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# Cartographic rules for visualisation of

# time related geographical data sets

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# Cartographic rules for visualisation of time related geographical data sets

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Abstract


**Cartographic rules for new visualisation opportunities in GIS**

To visualise regular 2-D map elements one can use the Cartographic Grammar as set up by Bertin (1973). The guidelines he made for visualisation of qualitative, ordinal and quantitative data sets are used by cartographers all over the world and can be used by GIS users who like to produce effective maps.

GIS software and hardware possibilities however, made it possible to make new kinds of maps from non-regular data sets. For instance by connecting a database to spatial features it is possible to make time sequences of each object. But also the new technical possibilities as multimedia, quick regenerating of the display devices and software possibilities for generating red/green 3D images generates new output products. These new possibilities have a great new impulse in the world of cartography. The possibility of representing time in maps is one of those new research items.

Research on this new aspect in Cartography has started. In 1994 MacEachren stated "Animation provides a new cartographic variable that can increase the possibilities of exploratory data analysis". He also suggested that "it should be useful to consider this new variable in relation to Bertin's work".

Subject of interest is to set up new easy to use rules, just like Bertin's grammar, which can be used by GIS users as a guideline for choosing the most effective representation to express their particular time variant.

i

In this thesis these issues are explored in theory. An overview is given of Bertin's theory and the characteristics of time related geographical data sets. An evaluation of the extensions made by fellow cartographers to the theory of Bertin in order to incorporate the factor time in his scheme is made. Finally, a personal proposal of the representation of time related geographical data sets is given, based on the theory models available and extended with new selection criteria. A selection scheme will help a mapmaker in his creating process based on the kind of data, goal and technical possibilities.

## TABLE OF CONTENTS

Caroline Pennekamp        May 1999

iv

# TABLE OF FIGURES

**DISCLAIMER**

**The results presented in this dissertation are based on my own research in the Department of Environmental and Geographical Sciences, Manchester Metropolitan University. All assistance received from other individuals and organisations has been acknowledged and full reference is made to all published and unpublished sources used.**

**This thesis has not been submitted previously for a degree at any Institution.**

**Signed:**


**Date:**

# 1.       INTRODUCTION

The use of Geographic Information Systems (GIS) has risen to a high level in all working areas using spatial information. Once started as a tool for manipulating spatial data it is now a fully integrated part within all organisations dealing with spatial related features. Beside the analyses made on digital spatial data, GIS is nowadays used for more complex operations like the exploration of the data. However, GIS is also the tool for the computerisation of the map production process. Cartographers were cautious of these new developments. They worried about their jobs because of the expectation that all GIS users would provide their own maps instead of asking the cartographer in the organisation to make a nice and efficient map of their data.

Although their job is more then selecting the best map type for representation of the data, it is one of the core activities. Unpleasantly this part is very easily to learn for GIS users. With the help of the 'cartographic grammar' made by a man called Bertin, the right representation of ordinary 2-d data is easily chosen. He made guidelines for representation of three kinds of data sets: qualitative, ordinal and quantitative data. Depending on the desired signifying properties of the visual variables an expressing method can be derived.

However the bad expectations changed into hope for the cartographers. GIS software and new hardware possibilities made it possible to make all new kinds of maps from non regular data sets. Beside this new opportunity, the GIS users came back to them asking assistance in the map making process. They perceived that the cartographic section could make the end maps quicker (cheaper) and more beautiful than themselves.

1

The traditional map making process is of course no problem but the new opportunities like multi-media, multi-views, sound, animation, hyper links, quick regenerating display devices and software possibilities for generating red/green 3D images are present a set of research problems. Representation of other -non regular- data sets is now perhaps more possible. Visualisation of data with a time aspect is one of those problems that should be researched.

Research on this new aspect in cartography is already underway, for instance A.M. MacEachren (1994) called animation "a new cartographic variable that can increase the possibilities of exploratory data analysis". He also suggests that "it should be useful to consider this new variable in relation to Bertin's work".

The goals of this thesis are first to evaluate the extensions made by fellow cartographers to the theory of Bertin in order to incorporate the time factor in his scheme. Secondly to develop the methodological base for representation of time based on the theory models available and extended with new selection criteria. The object is to develop a selection scheme which will help a mapmaker in his creating process based on the kind of data, goal and technical possibilities.

## 2.    GIS, VISUALISATION AND CARTOGRAPHY

### 2.1    INTRODUCTION

> "Cartography is a field with a long practical history but a short academic
> one", A.M. MacEachren (1995)

Before starting a research on the visualisation possibilities of time related
data sets it is essential to start with the basics of the relevant disciplines:
GIS, visualisation and cartography. As stated in the introduction
cartographers were very cautious of GIS software in the eighties. At the
same time they started the conversion of an analogue working process
into a digital process. Whole new, mostly technical problems appeared
and resulted in little time left for fundamental research. This thesis is a
start in new fundamental research on visualisation.
In this chapter first the definition of the key issues (§2.2) are examined.
After the definitions, the importance of cartography is highlighted,
followed by the relation GIS-Cartography. In §2.5 the new technical
possibilities are mentioned and discussed. In the last section the human
aspect of visualisation is worked out.

