DYNAMIC VISUALIZATION VARIABLES IN A DEVELOPING FRAMEWORK FOR THE REPRESENTATION OF GEOGRAPHIC DATA

By Connie BLOK
ITC - Cartography Division - P.O.Box 6 - 7500 AA Enschede
The Netherlands - Blok@itc.nl

ABSTRACT

In order to translate the characteristics of geographic data into signs and signals that can be perceived from a cartographic representation, one or more languages consisting of building blocks and related syntatics are required. The first language to be developed was a graphic sign language, introduced by Bertin. His framework has been adapted and extended. Languages for other senses, like touch, hearing, smell and taste have been proposed, or are being investigated. In this paper it has been argued that the overall framework is continuously growing under the influence of technological, conceptual and user-oriented developments. Technological developments in particular are rapid. For example, they allow the representation of geographic data in virtual environments, which can be experienced through multiple senses. If cartographers want to play a role here, they should be willing to contribute to further extension of the framework, which may never be complete. In addition, current definitions of the concepts 'cartography' and 'map' have to be adapted. An example of user-oriented developments is the growing awareness of different types of map use, ranging from presentation to analysis/exploration. Application of the sign language may be different for each type of use, so the framework also needs further development in this direction. As an example, research ideas with respect to the use of dynamic visualization variables in cartographic animations for exploration purposes are included.

Introduction

Jacques Bertin can be considered as the founder of an important theoretical framework regarding the representation of geographic data (Bertin, 1967/1974). The overall framework is about the translation of characteristics of geographic data into signs or signals that can somehow be perceived by human beings. Bertin's *SO(',e)miologie Graphique* deals with a part of that framework: the translation into signs that can be *visually* perceived, and are mainly meant to be used in *2D, static* graphics for *presentation* purposes. The influence of this work has been considerable, and it inspired many cartographers and geographers to attempts to adapt and extend the original framework.

In this paper some of the ongoing efforts to extend and adapt Bertin's original framework will be dealt with first. The scope is limited to maps, other graphics are not considered. The paper then focuses on attempts to extend the framework for dynamic vizualization variables in cartographic animations. Research plans of the author and some initial thoughts about those variables will be presented. Finally, a discussion on the extent of cartographic involvement in the representation of geographic data by non-graphic signs or signals is presented, and some conclusions will be given.

Ongoing construction of a theoretical framework

Bertin (1967/1974) deserves credit for the introduction of a graphic sign language in cartography. He proposed seven variables as the building blocks of the language, and syntactic rules to match the variables to characteristics of geographic data. His work needs no further elaboration here, but it is clear that it can be considered as a solid basis for a more extensive framework for the representation of geographic data by signs or signals in cartographic representations.

Extensions to the graphic variables are proposed by several authors. They sometimes consider the variables as composites rather than primitives. The examples mentioned below are provied by MacEachren (1995). Morrison - in 1974 - suggested to add *colour saturation*. Although saturation was mentioned by Bertin, he did not separate it from hue. Most graphics software, however, allows individual manipulation of all three aspects of colour: hue, value (or lightness) and saturation. Caivano - in 1990 - found that *texture* has three aspects, all refering to variation in the texture elements: directionality (ratio of length to width), size and density. However, density (as illustrated in figure 1) more resembles Bertin's variable value.

