An Evaluation Method for Determining Map-Quality

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Abstract

The quality of maps, geo-visualization and usage of multimedia presentation techniques for spatial communication is an important issue for map creation, distribution and acceptance of these information systems (IS) by a public community. The purpose of this paper is to present an evaluation method based on stochastic reasoning for supporting map designers. We investigate the applicability of Bayesian Belief networks and present a prototypical implementation. We will give an outlook to future research questions.

1 Introduction

The quality of maps, geo-visualization and usage of multimedia presentation techniques for spatial communication is an important issue for map creation, distribution and acceptance of these information systems by a public community. In general the creation of an information system, its functionality and human-to-computer interface is supported by evaluations with aimed user groups. This time- and cost-consuming testing of users helps to specify efficient user interfaces and adapted functionality according to the provided knowledge basis. Every time an influencing parameter changes or becomes adapted, the investigation has to be done again to proof the results. Influencing parameters name isolated units which take effect on the quality of the map, thus the understanding, perception and usefulness (in aspect of given situation) of presented information.

The present work addresses the possibility of modeling the influencing parameters in maps, by building an evaluation network and produce stochastic ratings for the quality of geospatial presentation forms. Different methods of uncertain reasoning have been considered. Bayesian Belief Networks got very popular in the recent years. They allow to model relations between causes and effects and can be used for causal as well as diagnostic reasoning. We exploited the Bayesian Network mechanism to build a conceptual model of a cartographic toolbox. It aims to support the evaluation process in user interface creation and functionality implementation.

Instead of a holistic access to the cartographic communication process, a segmentation of this process is intended, which should lead to small model able parts for further usage in the evaluation method. One main characteristic of this functional evaluation method is its ability of completion by expanding the Bayesian network. Thus a concentration on specific parts of the communication process in context with evaluations and preparations seem to be an appropriate way for a first implementation of a basic and straightforward functional model in order to identify and assess if the estimated use of this method would work.

The remainder of the paper is organized as following: Section 2 describes the cartographic communication process as found in the literature. In section 3 we present the part of the process that is in the focus of the present paper. A conceptual model is worked out in section 4. Section 5 introduces the Bayesian approach and how it can be used to create an evaluation method for map quality. A computational model and the results achieved are discussed. In the concluding sixth section we give an outlook to future research questions.

2 A cartographic communication in detail

In general the traditional, simple model of communication is presented by a sender to receiver relation using some medium for information transfer [1]. Information is coded to a signal and transmitted over a transmission line. For cartographic communication this transmission process seems to be expanded due to preparation of semiotic, semantic, pragmatic and cognitive requirements [2]. In its most comprehensive form the process spans from data acquisition to information dissemination with various available technologies. Thus it includes procedures and considerations concerning data quality due to acquisition and structuring techniques, topology and semantic model creation, generalization, structuring and preparation methods for the presentation model and cognitive aspects for the spatial information communication using various depth cues, sensual modes and metaphoric forms of semiotic. Kraak and Ormeling [3] offer a sequence of abstraction and transformation from “reality” (geographic real world objects) to the “mental-map” (the mental model of the user) as interpreted in the mind of the viewer. The steps of abstraction go from reality to digital landscape model and digital cartographic model and reach the visual map and finally the mental map. The transformations are processes leading from one state of abstraction to another. A similar approach is mentioned by Kelnhofer et al [4] where the cartographic communication process is build up by primary, secondary and tertiary information models which are connected with transformation procedures.

The primary model describes a state of data management and analysis, where problems of topology, various data qualities and similar aspects concerning structuring, combination and simplification of data coming from different kinds of measurements and acquisition techniques were mostly solved. This model forms the basis for analytical procedures used by the map-presentation afterwards. For instance a calculation of distance between two cities should use information of the primary data model in order to make use of “real” distances and not the simplified line distances of the cartographic model used within the presentation.

The secondary model names the cartographic presentation model, which takes account for the different cartographic presentation methods. According to a usable and chosen interface (paper, screen, real3d unit or similar) data of the primary model have to be transformed to fit a specific scale definition, resolution of the interface, effectiveness-, expressiveness-criteria and perceptional values. The aspect of perception seems to be one most important to enable information and knowledge extraction. Ignoring perceptional constraints may lead to massive information loss, although all requested data are put on the interface, as consequence of heavy information overload. The user is neither able to extract relevant information nor distinct various layers and identify any kind of information. In the same way the notions expressiveness and effectiveness explain a useful adaptation of information to the specific user interface.

