CARTOGRAPHIC GUIDELINES ON THE VISUALIZATION OF ATTRIBUTE ACCURACY

Michael Leitner
Department of Geography and Anthropology
Louisiana State University, Baton Rouge, LA 70803
email mleitne@unix1.sncc.lsu.edu

Barbara P. Buttenfield
Department of Geography
University of Colorado, Boulder, CO 80309
email babs@colorado.edu

This research establishes cartographic guidelines for mapping one specific aspect of data quality, namely attribute accuracy. The guidelines were derived through an empirical study in which test subjects simulated two different siting decisions on a CRT: the location of a natural conservation park and the location of an airport. Both siting tasks needed to incorporate the spatial distribution of wetlands that were dominant in the selected study area. The main goal of the experiment was to find out, if the correctness, the timing, and the confidence of both siting decisions varied due to the inclusion of certainty information about the wetlands locations, the number of classes for wetlands, and the graphical treatment of certainty information about the wetlands locations.

This research continues the trend re-establishing empirical testing as a valid paradigm for eliciting and formalizing cartographic design knowledge. The symbolization schemes for attribute accuracy developed in this paper should be incorporated as GIS graphical defaults in anticipation of digital datasets that include data quality information. Such cartographic guidelines, if expressed in the form of production rules, can also be implemented in expert systems for cartographic design. Such expert systems currently lack formalized knowledge about cartographic design principles, especially in the realm of symbolization.

INTRODUCTION

A major impediment to the development of a full-scale expert system in cartographic design is the lack of formalized knowledge about cartographic design principles (Buttenfield and Mark, 1991). Formalizing cartographic design principles requires acquisition and re-expression in the form of semantic nets, frames, production rules, or similar formalization methods. Techniques for the acquisition of cartographic knowledge for automated map generalization have been summarized by Weibel (1995). They include conventional knowledge engineering through interviews and observation of practitioners on the job or on artificial problems and reverse engineering, which tries to recapitulate decisions made on published documents or maps. Unfortunately, the techniques for cartographic knowledge acquisition have been discussed almost exclusively on a theoretical level and to date, little empirical research has been conducted. One of the few empirical studies, applying reverse engineering, was conducted by Leitner and Buttenfield (1995). They utilized a computer-assisted inventory of the Austrian National Topographic Map Series in order to reconstruct the decisions made by cartographers during map compilation. The cartographic knowledge acquired in this study revealed quantitative relations between map elements (e.g., settlement, transportation, and hydrography) and the changes in these relations that occur with scale transition.

The lack of formalized cartographic knowledge is due to the fact that formalization usually involves empirical research (e.g., interviews, text analysis, inventory, etc.) that is in most cases very tedious and time-consuming. Complicating this matter is the fact that some design variables, such as visual balance and contrast, are by their very nature difficult to formalize. Textbooks (e.g., Robinson et al., 1984; Dent, 1996) usually offer some guidelines for such aesthetic issues, but these guidelines have not been expressed numerically nor have they been stated in form of rules. Another fertile yet untapped area for expert systems lies in the realm of symbolization. Expert systems have been successfully developed for map production, especially for displacement of map features and label placement of feature labels.

This paper reports on the elicitation of guidelines for mapping one specific aspect of data quality, namely attribute accuracy. The guidelines are based on empirical testing. This is the first time (to the knowledge of the authors), that guidelines about the use of attribute accuracy in maps have been based on an empirical investigation. Attribute accuracy as defined in the US Federal Information Processing Standard (FIPS) 173 refers to discrepancies in categorization or the probabilities of misclassification. Together with positional accuracy, logical consistency, completeness and lineage, attribute accuracy constitutes data quality (FGDC, 1992). In the context of this research attribute accuracy is parameterized in the following way: An attribute is confirmed at a given location by demonstrating that the same location is attributed identically in a second independent data source of equal or better quality. For example, one may be more certain of a location whose land cover is attributed to 'wetlands' by two databases, than of a location attributed to 'wetlands' in one database, but not in the other. Throughout this paper, attribute accuracy and attribute certainty will be used interchangeably.