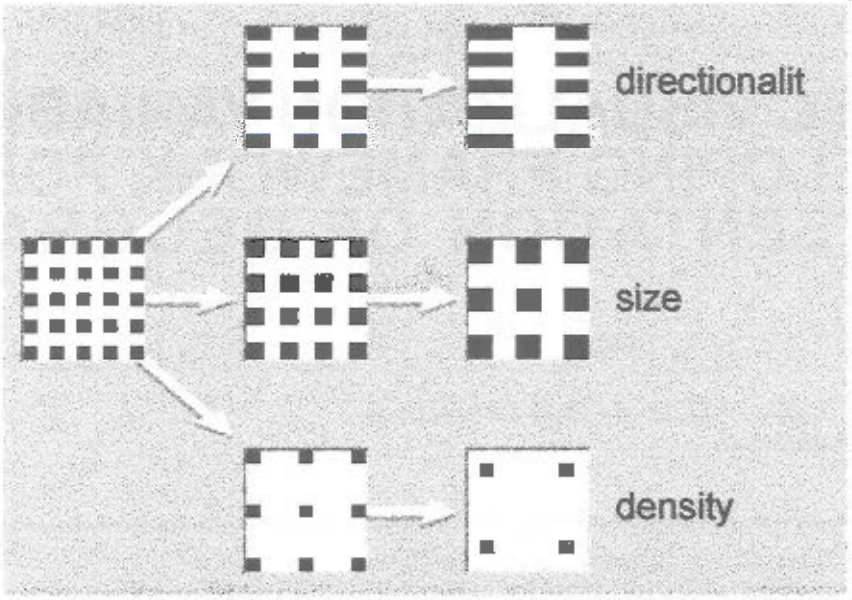

Figure 1. Example of the composite graphic variable texture, as proposed by Caivano in 1990 (after MacEachren, 1995)

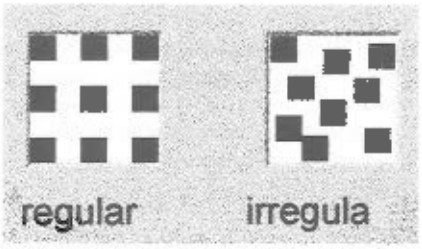

Figure 2. Example of the graphic variable pattern arrangement, as proposed by Morrison in 1974 (after MacEachren, 1995)

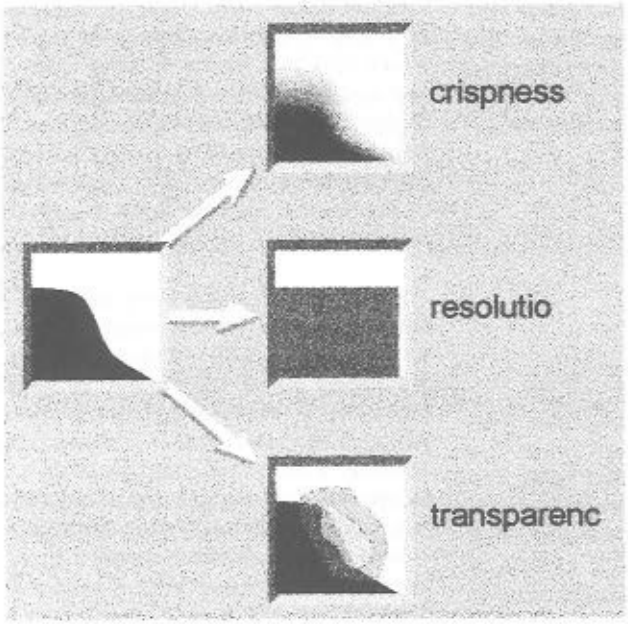

Figure 3. Example of the composite graphic variable clarity, as proposed by MacEachren (after MacEachren, 1995)

MacEachren himself proposed *pattern* as a graphic variable at a higher level. Patterns consist of elements that have shape, orientation, texture, size and arrangement. *Pattern arrangement* (or regularity; figure 2) was originally introduced by Morrison in 1974, and added - together with colour saturation - to Bertin's list of variables.

In 1992 MacEachren introduced *focus* (the sharpness of details) as a composite variable. Later he changed it into *clarity* (figure 3). It consists of the variables crispness (of symbol edge and/or infill, in figure 3 only illustrated by a vague edge), resolution (or level of abstraction of the base map) and transparency (of an intervening layer, giving an illusion of various degrees of fog).

Adaptions to the syntactics are also suggested. Morrison's nine variables were matched to only two data levels: either nominal or ordinal/interval/ratio. On the other hand, he distinguished three degrees of appropriateness for application of the variables: useable, possible and impossible. The 'possible' category was dropped later, in 1984.

Based on his own research and on evaluation of the findings of others, MacEachren's system - as proposed in 1995 - contains twelve variables which can be matched to nominal, ordinal or interval/ratio data with three degrees of appropriateness. In addition, he indicated the capability of the variables to isolate data visually, and to distinguish visual levels (figure 4). In his classification texture seems better suited for nominal than for ordinal data. Perhaps MacEachren's conception of texture deviates somewhat from Bertin's. More surprisingly however, the variable size is indicated as 'good' for the whole range of data, *including* nominal level.

Other researchers have also attempted to adapt elements of the graphic sign language, sometimes for particular applications only. And numerous people have applied it for the representation of data, and even meta data, or data quality aspects (e.g. Van der Wel et. al., 1994, MacEachren, 1994a).