### 2.2    DEFINITION OF GIS, VISUALISATION AND CARTOGRAPHY

### 2.2.1    Definition of GIS

There are several definitions for Geographical Information Systems
(GIS), Kraak and Ormeling (1996,p 9) state that there are two categories:
those with a technological perspective and those with an institutional
perspective.

From a technological point of view Burrough (1986) makes the definition:

*'A powerful set of tools for collecting, storing, retrieval at will,*

*transforming and displaying spatial data from the real world'.*

From an institutional point of view Cowen (1988) stated:

*'A decision support system involving the interaction of spatial referenced*

*data in a problem-solving environment'.*

For this thesis I would like to use a definition which is the combination of

these statements. *A GIS is a software package for collecting, storing,*

*manipulating and representing of spatial data sets with the purpose of a*

*decision supported system.*

Representing spatail data sets can be rewritten which the term

visualisation, the key issue of the next section.

### 2.2.2        Definition of visualisation

The International Cartographic Association (ICA) was founded in 1959.

One of the principle departments of this association is a group of

scientific cartographers who collaborate in research. A hot topic at the

moment is visualisation. They mentioned that the use of the term

visualisation in the cartographic literature can be traced back at least

four decades. (URL: ICA, 1998)

Kraak (1997) defined visualisation as 1) *visible* and 2) *modern*

*technology that offers the opportunity for real-time and interactive*

*presentation.*

On the other hand Taylor (URL: ICA, 1998) presented in 1991

visualisation as *the intersection of research on cognition, communication,*

*and formalism* (with the latter implying strict adherence to rule structures

4

dictated by digital computer systems). In a modification of this model in 1994 he made clear that he does not equate "visualisation" with "cartography" (Figure 1: Taylor's (1994) extended and revised conception of visualisation in cartography.).
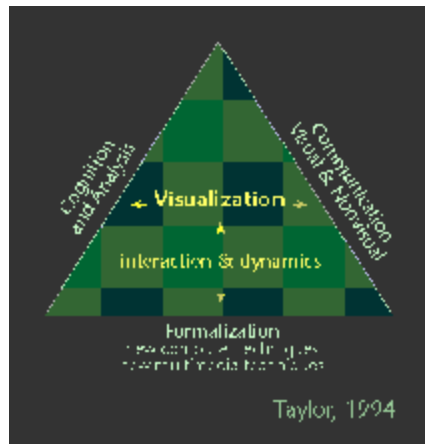


*Figure 1 Conception of visual cartography (©Taylor)*

Blok and Köbben (1998) concluded that visualisation seems to have at least three meanings: the production of (carto) graphical representations of data, the use of (advanced) display technology that acts as an interface between data and user, and the production of cognitive (mental) representations.

### 2.2.3      Definition of cartography

The Dutch cartographic society defined cartography (Bos et al, 1991) as:
*"The total of scientific, technical and artistic activities focussed on the production and the use of cartographic products. "*
In this case not only maps but also map-related representations and cartographic databases are included.

Visualisation can thus be seen as part of the cartographic process but also as an independent topic with links to cartography as maps are used in a visualisation process.

Kraak stated in his Inaugural address that nowadays the purpose of cartography is not longer only the making of a map, but also the question of the effectiveness of a map. To "How do I say what to whom" he adds "and is it effective?".

## 2.3    CARTOGRAPHY

Cartography is also the activity that is focussed on the representation of space and reality.  Since man considered land as his property, sketches of parcels were made. Also topographical maps were created for instance for orientation reasons. The goal for both types of maps is to make the best representation of the situation. Of course it would also be possible to try to put into words the spatial attributes of a location, however one map tells more than thousand words. The essential difference with spoken/written text is time itself. Written text is always sequential instead of graphical communication forms, which are spatial. In a map one can see multiple features at the same time which is almost impossible with sound/text communication.

The graphical communication (maps, graphs, pictograms) can also be modelled themselve. Wieland (1980) made such a model to represent the communication process.
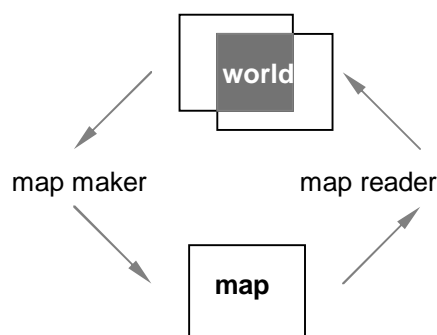
*Figure 2 The communication process of maps (Wieland)*

In this scheme he wants to express the fact that a map-maker interprets the 'world' in his own way and represented his ideas in his map. A map-reader interprets this map and creates his own idea about the world that is represented in the map. The grey rectangle represents the overlap between the real world and the world of the map-reader. The bigger the overlap the better the job of the cartographer.

Cartographers should therefor always bear in mind the way the map user is likely going to look. This is called the map-reader perceptive and is discussed further in §3.4.4.