Guidelines for the visualization of data quality and of attribute accuracy in specifically have been mainly discussed on a theoretical level. In many instances, the starting point in such discussions is Bertin's six graphic variables (Bertin, 1983) and how these variables (with possible additions or modifications) might be logically matched with different components of data quality (Buttenfield 1991, MacEachren 1992, van der Wel et al. 1994). MacEachren (1992) for example states that Bertin's variables size and color value are most appropriate for depicting uncertainty in numerical information, while color hue, shape, and perhaps orientation can be used for uncertainty in nominal information. Although not included in Bertin's original variables, color saturation and 'focus' can also be used for depicting uncertainty. Saturation can be varied from pure hues for very certain information to unsaturated (i.e., gray) hues for uncertain information. 'Focus' refers to the visual sharpness of a symbol. Presenting data 'out of focus', or at lower spatial resolution, might be an ideal way to depict uncertainty (MacEachren, 1992).

Van der Wel et al. (1994) present a framework for the visualization of quality information in which they correlate graphic variables with data quality components at different levels of measurement. According to this framework, the graphic variables associated with attribute accuracy are color hue, size, texture, value and color saturation. A similar framework was proposed by Buttenfield (1991), in which the relationship between the quality components and data types is established through differing graphic variables.

The above approaches for displaying data quality encode quality information in an implicit manner (McGranaghan, 1993). In general, implicit symbology for data quality uses graphic ambiguity to create visual and cognitive ambiguity related to uncertainty in the data. Attribute ambiguity, for example, could be encoded by symbols which blend or mask the character of attributes. Fuzzy or indistinct symbols and animation are further approaches to create graphical ambiguity (McGranaghan, 1993).

It can be anticipated that merging data with their quality information into compound symbols (or what McGranaghan (1993) refers to as 'implicit symbology') make maps more complex and difficult to read. This issue is complicated by the fact that people are not used to having data quality information incorporated in a map display. On the other hand, the addition of interactivity, animation, and sound (Fischer 1994a, 1994b) opens up several possibilities for providing attribute information without interfering with the visibility of features that are present in the display (MacEachren, 1992). The results of this research however indicate that attribute accuracy, if applied appropriately can be embedded in maps without confusing map readers. It would seem that map certainty information is understood as clarification rather than adding complexity to a map display.

EXERIMENTAL DESIGN

The cartographic guidelines derived in this paper stem from an empirical study that investigated the impact of attribute accuracy displays of wetland areas on spatial decision support. During an experiment test subjects were asked to site a park and subsequently an airport in an under-developed region. The experiment was designed to observe how both decisions were made, in terms of how often decisions were made correctly, how long the decisions took, and how confident the subjects were about their siting choices. Multiple trials of the experiment varied the inclusion/exclusion of certainty about wetlands locations, the number of classes for wetlands (one or three), and the graphical treatment of certainty (by value, saturation, or texture). In each trial, one of eight possible test maps were randomly presented to each test subject.

The eight test maps differ in the depiction of wetland areas. The scale, study area, and base map information remain the same. One test map (hereafter

Map1) shows a single wetland class. Map1 can be characterized by low attribute detail and no certainty information about wetland locations. Another test map (hereafter Map3) depicts three different wetland classes (fresh water marsh, lake, and lagoon). Compared with Map1, Map3 possesses more detail, but no certainty information. The other six test maps display attribute certainty for wetland locations in two classes (more certain and less certain). One pair symbolizes certainty by varying texture (MapT and MapTi), a second pair varies value (MapV and Map Vi) and a third pair varies saturation (MapS and MapSi). MapT, MapV and MapS depict more certainty by (respectively) darker value, finer texture, and more saturated color. The subscript i indicates reversed symbolization, with more certainty shown by (respectively) lighter value, coarser texture, and more pastel color. Pairs of value and saturation were determined by pre-tests. Texture pairs were drawn from Zirbel (1978).