So far, reference has been made to sign systems which are basically designed for 2D representation of data. If applied to create 3D maps, the viewer may encounter interpretation problems if the third dimension is simulated on a 2D surface by depth cues. Examples of depth cues are perspective, colour, shading, texture, overlap, etc. A number of them resemble the graphic variables. Kraak (1988) investigated whether the perception properties of the graphic variables still hold in 3D maps on screen. In his experiments he found that depth cues had no positive effect on interpretation speed, they sometimes even slowed down the processing. The effects on interpretation quality varied from positive, via not significant, to negative influence.

The sign systems mentioned above can be used to represent spatial *and* temporal aspects of geographic data within the available spatial dimensions of the paper or the screen. In cartographic animations a temporal dimension, display time, can be added. Within display time a number of variables can be applied to control the animation. Several so-called *dynamic variables*[1] (figure 5) have been distinguished (DiBiase et.al, 1992; MacEachren, 1994b).. Attempts have been made to develop a syntactics as well, but some questions remain to be answered (see below).

Characteristics of geographic data can also be translated into signs or signals for other modes of perception than sight. Vasconcellos (1993) tried to define the tactual equivalents of Bertin's graphic variables for visually handicapped people. She concluded that colour (hue/saturation) is the only variable that cannot be applied, but different textures can be used instead: '...with equal value for qualitative data or with different values to express order' (Vasconcellos, 1993, pp. 997). Elevation is an additional tactual variable. Similar syntactic rules can apparantly be applied as in the visual domain. Some comments can be made. Texture 'with equal value ' may be confused with symbols consisting of elements having different *shapes*. Furthermore, deformation of the finger skin is fundamental for tactual perception, and the degree and speed of deformation are mainly influenced by elevation, texture and sharpness of the tactual symbols (Jansson, 1972). Elevation is commonly applied to differentiate between point, line, area symbols and braille. Therefore, its use to express measurement levels of data is limited.

MacEachren (1995) mentiones that sound variables have been proposed by Krygier. Most of them can be considered as sonic equivalents of the graphic and dynamic variables of the visual system. The related syntactic rules (leading to an aural sign language) refer to the representation of geographic data at two levels: nominal and above nominal. Kimerling & Buckley (1997) seem to attempt to even further extend the framework. They are conducting experiments with choropleth maps to establish taste and smell variables (which may ultimately lead to the establishment of a gustatory and olfactory language). At the moment these variables can only be used in hard copy maps, but it may well be possible to use smell, and perhaps even taste variables in a computer-generated representation of geographic data in the future.

The examples mentioned above are mainly limited to Anglo-Dutch research. It is, however, not intended to produce a complete overview of all attempts made to build on Bertin's work in this paper, but to show that the original framework has almost continuously been adapted and extended. This happened under the influence of the same factors which according to Kraak & Ormeling (1996, pp. 2) contribute to the '...changing world of spatial data handling...': technological, conceptual and user-oriented developments. Technological developments include those in hardware, software and in networks like the Internet. New techniques and applications could be developed based upon these, like 3D mapping, animation etc. Examples of conceptual developments are the recognition of composite, and the definition of dynamic variables. User-oriented developments include the growing awareness within the cartographic community of the distinction between map use for presentation (where the map is supposed to communicate 'knowns' to a wider audience), and for analysis/exploration (where the map is used as a visual tool to stimulate thinking, and the user tries to discover 'unknowns'). Application of cartographic i.e. syntactic rules may be different, although there may also be rules which can be applied to the whole range of map use. MacEachren (1994) suggests that application of visual logic in the translation of data is very important for presentation, while visual contrast seems to be particularly relevant for exploration. Further research in exploratory map use, and in the cognitive aspects involved in visual information processing, is required to gain more insight. In figure 6 the developing framework for the representation

[1] Since the term «variable» implies change, or dynamics, the author prefers to refer to the visualization process in which the variables are used, and call them *dynamic visualization* variables.