Result of traditional cartographic work is most of the time a two-dimensional map, either a topographical representation or a thematic representation of the real world. To represent an effective map there are numerous rules and guidelines written down in books. Bertin's book (1981) concentrate for instance on classifying data and gives the onset of the cartographic grammar; Tufte's books (1983,1990) concentrate on maximalisation of data with use of minimum of symboligy. Other books like the books written by Kraak and Ormelings (1996) and Monmonier (1996) are focussing on the total design of maps. In this books one can find items related to pure map design but also (geographical) data manipulation, projections and technical reproduction facilities.

## 2.4      GIS AND CARTOGRAPHY

Just like the traditional cartographic products, the main output products from a GIS are 2-D maps. The output can either be on screen or printed out. Due to the fact that printed maps are just like most of the traditional

cartographic maps made for other map-readers and not for pure private use, all cartographic design rules should be used to make an effective map.

Cartographic design rules which should be used are for instance rules dealing with the:

- lay-out

- typology

- text placing

- generalisation

- classification

- use of correct visual variables (Bertin's grammar)

Of course there are also differences between cartographic rules and the visualisation part of a GIS. One of the most important one is the difference in standard output device. In a GIS a screen is the most common output not paper. The way of looking to a screen and the possibilities to interact, are different compared to the use a two dimensional maps. The maximum size and resolution are different and even colours are created in a different way. On a screen the primary colours are Red-Green-Blue, also called the additive primary colour set. Printed maps are based on subtractive colours (Yellow-Magenta -Cyan). Other differences are the greater potential interaction possibilities of GIS users comparing to map-readers of the static properties of a printed map.

### 2.5 NEW POSSIBILITIES WITHIN GIS FOR CARTOGRAPHERS

In the last few years, changes in traditional cartography have become noticeable: data are stored in digital volumes and there is an ongoing discussion about the introduction of interactive and dynamic ways of

visualisation, using new technological possibilities like animations, multi media, virtual reality, sound and 3 D (Kraak, 1998).

This resulted in an extensive list of current research topics for the researches assembled in the ICA [URL: ICA, 1998]. The most important ones are:

§ TIME: development of a conceptual model and associated tools for the visualisation of spatial-temporal process information (see Slocum and Egbert, 1991, for a review of relevant work in cartographic animation; Kraak and MacEachren, 1994, for discussion of approaches to the representation of spatio-temporal information via maps).

§ FUZZY: development of a conceptual model and associated tools for the visualisation of data quality/reliability.

§ MCA/DSS: explore the impact of map-based spatial decision support tools on decision making strategies and on the outcome of decision-making.

§ 3D: study the potential of three-dimensional representation tools and the corresponding implications of both three-dimensional display and the associated general trend toward realism (versus abstraction) in scientific representation - see MacEachren, et al., 1994 for an initial discussion.

§ Multi media: address implications, for our approaches to map design, of the ability to link many representation forms together in hypermedia documents (e.g., maps, graphs, text, audio narratives, sonic data representation, etc.).


These new topics can be grouped in four basic categories:

a) The geographical possibilities

§ registration of third dimension

b) The databases possibilities

- § registration of time aspect
- § easier aggregation of data sets
- § larger data sets
- § use of relational or object oriented databases

c) The GIS facilities

- § Geo-statistics
- § Multi Criteria Analyses / Decision Support Systems

d) The technical/graphical possibilities

- § hyper links and dynamic linked views
- § animations (temporal or non-temporal)
- § fly over (3D)
- § multi media
- § multi views: same data, multiple expressions, multiple views.
- § interaction
- § sound

## 2.6     SELECTING TIME AS POINT OF INTEREST

Out all of the new research topics the visualisation of spatial-temporal
data is an interesting and often mentioned term within both the field of
cartography and GIS. It concerns not only the latest technical possibilities
in a GIS, like the database part and the new graphical possibilities but
also the cartographic rules and the impact of the new graphical
possibilities on the map-reader.

For 'normal' 2 D non temporal maps the design rules and the
effectiveness are well known due to the efforts Bertin (1981) made. His
(grammar) rules are very useful for 'regular' map design and adapted by

cartographers all over the world. In the next chapter his rules are discussed further on.

However the visualisation of spatial-temporal data does not fit in his grammar. The type of data (time related data sets) nor the latest graphical possibilities can be found in this schemes. Looking for new or possible extended rules are the challenge for the following sections. With these new rules mapmakers can be guided in their creative process to produce maps which are likely to be effective regarding the kind of data, goal and available technical possibilities.

## 3.　BERTIN'S CARTOGRAPHIC GRAMMAR

### 3.1　INTRODUCTION

There are numerous books written about Cartography, however the most important one is the French book called Semiologie Graphique written by Jacques Bertin in 1967. This book deals with the technique of ordering and classification of data sets. The last chapters of the book are more graphical oriented. Though, these chapters are so evident that they became the basis of cartographic visualisation. He structures the process of map design and more specific the communication process. Due to his schedules it is easy to understand how the communication process is best steered.