Expressiveness refers to visualization capacity of the interface, which concerns the semiotic question of representing all important and necessary details of recorded objects in order to preserve semantic. Is it possible to present all the detailed information with the “low” resolution and “few” communication parameters the interface offers? For instance, if the resolution of the interface (e.g. screen) is lower than the number of desired detail values, the expressiveness criterion will not be met. Some detail values will then not be perceivable. Only if the number of resolution-pixels of the interface matches or is higher than the detail values, the desired univocal relationship becomes established [5] and all details of the object will be presentable on the interface. Mapping more detail values onto one single resolution-pixel makes determination impossible.

Effectiveness regards aesthetic concerns as well as perceptional information acquisition, immersive interface use, optimization processes for data simplification and visual rendering improvements. The quality of presentation and thus success of communication process is mainly depending on the understanding and acceptance of the user. The simulation or rebuilding of an interactive environment that is similar to the surrounding of everyday life by means of perception, multi-modality and interaction, seems to make the presentation more effective. By these means Egenhofer and Mark speak of “naive geography”, where one main claim is that maps provide a very natural means to explore geographic space and that people perceive map space as more real then the experienced actual geographic environment itself [6].

The tertiary model of cartographic communication process names the user’s mental model that forms the source for decision making and is build up by cognitive and psychological processes sequencing information perception and existing knowledge basis. Presented information becomes filtered by existing knowledge content [7]. Adaptable and understandable parts may be added to the existing knowledge base, whereas the rest may be rejected.

These three main states of cartographic communication and their transformations seem to clearly split the whole communication process into few parts. In fact this classification is more complicated. For instance a chosen interface needs a specific abstraction and scale of data in order to fulfill expressiveness criteria. This higher degree of abstraction calls for a given knowledge at the user-side to make information readable. Thus the transformation process from primary to secondary model is influenced by the user’s mental model, if the map should be understandable, add new knowledge to the users knowledge and support decision making. The example may be the other way around, so that the used interface and presentation form supports spatial communication and there is no presumption for specific user knowledge, like surveys showed up for the communication of topographic data with the help of 3D presentations and interfaces [8].

The chain of the previously depicted communication model with its cross-connections makes some difficulties for the creation of an evaluation model obvious. This allows us to conclude that the cartographic communication process is simple utilizing the users aim and the according simplified data. Then, generally, discrepancies between the defined communication model and actual use of maps for knowledge acquisition may occur. When focusing on the main task of cartography, to efficiently transmit spatial correlated information [9], all influencing factors, from primary model data structure to creation of user's mental model, seem to be worthwhile considered for a determination of map quality.

3 Aspects of map-quality

The definition of map quality may be constituted on different parameters, which either focus on the consequence of cartographic communication and thus provide a holistic description of the communication process quality or concentrate on specific parts like semiotic (for a selected purpose of map-use), structuring of semantic map content, primary model data-quality (as result of consistency of a database) or similar.

A holistic approach mainly explores the effects of cartographic communication, thus how maps communicate spatial situations. The creation of formal processes of map production and use should help to judge map quality independent from map construction and map reading. Both imply intelligent human interpretation [10]. The factor of aesthetics based on the individual map-user is intended not to be useful within the judgment, because it hardly may be modeled.

On the other hand the splitting of cartographic communication process into small segments, the evaluation of quality of these parts, identification of cross-connections and subsequent calculation of the "system" quality seems to be another potential strategy for quality evaluation. The idea of this method is particularly applied in the segment of user-interface design at present [11]. The access of functionality by dint of a drafted layout is tested with an arbitrary selection of users. The analysis of user activity results in redesign and revision of the interface design. This procedure is to be repeated several times. It is obvious that this time and cost consuming method is rarely applied for commercial products, in particular if one single segment of the whole communication process uses this kind of enormous expense.

The evaluation of map usability employs various quality definitions, whereas "usability" specifies among others understanding of map content by the user, possibility to utilize the map for desired purpose, compliance with effectiveness as well as expressiveness criteria and consistency of data (primary level) and content (secondary model). The definitions concern the quality of data, content, product or transmission.

Data quality describe consistency of data base on one hand and is structured to main indicators like completeness, legal consistency, positional, temporal, and thematic accuracy on the other [12].

Content quality concerns the group of map elements (secondary model) and their transported knowledge. A high content quality may be described by a good rate of cartographic completeness and geometric correctness. Following the rules of carto-semiotic for the most part ensures high content quality. For instance the cartographic principle of geometric correctness is violated by the enlarging of cartographic objects due to visual perception, because objects have to be displaced in order to be readable. In addition the cartographic principle of completeness becomes violated by simplifying, grouping and omitting objects in order to save space for incorporating additional information [13].