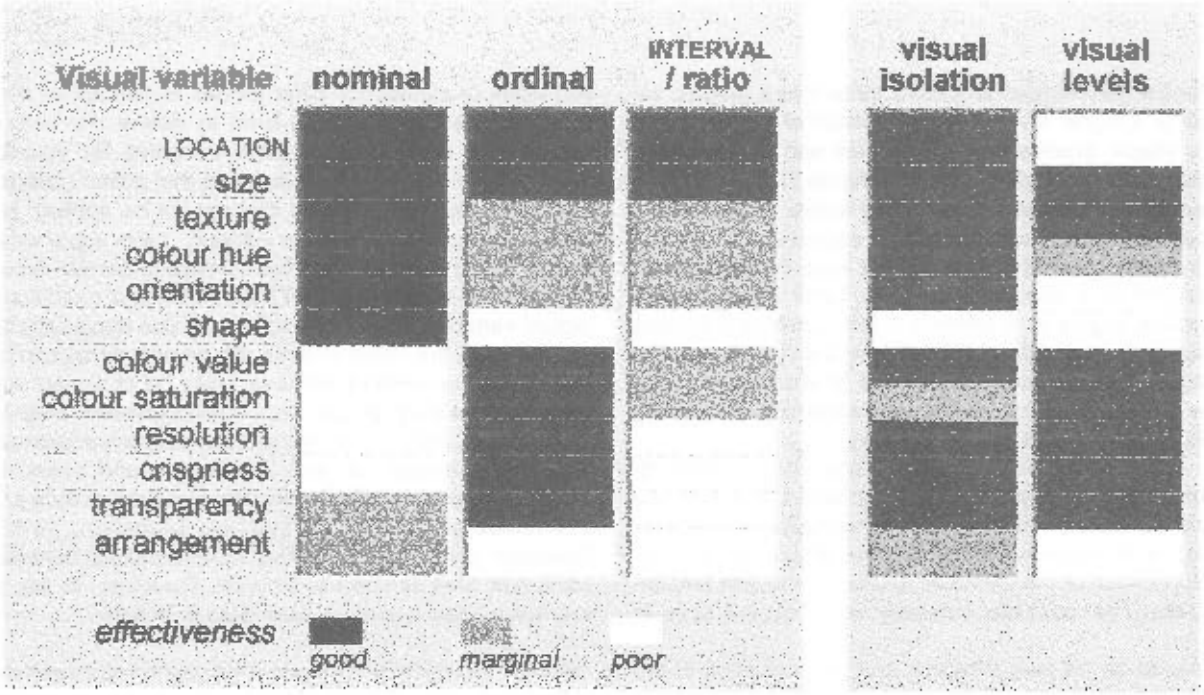

Figure 4. MacEachren's proposal for an extended graphic variable syntactics. The variables have been rearranged based on their effectiveness for the different measurement levels (after MacEachren, 1995)