In this chapter his theory is discussed, the relation to GIS is laid and the modifications made on his theory suggested by other researches are presented.

### 3.2　THEORY

Bertin stated in his book Graphics and Geographic Information Processing that persons always look at a map with a certain underlying question. This can be "Where is …?" or "What is there?".

In the 1960s Bertin for the first time systematically studied the graphical elements in a map which he called visual variables, and their impact on the map-reader which he called signifying properties.

For regular 2 Dimensional static maps, Bertin identified eight visual variables, four signifying properties of the visual variables and three levels of measurement for the data sets. His main goal was to link these categories to each other to help the map maker in his decision of choosing the most effective way of representing the thematic spatial data

based on the type of data and the signifying properties of the selected symbols.

### 3.2.1 The visual variables

Visual variables are the representation possibilities of spatial data, which are available for cartographers to represent spatial features on a map. Bertin distinguished eight visual variables into two different groups. The first group of four visual variables is:

§ X

§ Y            >> the two dimensions of the plane

§ size

§ value        >> the z-value of the plane

The other variables he called the differential variables:

§ texture

§ colour

§ orientation

§ shape

He expressed this classification in the –original- scheme below:



*Figure 3 Visual variables (©Bertin)*

As can be seen, the representation possibilities can be applied to both point, line or polygon features in a map. However size is only very incidental used in relation to polygon features.

Movement can be an additional variable in this scheme, however Bertin (1981,p 42) argued that "although movement introduces only one additional variable, it is an overwhelming one; it so dominates perception that it is severely limits attention which can be given to the meaning of the other variables". For this reason he skipped movement out of this list of variables and out of his theory.

**3.2.2**     **Signifying properties**

For each visual variable, Bertin proposed rules for their appropriate use based on the signifying properties of each visual variable. The term signifying property can be explained as the impression that the map-reader gets when looking at a map, or more specifically, looking at a visual variable.

He distinguished four different kind of signifying properties:

§    similar   ($^O$)

§    differential  ($^1$)

§    ordered   (**O**)

§    proportional (**Q**)

**Example**

As an example he used the following drawing:
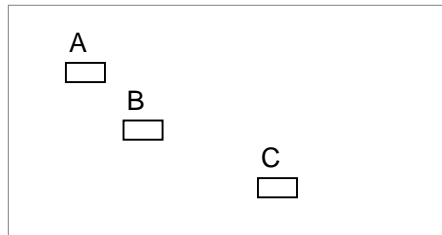
*Figure 4 Example of signifying properties*

- Features A,B,C are distinguishable. They are therefore *different* ($^1$)

  although they are *similar* ($^O$) points.

- B is between C and A. The three points are *ordered* (**O**).

- BC is twice as long as AB. AB is a unit for measuring BC and AC,

  and the eye sees *proportions* (**Q**).

Geels (1987) gave another, easier to understand description:

| | |
|---|---|
| Similar ($^O$) or association | It is possible to neglect the differences between the symbols in order to see the corporate figure |
| Differential ($^1$) or selection | It is possible to isolate all spots with the same symbol in order to detect the pattern that they form. |
| Ordered (**O**) | It is possible to order the symbols in an unambiguously way. |
| Proportional (**Q**) | It is possible to estimate the proportion of two symbols. |

### 3.2.3 Level of measurement

Separately from the visual variables there are the statistical variables;

the classification of the original data set. The thematic data that should

be represented can be classified in three different types of data. The

classification is based on the mathematics. One of his 'mistakes' is that he merged the classification of ratio data sets with interval data sets in one class called quantitative data sets.

His three classes of data sets are:

- Quantitative (ratio and interval):

  Attributes of features who represent an amount. Ratio data (like distance, or inhabitants) can be manipulated with all kind of mathematical operations without losing total sense. Interval data (like temperature) represents also an amount and has also units with a fixed interval, just like ratio data, however without a absolute zero.

- Ordinal:

  Attributes of features who can be ranked (like suitability of soil types for maize), however mathematical calculation like calculating average and sum give no sense due to the fact that the units do not have a fixed interval.

- Nominal or qualitative:

  Attributes of features (e.g. provinces, soil types or ID numbers) who have no evident order. Calculation with (ID) numbers gives no sense.

### 3.2.4 The relation

Bertin connected these elements to each other based on the signifying properties and put it in one scheme. In the scheme itself he does not declare the x and y values. Yet, in the rows are the visual variables declared in the same order as in Figure 3, the columns are the signifying properties which can be used based on the level of measurement of the data. For example ordered or quantitative data can only be represented correct by value and size.

Nine out of the 28 possible combinations between visual variables at one side and signifying properties/level of measurement at the other side are not possible. Bertin calls this transcription useless and warns that this combination will destroy the meaning of the data totally.

**Examples:**

§ Representing the suitability of soil type for crowing crops like wheat by use of the visual variable colour results in a map that gives the false impression.