The depth of information, thus the complexity of integrated knowledge, in combination with a successful use of metaphoric description [14] and hierarchical structured functionality may characterize map application quality.

Quality of content transmission bases upon an unambiguous transfer of map information [2]. Instead of a straight forward transformation/transmission from cartographic model (secondary model) to the mental model of the user, this process is under individual influence of existing knowledge conditions and issues of interface immersion. Existing knowledge and emotional response of the user to real-world objects may influence the transmission of map content and its understanding. As well as the design of the human-computer interface and its grade of immersion take influence on the quality and intuition of communication process.

The important role of carto-semiotic with its syntactic, semantic and pragmatic formulation for a successful map communication process provides a first structure for conceptualizing an automated evaluation tool for proofing map quality. In addition the complex structure of quality predefinition for maps seems to support the splitting of the cartographic communication model in very small parts, always concerning the question of communication quality for the specific part, identify cross-connections (e.g. from the scale independent data model to the mental model of the user) and incrementally implement these insights to a global geo-communication model.

4 Determining simple model parameters

In order to keep our research question small a simple conceptual model for cartographic parameters has been setup. We investigate map quality by defining three parameters that influence the visual perception of symbols and text: element size, overlay and lightness. Figure 1 compares map presentations ignoring the chosen parameters and one considering cartographic guidelines.

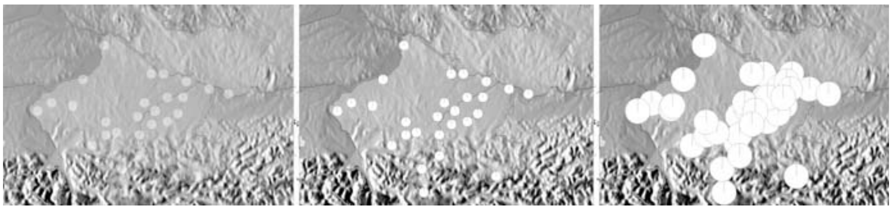

Fig. 1. A map representation that does not consider lightness (left) and element size (right) lowers the readability of a map. A sound cartographic design will raise map quality (middle).

The validity and functioning of an evaluation model in this context is presented by a very simple selection of parameters and their relations. The chosen segment within cartographic communication pertains to point symbols as graphic variables of visual map content. A selection of three parameters makes some reply on quality of perception.

The size of a point element in a map is an interplay of perceptibility and overlay. If the size of the element is to small it will neither be presentable on the interface nor ascertainable for the user. On the opposite an oversized element will overlay others and hide requested information.

Lightness is often used to visualize a rank order of information. Problems occur when point elements become too light or too dark, thus are troublesome visible and distinct able on the interface and result in information loss. In addition a high saturation of big elements attracts attention and lead to a distortion of map balance. Therefore bigger elements should be lighter.

The third parameter overlay simply assesses the rule that fewer information is presentable with increasing overlay. Figure 2 shows the parameters and their connections.

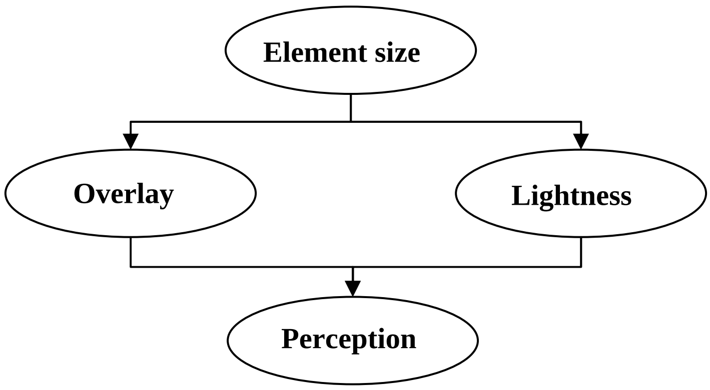

Fig. 2. A graph model of the investigated parameters and their influence on each other is shown in the figure above.

5 Evaluation Tool

A simple evaluation tool is proposed that aims to support map designers. Not all users possess the expert knowledge to choose the appropriate parameters for designing maps. The intended tool shall support layman in the map creation process and contribute to an increase of high quality maps.

5.1 Bayesian Networks

Research in stochastic methods goes back to the 18th century. Nowadays stochastic reasoning can be found in various domains like diagnostic reasoning, natural language understanding, planning, scheduling, and learning [15]. Applications for searching minerals, filtering spam emails or provide help in troubleshooting a printer are just a few examples for the use of Bayesian Networks. In the field of geographic information systems Bayesian networks have been recently used to automatically provide the user with the appropriate data sets to a given question [16, 17]. We propose a model based on the Bayesian Network mechanism [18] to assist layman in cartographic design. The present article will not go into detail on the mathematics, but refers to the available literature [15, 18-20].