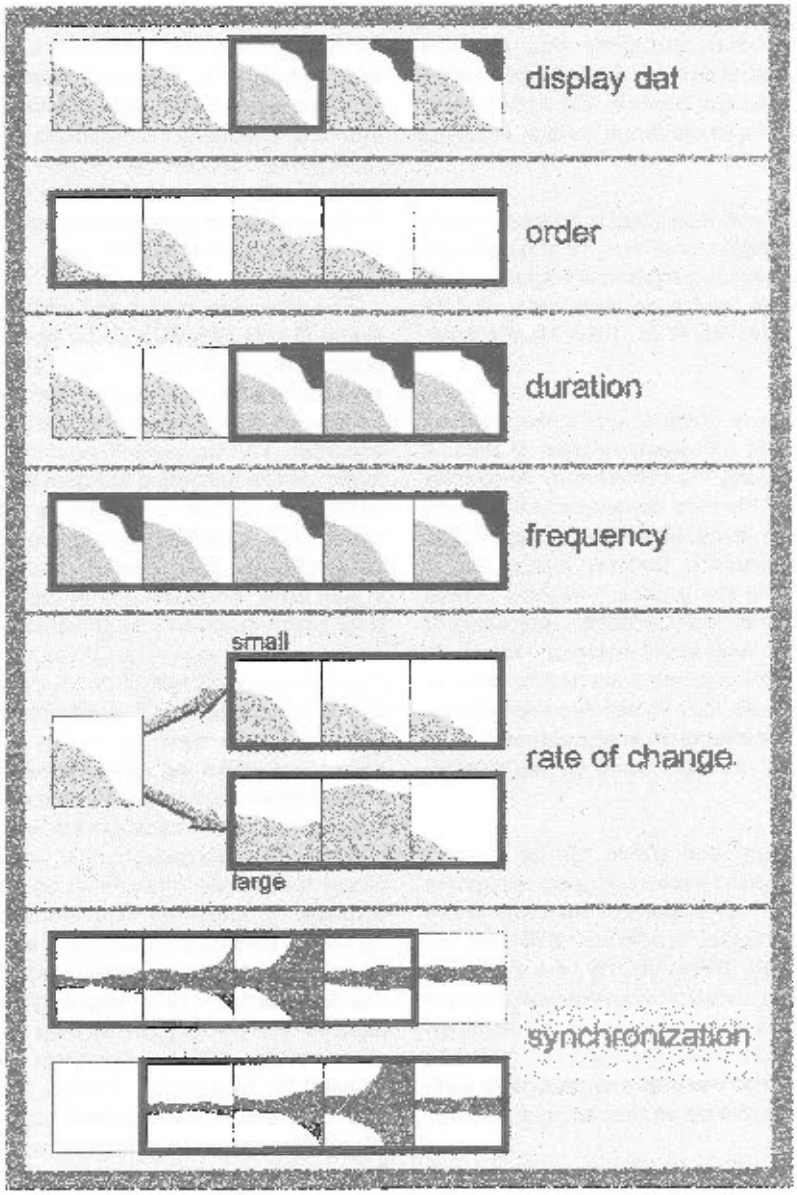

Figure 5. Illustration of the dynamic visualization variables (after DiBiase et.al., 1992 and MacEachren, 1994). The highlighted frames of the sequences show the effect of the dynamic visualization variables