§ Representing of inhabitants per county by use of size gives the correct impression of proportion.
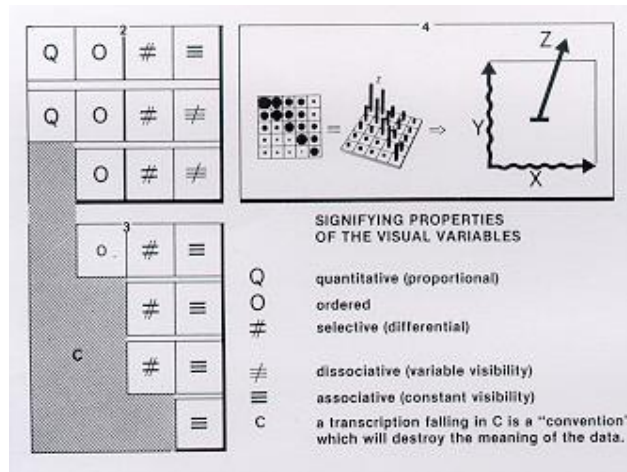


*Figure 5 Bertin's scheme*

Although not always easy to understand the way Bertin orders his scheme, it is very helpful by the decision which visual variable can be best used to represent the original data set.

**3.3**     **WEAKNESS AND RESTRICTIONS OF GRAMMAR THEORY**

All cartographers adapt the theory however the theory is not completely solid and there are certain restrictions in the use of it. One of the weakest points is that the relation between scale of measurement and the signifying properties of these variables is not stated clearly. In his scheme (fig 5) he mixes the items as can be seen clearly in 'the legend' of the scheme.

Another omission is the lack of guidance in how to handle the case more than one visual variable is used. Geels (1987) tried to put these omissions in a new more extensive grammar scheme (see § 3.4.3). Beside the weakness of the theory there are also restrictions to the use of it. The grammar is intended to use for quantitative, ordered or qualitative data sets. Data sets with more exceptional data like time related data, 3-dimensional data or sound are less suitable for this model. For instance, Bertin use x,y co-ordinates in his scheme as the two dimensions of the plane and he defined size and value as the z-value instead of real z-co-ordinates. Also time date, like the time interval of an event, is difficult to classify into one of the three level of measurements.

**3.4**     **MODIFICATIONS AND ADDED FEATURES OF OTHER SCIENTISTS**

Due to the weakness of the model other cartographic scientist tried to improve the model. The new schemes are more or less a variation on the original one, but more 'complete'.

**3.4.1**     **Morrison**

One of the first critics who suggested additions was Morisson (1974). He added arrangement and the third dimension of colour, saturation, to the

list. Bertin used the term colour for the mixture of hue and saturation.
Morrisson stated that with the advent of computer-specified colours,
colour saturation could be seen as an important new visual variable.
Morrison distinguished also another new visual variable: pattern
arrangement.

All these visual variables are matched which only two(!) categories of
information; either nominal- or ordinal-interval-ratio. Matches between
graphic variables and the two levels of measurement are depicted as
'usable', 'possible' or 'impossible'.



*Figure 6 Morrison's variable syntactics*

### 3.4.2 MacEachren

Allan M. MacEachren (1995,p 276) also argued that a further addition to
Bertin's variables is needed. He proposed the term 'clarity, which he
divided in three visual variables or subdivisions:

- crispness: adjustment of the visible detail of a map;

- resolution: spatial precision;

- transparency: a fog that obscures the map theme in proportion to the uncertainty in data about the theme.

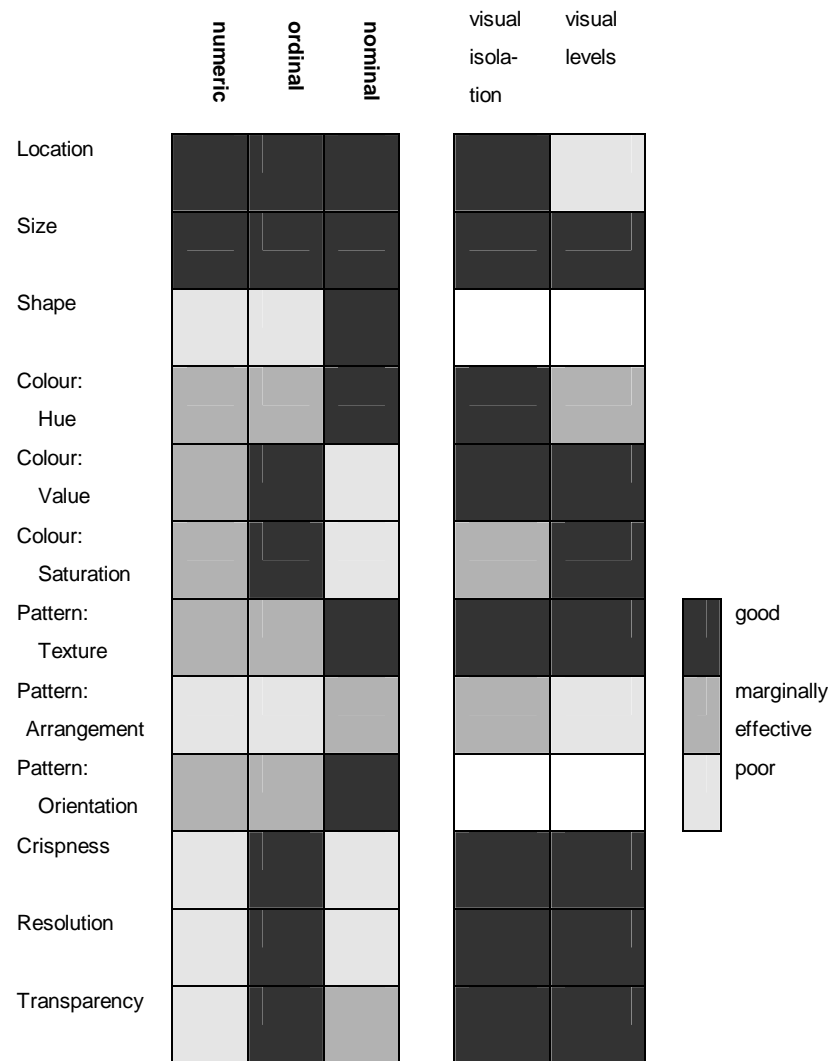| | numeric | ordinal | nominal | visual isola-tion | visual levels |
|---|---|---|---|---|---|
| Location | | | | | |
| Size | | | | | |
| Shape | | | | | |
| Colour: Hue | | | | | |
| Colour: Value | | | | | |
| Colour: Saturation | | | | | |
| Pattern: Texture | | | | | |
| Pattern: Arrangement | | | | | |
| Pattern: Orientation | | | | | |
| Crispness | | | | | |
| Resolution | | | | | |
| Transparency | | | | | |