The experiment was set up in MacroMediaDirector running on Power Macintoshes 7100/80. Sixty-eight test subjects participated in the experiment and their responses were collected on-the-fly. A detailed description of the experiment, including the test maps can be found in Leitner and Buttenfield (1996) and Leitner (1997).

SYMBOLIZATION SCHEMES FOR MOST CORRECT, FASTEST AND MOST CONFIDENT SITING DECISIONS

The performance of many GIS applications for spatial decision support is dependent on the correctness of the decision, the speed with which the decision is made, and the confidence level after having made the decision.

The following discussion intends to establish empirical evidence documenting graphical guidelines that may be incorporated as GIS system defaults for mapping attribute accuracy. The first section discusses which visual variable(s) shall be selected when the correctness of the siting decision is of foremost importance. The following section suggests visualization guidelines yielding the fastest siting decisions. The last section discusses symbolization schemes that should be applied in order to achieve most confident siting decisions. Since space is limited, only the results with respect to the park location will be discussed in this paper. The results for the selection of the airport location can be found in Leitner (1997).

Symbolization schemes for making correct siting decisions

The Friedman-Test was calculated between Map1 and Map3; between Map1 and each of the six certainty maps (in pairs); between all six certainty maps (in pairs); and between all six certainty maps at the same time. The results of the Friedman-Test are shown in Table 1. When comparing pairs of certainty maps, only the statistically significant results are shown in Table 1. The first value in the 'mean rank' column refers to the first test map in the 'test maps' column, the second value, to the second test map. A higher frequency of correct siting decisions are indicated by a lower 'mean rank'.

TEST MAPS	MEAN RANK	CHI-SQUARE	D.F.	SIGN.
Map$_1$ and Map$_3$	1.54 / 1.46	0.8182	1	0.3657
Map$_1$ and Map$_S$	1.54 / 1.46	1.2857	1	0.2568
Map$_1$ and Map$_{Si}$	1.54 / 1.46	0.8182	1	0.3657
Map$_1$ and Map$_V$	1.47 / 1.53	0.4000	1	0.5271
Map$_1$ and Map$_{Vi}$	1.60 / 1.40	5.4444	1	**0.0196**
Map$_1$ and Map$_T$	1.57 / 1.43	2.7778	1	**0.0956**
Map$_1$ and Map$_{Ti}$	1.53 / 1.47	0.3333	1	0.5637
Map$_V$ and Map$_{Vi}$	1.63 / 1.37	7.3636	1	**0.0067**
Map$_S$ and Map$_V$	1.43 / 1.57	7.3636	1	**0.0588**
Map$_{Si}$ and Map$_{Vi}$	1.54 / 1.46	3.0000	1	**0.0833**
Map$_V$ and Map$_T$	1.60 / 1.40	3.7692	1	**0.0522**
Map$_{Vi}$ and Map$_{Ti}$	1.43 / 1.57	3.5714	1	**0.0588**
All Certainty Maps	*	12.5893	5	**0.0275**

The table entries show the results of the Friedman-Test. When two certainty maps are compared, only statistically significant results are shown.

D.F. : degrees of freedom; **SIGN.**: level of significance

* The mean ranks are: Map$_{Vi}$=3.16; Map$_T$=3.32; Map$_{Si}$=3.46; Map$_S$=3.50; Map$_{Ti}$=3.60; Map$_V$=3.96

Table 1:

Correctness of Park Selections Compared for Different Test Maps

Overall, the results show that an increase in attribute detail translates into more correct answers for the park selection. This is true whether the increase in attribute detail relates to an increase in more attribute classes or to the addition of certainty information. However, only MapVi yields statistically significant improvement over Map1 at the 0.95 confidence interval. This is also true for MapT, but at a lower confidence interval (0.9). The results of the Friedman-Test for the category 'all certainty maps' (last line in Table 1) indicate statistically significant differences for the number of correct siting choices between the six certainty maps. The lowest mean rank among the certainty maps is yielded by MapVi (3.16), the second lowest by MapT (3.32).