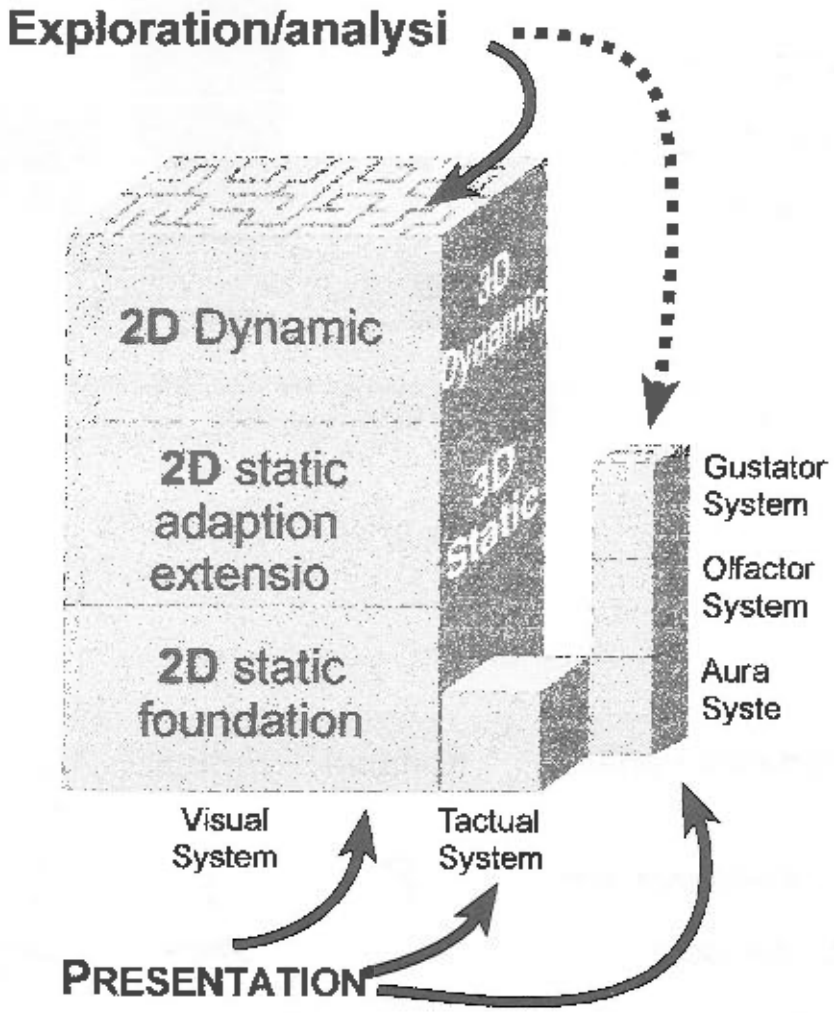

Figure 6. A developing framework for the representation of geographic data

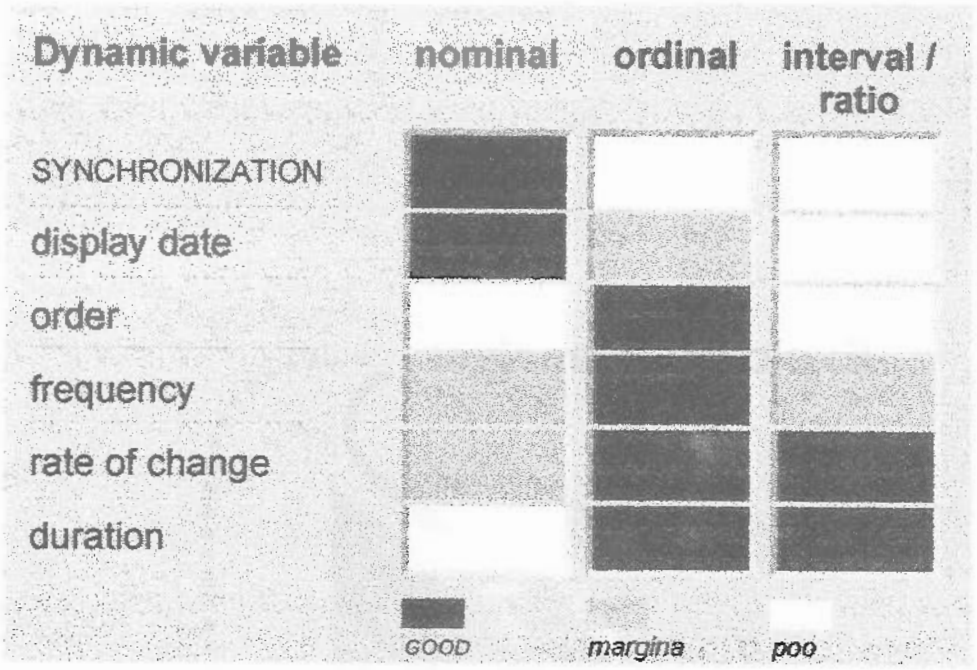

Figure 7. MacEachren's syntactics proposal for dynamic variables. The variables have been rearranged based on their effectiveness for the different measurement levels (after MacEachren, 1995)

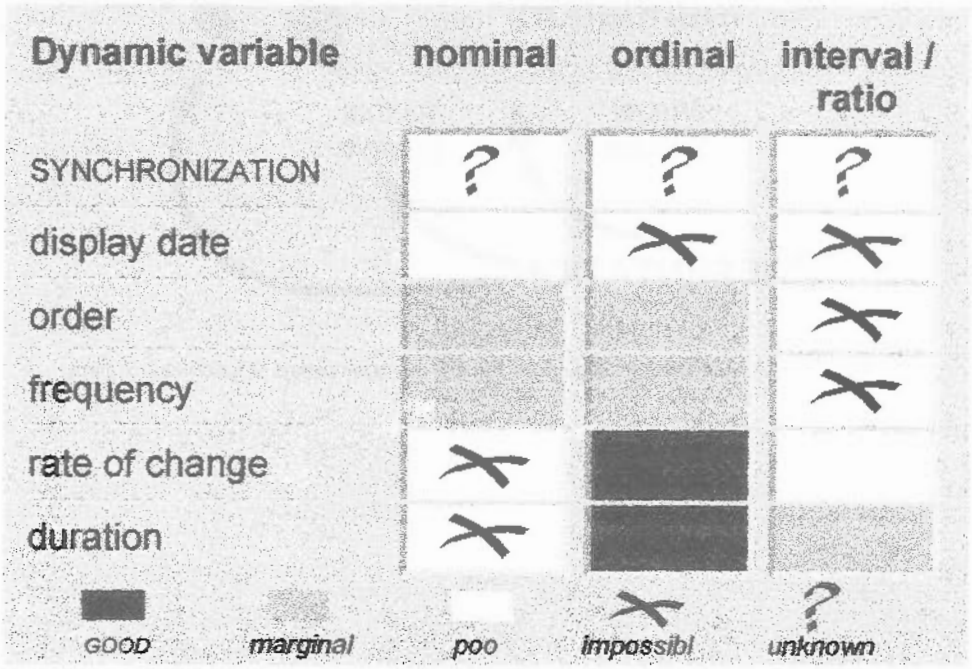

Figure 8. A transformation of KO(«,o)bben & Yaman's syntac for dynamic variables (after KO(«,o)bben& Yaman, 1996)

of geographic data is presented. The fact that the sign language may work differently for presentation to the 'outside' world and for exploration to gain 'insights' is also represented. In the next section, an example of research in map use for exploration will be given.