good

marginally effective

poor

*Figure 7 MacEachren's extended variable syntactics*

In his scheme a visual variable syntactics representing the expanded variable typology is presented. The two columns on the right represent Bertin's concepts of associatively ([O]) and selectivity ([1]).

In 1991 a seminar directed by MacEachren led to the conclusion that an extension to Bertin's grammar/syntactics should be made. Although Bertin explicitly stated that his principles concerning visual variables were not applicable to dynamic display, their initial explorations suggest otherwise.

They expected that movement would be a powerful map "variable" because it combines the two indispensable variables of time and space. On the other hand they admit that is probably true that on a dynamic map things that change would attract more attention than things that do not and things that move probably attract more attention than things that change in place. He stated that "The fact that the use of time gives the map designer a powerful new graphic tools is a reason to explore that tool in detail rather than to exclude it from consideration". MacEachren (1995,p 280).

As a result of the seminar he designed the first rules for representing time. These rules are extensively discussed in chapter 6.

### 3.4.3    Geels

At the University of Utrecht seminars were organised for students in order to learn the syntactical grammar of Bertin. Geels was one of the instructors in the eighties. Due to the fact that he was forced to explain the theory step by step he detected that certain steps in the theory were missing. One of the weakest points is that the relation between scale of measurement and the signifying properties of these variables is not stated clearly. Another omission is the lack of guidance in how to handle cases where more than one visual variable is suitable.

First he looked for the relation between the measurement level and the visual variables based on the signifying properties of the visual variables.

Bertin already mentioned two connections (order and proportion) in the original scheme. Geels added two new ones, differentiation and distance. Secondly Geels looked for a place in his scheme for the last two signifying properties Bertin has stated, association ([O]) and selection ([1]).

He added a third signifying property to this list, called differentiation. To explain this he gave the following guidelines.

| Signifying property name | "What do you want to see?" |
|---|---|
| Association or overall impression | see all of all |
| Selection | see all of one |
| Differentiation | see one by one |

He puts all together in a new, more extensive scheme (see fig 8)

This scheme is helpful for students to select the optimal visual variable in relation to the available data set and in relation to the desired impact of the image. However, the scheme is focussed on the selection of an optimal visual variable for area features and is not tested for linear and points features.

*Figure 8 Geels' scheme*

### 3.4.4 Map reader perceptive

Beside the adaptations mentioned above, can be looked with another perspective at the generation of maps: The human perspective. Bertin's main goal is how to make a map that gives the best overall impression. However sometimes a map reader wants more than an overall view, for instance when he looks for mutual relations between the surface height of an area and the geological structure. In that case he wants to 'explore' a complex map.

MacEachren (1995) jumped on this problem and came out with a human-map interaction cube. The cube is defined by three axes, ranging from public to private map use, from presenting known data to exploring unknown data, and from low to high interaction with the data. Maps should be made according to the corner of the cube that best describes the human-map interaction level. There are three corners explicitly mentioned by MacEachren:

- the private corner

- the exploratory corner

- the high interaction corner.
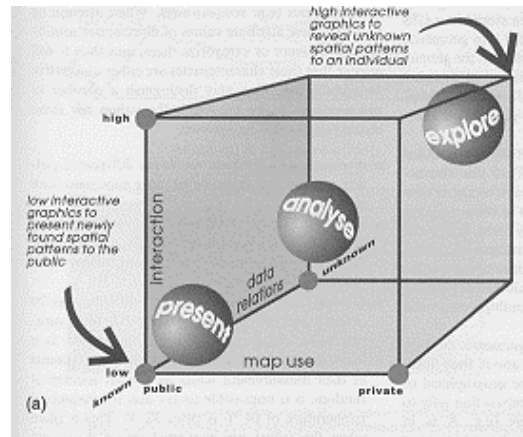
*Figure 9 Human-map interaction cube (©MacEachren/Kraak)*