Bayesian networks are members of the family of graphical models. They can be represented in a directed acyclic graph structure. The nodes of the graph represent random variables or uncertain events in the world; the arcs are conditional probabilities between the variables. An arc that is directed from node A to node B can be translated to an event A causing event B.

The cause-effect relationships may be defined by an expert. Another method to obtain the relationships between the variables would be to learn them by statistical analysis from given data. The network helps to answer the question which factors influence a particular event.

The mathematical mechanism is Bayes formula that allows to calculate a posteriori probabilities for the nodes given a priori probabilities and a new evidence from current data. The network reflects the change of beliefs in the light of new evidence. A Bayesian network can calculate the probabilities of the states of each node in the network after new evidence has arrived.

According to Heckerman Bayesian networks offer four benefits. They endow users to handle incomplete data sets. Users can learn about causal relationships, connect knowledge of experts with statistical analysis, and avoid over fitting of data [19].

Another benefit is that Bayesian Networks are close to human thinking. Experiments with children have shown that in tasks where conditional reasoning is required the predictive actions of the children can be simulated with a Bayesian Belief Network mechanism [21].

5.2 Computational Model

A simple computational model is proposed that aims to support a map designer in the creation of perceptible maps. The map designer is still assumed to be an expert on choosing the right parameters and the interactions between them. The computational model just helps him in his decision process.

In order to test our model we used a Bayesian Network library provided by Microsoft Research [20]. Bayesian Belief networks can be defined using a graphical editor and stored in a XML data structure. To extend the graph presented in figure 2 towards a Bayesian Network, conditional probability distributions have to be defined for each of the nodes. The event visual perception has been defined by two causes the lightness and the overlay (see figure 3).

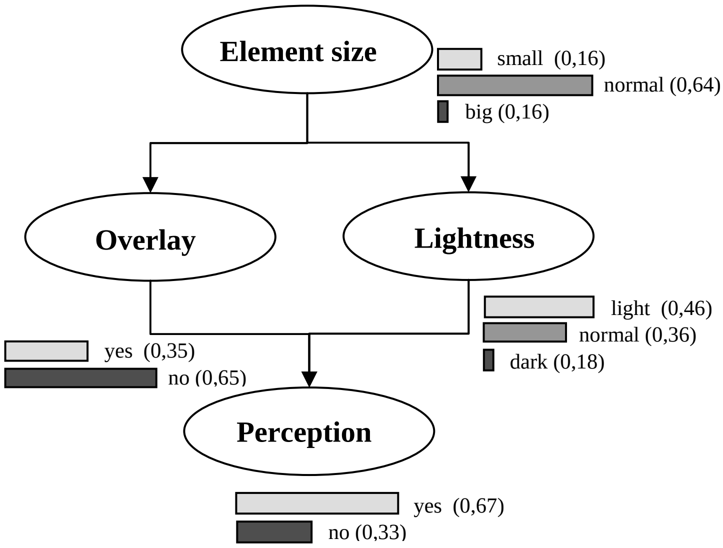

Fig. 3. The numbers, respectively bar charts at each node represent the conditional probabilities of the node states. The whole network represents a single joint probability distribution.

In the case a user has the feeling that the map is not perceptible we can use the Bayesian network as a diagnostic tool and ask for the cause. For our simple model we can calculate if it is more likely that lightness or overlay influence the visual perception. This is bottom up reasoning. Given a certain element size we could also do a top down reasoning and ask to which degree the map is perceptible.

An advantage of the approach is that the network can start with an imperfect knowledge base, and incrementally, with new evidence the quality of the network will improve. The parameters of future models have to be chosen in interplay with empirical studies on map use. Once having enough data initial models could be also built by statistical analysis. At the time the approach relies on models built by experts, an extension to other model parameters is necessary.

6 Conclusions

A concept for a evaluation model for determining map-quality has been presented. A specific part of the cartographic modeling process has been chosen and its model parameters investigated. The present model is based on a mathematical approach that allows to combine statistical analysis and expert knowledge. The intention is to save experimentation time when testing map design parameters. The model shall also support layman in the map creation process and increase to overall quality of available maps.

The simple model has to be extended in several directions. More model parameters have to be identified and included into the model. A tool for the layman has to be implemented with an easy to use interface. Other methods of uncertain reasoning have not been investigated and are of research interest for the development of such a tool. The definition of the interaction between the parameters to define the overall cartographic communication process has to be investigated.

The current findings motivate further research on an evaluation method for map quality and simplify the cartographic modeling process for layman towards automated mechanisms.

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