles of graphical presentation of information that prevents misinterpretation of the displays by the user.

Automation of map generation gives many benefits to the user. The user is required only to select data subsets for analysis, and after this s/he can concentrate directly on problem solving. S/he does not need to care about what presentation methods to select and which GIS operations to employ for producing the map. User's time and efforts are saved. Work with the system is easy. The user is not required to be an expert in cartography.

It is important that IRIS, whenever possible, provides the user with several maps and auxiliary displays showing the same data. Each of these presentations gives somewhat different view on the data and allows seeing different features of them. In this way conditions are created for comprehensive study of the

[2] The system is available at the URL http://allanon.gmd.de/and/java/iris/

data.

Dynamic manipulation tools are supposed to support map exploitation for data analysis. Our approach is to create for each presentation method a specific tool that takes advantage of the principal features of the method and promotes the kind of analysis this method is best suitable for. We expect that in this way the user can utilize the potential of each presentation more completely and effectively.

The system was tested in various domains. In all cases the maps built by the system were consistent with characteristics of data under analysis. The maps made apparent the peculiarities of the analyzed phenomena previously known to domain experts. This evidences the correctness of reflection of the data. In some cases the experts uncovered interesting facts and relationships that were earlier unknown to them. This makes us believe that instruments offered by IRIS do support the main goal of data exploration: to gain new knowledge about data.

The work on reinforcing visualization by dynamic manipulation tools is to be continued. We also plan to undertake the users study for more strict and objective evaluation of the tools from the perspective of their productiveness for data exploration.

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