Kraak and MacEachren (1997) concluded that there are four overall map goals that could be positioned with respect to the axes in the cube:

1. exploration

2. analysis

3. synthesis

4. presentation

For a long time cartographers made just presentations. Bertin's theory best fits on this goal. However it is not clear that the theory is also the best theory for exploratory maps. Perhaps the theory should be adjusted to the goal of the map.

## 3.5 THEORY IN RELATION TO GIS

In most cases Bertin's theory is useful in a GIS surrounding. In a GIS numerous maps and all kind of attribute data are stored. Most users use a GIS just as a tool to generated maps out of a general database and print them out. Outcomes in between are only presented on the screen. These 2-Dimensional representations are most of the time just as static

as ordinal printed maps and just for presentation goals. For a good representation the grammar rules of Bertin can then be used.

Also the standard software possibilities in most GIS systems are based on his theory. For instance the Legend Editor of ArcView selects standard all kinds of different colours -without an order- in a colour set to represent attributes with the option Unique Value, and for proportional representation of data only numerical data can be used.

Real cartographic expert systems are very scarce. They are not implemented in regular GIS packages and only used by few cartographers just to accelerate their own work.

So, if a GIS user wants more then just creating regular 2-dimensional maps for presentation goals Bertin's grammar and standard cartographic utilities within the GIS packages can be used. However, when a GIS user wants to represent data sets like time related data or three dimensional data and/or wants to use other visual variables like crispness, transparency or animation extended guidelines are desirable. Also new research is necessary to calibrate the grammar rules for other map reader perceptives like analysis and exploration goals.

# 4.     TIME DATA WITH A GEOGRAPHIC COMPONENT

## 4.1     INTRODUCTION

In a GIS all kinds of geographical data are stored, managed and explored. However the ability to trace changes in an area by storing historic and anticipated geographic data is hardly used. The former analogue systems tend to provide even a better historic overview of the data than the newer digital systems! Erasing of ink-lines can be easily traced back on an analogue map, but not in a digital file that is stored on (hard) disk. Also revision dates are normally put on the analogue maps. Meta data about digital sets are still scarcely recorded nowadays. Registration and use of time components related to map features are hardly known in GIS business and also the cartographic divisions, who should be responsible for a correct representation, using the new digital techniques, are hardly involved in it.

Before looking to the representation possibilities and new cartographic rules to represent time it is useful to start with focussing on the subject time. In this chapter, three different points of views are considered. First the classification of time in different components (§ 4.2) followed by the technological possibilities to register time in a GIS (§ 4.3) and finally the combination of time and GIS in § 4.4.

## 4.2     CLASSIFICATION OF TIME

Time is a continuing story for man, however if we look better time can be classified into six different classes.
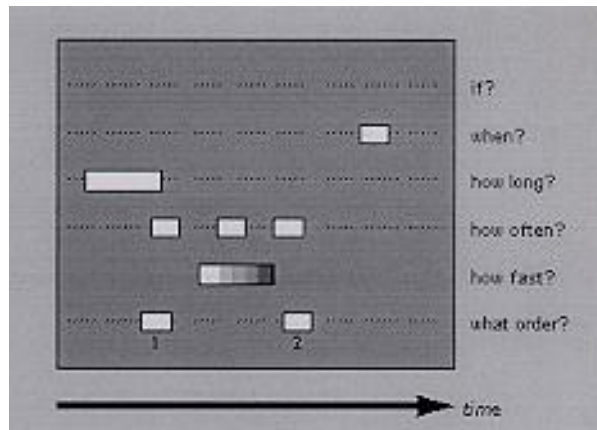
*Figure 10 Time classes (ÓKraak, Edsall and MacEachren)*

- IF:

  The base question: "Did an entity exist or appear?"

  Temporal existence is context-dependent just like spatial existence.

  The required resolution specifies if an entity exists or not.

- WHEN:

  "What is the temporal location of the object?" Temporal location can

  be treated as a point or interval at the time bar. (E.g. December 14,

  1964)

- HOW LONG:

  "What is the time interval of the entities?" The time span between

  start and end point or between end- and start point. (E.g. three weeks)

- HOW OFTEN:

  "What is the temporal texture?" It is a function of time interval

  between entities in relation to another time unit. (E.g. once in a year)

- HOW FAST/HOW MUCH DIFFERENCE:

  What is the rate of change. The rate of change can be calculated in

  relation to the time span or in relation to the mutation of the object.

- WHAT ORDER:

  What is the sequence of the entities. Sequence can be applied to

  both temporal points and intervals.

This classification is also common used in the world of ecology. They use this classification to classify the different growing stages of vegetation types.