Proposed research on dynamic visualization variables

Several dynamic visualization variables have been distinguished (see above), and they are also applied in a number of experiments. However, some questions remain to be answered, such as: what are their characteristics and relationships, what is the relation with the graphic variables, how can they be successfully applied, and for what? In an attempt to contribute to the extension of the theoretical framework for the representation of geographic data, research has been initiated in which dynamic visualization variables are used for a particular application: the monitoring of spatial dynamics. Many earth scientists are interested in monitoring. This interest may stem from a wish to understand processes, to interfere in undesired developments, or perhaps to extrapolate to future spatial situations. Monitoring can therefore be used as instrument in various kinds of decision making processes. The perspective taken in the research is that of a domain specialist - like an environmental scientist or planner - who is involved in the processing of spatio-temporal data for monitoring purposes in a GIS-environment. The specialist wants to reveal unknowns, and the visualization goal is exploration.

Spatial dynamics can be observed from changes in the characteristics of spatial objects in time, and an obvious way to visualize those objects in their spatial *and* temporal context is through animated maps or images. If a series of slightly different graphics is displayed as frames in an animations at a speed of at least 24-30 frames per second, the individual frames can no longer be observed, and dynamic transitions are perceived instead. Animations seem therefore very suitable for the representation of dynamic phenomena. Users do not have to compare individual displays of multiple time slices, and rely on memory deduction to obtain an impression of the changes. The dynamics can directly be viewed, and visual dynamics attract attention. However, many changes may occur in display time, and all over the display area. Therefore, cognitive processing of the spatial dynamics may be more difficult. It is likely that a viewer will miss at least some of the changes. *Not seeing* in visualizations is a common error (MacEachren & Ganter, 1990). The author wants to investigate whether *not seeing* the changes in spatio-temporal data can be reduced if the dynamic visualization variables are manipulated - or used as real design instruments - to control the animation in display time.

First, an attempt will be made to define the dynamic vizualization variables in the context of the research, and to determine their characteristics and relationships. Next, animations will be produced in which the variables are manipulated in several ways, and the ability of those variables to assist domain specialists in the detection of spatial dynamics will be tested. One of the results expected is a methodology for the application of dynamic visualization variables for the monitoring of spatial dynamics. This can be considered as a contribution to the developing framework described above. In addition, recommendations for the design of functionalities (animation tools) that allow domain specialists in a GIS environment to manipulate the variables in ways that prove to be relevant are expected.

In a next phase, efforts will be directed towards the design and implementation of a prototype with functionalities based on the recommendations mentioned above, including the necessary interface. However, full application of the functionalities depend on the timely availability of a link between the visualization environment and the GIS data base. It is beyond the scope of the research to cover that aspect, but software vendors may well have succeeded in providing the link by that time.

Some initial thoughts about dynamic visualization variables

The dynamic visualization variables have been defined by MacEachren (1995, pp 281-287) in the following way (see also figure 5):

- *display date* (or moment of display): the time at which some display change is initiated;
- *order*: the sequence of frames or scenes (a scene is a number of sequential frames with no changes);
- *duration*: the length of time between two identifiable states;
- *frequency*: the number of identifiable states per unit time;
- *rate of change:* the difference in magnitude of change per unit time for each of a sequence of frames or scenes;
- *synchronization* (or phase correspondence) : the temporal correspondence of two or more time series.

Synchronization refers to the possibility to run two (or more) temporal animations simultaneously, and shift them in time so that patterns are *in phase*, and relationships between data sets can be discovered (e.g. the pattern between emission levels of pollution and the occurrence of certain diseases may be similar, but may only become clear if the time lag has been removed). The question arises whether synchronization can be seen as a variable. According to the definition, a variable should have at least two identifiable states. *Synchronized* and its opposite, *not synchronized*, hardly seem appropriate for a variable. Phase (in phase correspondence) can perhaps be considered as a variable (with the states *in phase* and *out of phase*), but both synchronization and phase seem to deviate from the other dynamic visuzalization variables in at least three ways: they are dichotomies, two (or more) temporal animation have to run simultaneously to apply them, and it may require more than just a shift in time for relationships te become apparent (e.g. a change in the temporal resolution of one of the animations). Therefore, this author tends to consider them as analysis instruments, and may disregard them in the research mentioned above.