If more classes of attribute data are available, than they should be displayed in the map. If attribute certainty information is available than it should be included in the map. If the choices of depicting certainty information are by saturation, value, or texture, than value should be selected. More certain information should be visualized by lighter value. When value is not available, texture should be applied, such as that more certain information should be depicted with finer texture and less certain information with coarser texture.

Source of Variation	Total Variation	D.F.	F	SIGN.
Map$_1$ versus Map$_3$	1053	1	4.638	**0.035**
Sequence	11011	3	16.167	0.000
Map$_1$ versus Map$_S$	390	1	1.483	0.228
Sequence	9044	3	11.475	0.000
Map$_1$ versus Map$_{Si}$	159	1	1.114	0.295
Sequence	8701	3	16.585	0.000
Map$_1$ versus Map$_V$	57	1	0.193	0.662
Sequence	5476	3	6.186	0.001
Map$_1$ versus Map$_{Vi}$	19	1	0.092	0.763
Sequence	7472	3	11.907	0.000
Map$_1$ versus Map$_T$	2	1	0.008	0.929
Sequence	10314	3	18.052	0.000
Map$_1$ versus Map$_{Ti}$	295	1	0.982	0.326
Sequence	10254	3	11.386	0.000
Map$_S$ versus Map$_{Si}$	1135	1	5.012	**0.029**
Sequence	7523	3	11.069	0.000
Map$_{Si}$ versus Map$_{Ti}$	969	1	3.669	**0.060**
Sequence	8824	3	11.140	0.000
All Certainty Maps	2650	5	1.239	0.293
Sequence	18805	3	23.526	0.000

The table entries show the results of the ANOVA-Test. When two certainty maps are compared, only statistically significant results are shown. 'Sequence' refers to the sequence of the test map in the experiment.

D.F. : degrees of freedom; **SIGN.:** level of significance of F-Statistic

Table 2:

Response-Times of Park Selections Compared for Different Test Maps

This result appears to be counterintuitive at first, since darker value has been repeatedly suggested for the depiction of more certain information because it is perceived by map reader as being more prominent. Lighter value, on the contrary, is perceived as being less prominent (MacEachren, 1992; McGranaghan, 1993; van der Wel et al., 1994). It appears that this is true, if certainty information is depicted on printed paper, where colors are perceived by reflected light. On a CRT, however, where colors are perceived with emitted light the results might be reversed. Such change in perception has been already noted by Robinson et al. (1984).

Symbolization schemes for making fast siting decisions The ANOVA test was calculated between test maps to explore response times for the symbol schemes. Results are displayed in Table 2. An increase in map detail has differing effects on response times. Response times increase significantly when the number of attribute classes increase (comparing Map1 with Map3). Test subjects seem to need more time to mentally process the additional attribute classes. However, when the additional attribute classes include map certainty information, response times are either the same as or shorter than the one-class map. None of the differences in the response times between each certainty map and the one-class map are statistically significant. It would seem that map certainty information is understood as clarification rather than adding complexity to a map display. This result reiterates the need for additional testing.

Which symbolization scheme for the display of attribute certainty should be chosen? The result of the ANOVA-Test for the category 'all certainty maps' shows that the response times for all six certainty maps are not significantly different from each other. However, the results of the ANOVA-Test calculated between MapS and MapSi, and between MapSi and MapTi are significantly different. This suggests that either saturation or texture can be used to symbolize certainty information when decisions must be made quickly. If the symbol choice is saturation, then more pastel shades should be used to display the more certain information.