MacEachren (1995) has suggested a syntactics for the dynamic visualization variables (figure 7).

In a small experiment, Yaman attempted to link Bertin=s perception properties to five dynamic visualization variables, synchronization was excluded (KO(«,o)bben & Yaman, 1996). The idea was mainly to obtain a first impression and to stimulate discussion. Not considering the question here whether it is correct to assume that the properties of the graphic variables are also exhibited by the dynamic variables, his results have been transformed to allow comparison with MacEachren=s suggestions. Bertin=s syntactic rules are used to match the properties of the variables to measurement levels (figure 8).

It seems, however, that these schemes cannot be used in the same way as the ones for the graphic variables. The measurement levels in figure 7 do not refer to attributes of the *data* which have to be represented, but to the *effect of the variable*. For example, display date - according to MacEachren (1995) - means that a phenomenon is *on* (initiation of a change) or *off*, and this is an effect at nominal scale, so it is indicated as >good= at nominal level. Synchronization (in or out of phase) is also an effect at nominal level. Duration can be measured at an ordinal or interval/ratio scale, and therefore these levels are indicated as >good=. If we look at measurement levels of *data*, however, it seems that the dynamic visualization variables mentioned above can all at least be used for nominal and higher than nominal levels. Some examples will be given to illustrate this. If changes in the extent of a tropical rainforest area have to be detected from an animated sequence of maps, the data are at nominal level (forest or some other type of land use), and *display date* can be used to show presence or absence of forest at various locations in time. But in another animation display date can also be used to show the initiation of a change from medium to low vegetation indices (ordered level). *Synchronization* can be used at nominal level to show the similarity in the spatial distribution of some kind of pollution and the occurance of a desease in time, but also at a higher level of measurement to show the correspondence between the change from medium to low average rainfall and changes in the vegetation indices. A longer *duration* can be applied to frames if vegetation indices drop below a threshold value (higher than nominal level), or if landslides occur in the displayed area (nominal level). For the author=s research, a link between types of spatio-temporal changes and dynamic visualization variables seems therefore more appropriate.

Discussion

The advent of the Internet, with its potential for the dissemination of data via the World Wide Web, allows us to think about the use of signs and signals for the representation of geographic data in cyberspace. Virtual worlds can be experienced through multiple senses. In the most extreme case of fully immersive virtual environments, sight, hearing and touch are currently possible, and in the future it may well include smell. Taste may be more difficult. At the less sophisticated end of the spectrum, Web-pages accessed on a normal PC currently address sight and hearing, but extension to other senses can be expected.

Cartographers are currently most familiar with the representation of geographic data by signs intended for visual perception, and have limited experience with the use of audio signals. Tactile symbols have only been used in the context of mapping for visually handicapped people, but they may have broader application possibilities in fully immersive virtual worlds. Finally, only a start has been made to address the other two senses.

The question may arise whether involvement beyond the graphics domain is still the cartographer's business. There seems to be no doubt about touch - at least if used for mapping for visually handicapped people - given Taylor=s definition of cartography of 1991: *'the organisation, presentation, communication and utilization of geo-information in graphic, digital or tactile form...*= and Board=s definition of a map (1990): *>a representation or abstraction of geographic reality. A tool for presenting geographic information in a way that is visual, digital or tactile.*= (as cited in Kraak & Ormeling, 1996, pp. 43).

Sound is by some cartographers already considered 'at the fringe', and signs or signals for the other two senses are likely to be considered even further away from the cartographic discipline. However, if the core business of cartography is *the representation of spatial data*, and the cartographic discipline wants to retain its role, the signs and signals for *all* senses have to be included. And definitions of >cartography= and >map= have to be developed that go beyond the ones given above.

The following conclusion seems justifiable. Bertin's *SO(',e)miologie Graphique*, published 30 years ago, laid the foundation for a theoretical framework for the representation of geographic data by signs or signals that can be perceived by human beings. The framework is a dynamic construction, it has been - and will be - extended and adapted. The author, for example, wants to contribute further to the dynamic part of the framework, and other extensions can certainly be expected as a response to technological, conceptual and user-oriented developments. It may therefore never be finished. But ongoing development seems to be in the interest of all those who work with geographic data.

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