Symbolization schemes for making confident siting decisions Results of comparing subjects' confidence about their decisions are shown in Table 3. No significant differences were found when comparing Map1 with Map 3, nor when comparing Map1 with any of the certainty symbolization schemes. This implies that the decisions were made with confidence regardless of introducing additional information (i.e., that it was an easy decision to make in any case). However, comparisons between value and texture symbolization schemes do show significant differences in subject confidence. Subjects are overall more confident of decisions when certainty is symbolized by either lighter or darker value, than when symbolized by texture.

SUMMARY

This research demonstrates that inclusion of attribute certainty on thematic maps does modify spatial decision-making. Improvements in the number of correct decisions were observed when attribute detail is increased, either by additional classes or by including certainty information. Of the three tested symbolization schemes, value and texture were shown to improve the frequency of correct decisions. When correct decisions are the highest priority, lighter values should symbolize more certain information. When value is not available (if it has been used to symbolize other information on the map), finer texture should be applied instead.

TEST MAPS	MEAN RANK	CHI-SQUARE	D.F.	SIGN.
Map_1 and Map_3	1.56 / 1.44	0.8889	1	0.3456
Map_1 and Map_S	1.54 / 1.46	1.0000	1	0.3173
Map_1 and Map_{Si}	1.50 / 1.50	0.0000	1	1.0000
Map_1 and Map_V	1.54 / 1.46	1.2857	1	0.2568
Map_1 and Map_{Vi}	1.56 / 1.44	1.1429	1	0.2850
Map_1 and Map_T	1.46 / 1.54	0.8182	1	0.3657
Map_1 and Map_{Ti}	1.53 / 1.47	0.4000	1	0.5271
Map_V and Map_T	1.41 / 1.59	3.0000	1	**0.0833**
Map_{Vi} and Map_T	1.41 / 1.59	4.0000	1	**0.0339**
All Certainty Maps	*	4.7036	5	0.4531

The table entries show the results of the Friedman-Test. When two certainty maps are compared, only statistically significant results are shown.

D.F. : degrees of freedom; **SIGN.:** level of significance

* The mean ranks are: Map_{Vi}=3.31; Map_V=3.37; Map_S=3.38; Map_{Ti}=3.46; Map_{Si}=3.65; Map_T=3.84;

Table 3:

Confidence Level of Park Selections Compared for Different Test Maps

The most interesting results in this research were discovered for subject response times. One would expect that adding attribute information of any kind should slow down subject response times. Adding attribute classes had exactly this effect. However (and this is the interesting result) adding attribute certainty did not increase response times. No significant differences in response times were found in comparing one class maps with attribute certainty maps. This finding implies that map readers do not assimilate attribute certainty in the same way as they assimilate added map detail. Inclusion of certainty information appears to clarify the map patterns without requiring additional time to reach a decision. An experiment to observe response times for one-, two-, and three-class maps would be one way to confirm these results. Fastest response times were discovered for certainty maps showing saturation, thus if a fast decision is the highest priority, attribute certainty should be symbolized by more pastel colors.

Results indicate that symbolizing certainty by value gives subjects' greatest confidence in their decisions, although the decision task in this experiment was considered by subjects to be easy enough that high confidence was reported regardless of the symbolization scheme. In conjunction with the other findings, one can propose that attribute certainty can be symbolized most effectively using lighter values for more certain information, to ensure that correct decisions will be made more often. When value is not available, fine textures can show attribute certainty almost as effectively. If quick decisions must be made, inclusion of attribute certainty will not impede response times, and use of saturation may in fact improve response times.

As a final point, one might consider the importance of empirical testing to establish guidelines for choosing effective map symbolization strategies. It is by means of rigorous subject testing that principles for map design may be formalized that were previously not known or not understood. In our work, the determination that introduction of certainty information may reduce the time required for spatial decision-making has been uncovered, and guidelines for symbol selection can be proposed. Additional testing can refine the results, of course. More important perhaps is the recognition that once the reasons for selecting a symbolization strategy have been formalized (in terms of correct decisions, or faster decisions), there are clear reasons for implementing such strategies as graphic defaults in mapping packages and decision support systems.

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