To link this classification with the level of measurement of Bertin is not easy. They do not fit 1:1. Based on the 'nature' of the time data set possible relations can be:

| Time classification | Level of measurement |
| --- | --- |
| Temporal existence (if) | Nominal |
| Temporal location (When) | Nominal or Quantitative |
| Time span (How long) | Quantitative (ratio) or Perhaps also ordinal |
| Temporal texture (how often) | Quantitative (ratio) |
| Rate of change (how fast) | Ordinal or Quantitative |
| Sequence (what order) | All levels |

The choice of a related level of measurement depends merely on the interpretation of the items within the time classification. For instance when the temporal location is seen as a moment (yes or no at a certain date) the level of measurment is nominal; however when it is seen as the date itself it can be seen as quantitative data.

In chapter six this is discussed further on.

### 4.3 TIME IN A GIS DATABASE

In a GIS the co-ordinates of the plane can be considered as the first two dimensions. Attributes of the spatial features can be seen as the third dimension. These attributes can be a description of the feature or the z-value (spatial description). Time can also be seen as an attribute (third dimension), however in literature it is normally seen as the fourth dimension.

Langram (1992), has visualised time of geographical features as a cube.
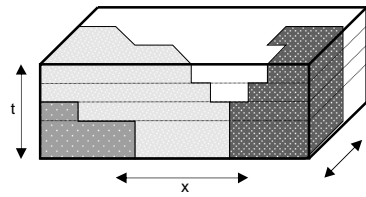


*Figure 11 Representation of time slices (Langram)*

In a vector GIS database each feature has at least two fields extra; start date and end date. In a raster GIS changes are also recorded and changes can easily and quick detected with help of the raster functions. In a vector GIS more complex overlay calculations should be made before changes can be visualised.

An important distinction of information processing is the difference between when events occur in the world and when the database records them. The first moment is called world time the second database time.

**World time**

Kraak (1996) defines world time as "the time-scale of reality, i.e. the moment an event takes place in the world". In the GIS database dates are stored either in millennia/years/seconds (e.g. the drift of the continents) or in a specific date format like the Christian time scale started in the year Christ was born. Although the moment in world time is distinct the storage format is not uniform all over the world!

**Database time**

Database time is defined as the moment a real world event is registered in the database.

**Display time**

Display time can be defined as the moment the map reader or the viewer of an animation actually sees the map/images.

**Example**

The topographic map is a good example of the three different types of time, due to the fact that there is a certain time space between the moment topography is changed until the map is printed out. World time is the moment a new road is built, database time is the moment that the mutation is measured or photographed, and display time is the moment an updated map is published.

**Linear versus periodic time**

Although time normally is seen as a linear feature, it is also possible to recognise periods with a fixed length. These periods are cycles like the days of a week, tides or the traffic volume per day.

## 4.4     TIME CHANGES IN GIS

Most mapped data fix time. Data that fix location rather than time are often time-sequenced statistics for specific locations. The greatest challenge is to fix neither location nor time but to describe the path of a moving object.

|  | Fixed | Controlled | Measured |
|---|---|---|---|
| Soil data | Time | attribute | location |
| Topographic data | Time | attribute | location |
| raster imagery | Time | location | attribute |
| weather reports | location | time | attribute |
| flood tables | location | time | attribute |
| tide table | location | attribute | time |
| airline schedules | location | attribute | time |
| moving objects | attribute | location | time |

*Figure 12 The representation of geographic data in various formats (Langram)*

Another way of representing the three spatial data components is to
arrange the components in a triangle.
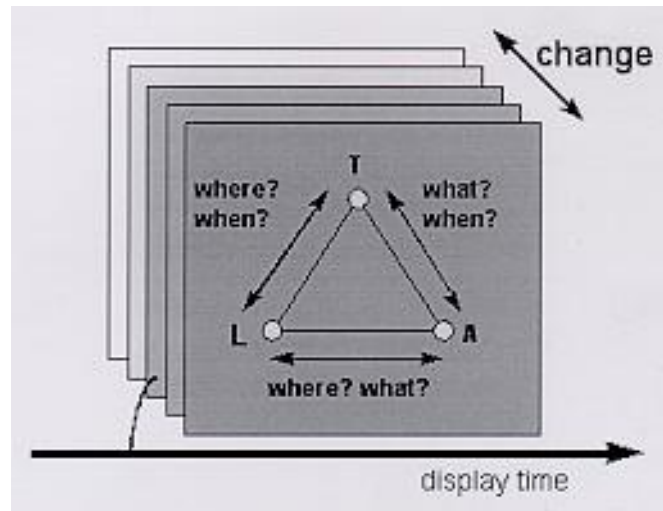


*Figure 13 Interrelation in time components*

**Time**

Normally we think about time as a particular moment, however as stated
in par 4.2 time can be divided in six different sub-classes.

**Location**

Location is the spot in the geographical plane where an entity or feature
is located.

**Attribute**

Attributes are the other more descriptive properties of an entity/feature.
For instance the kind of land use for a parcel or the amount of rain
measured in 24 hours on a control spot.

**4.5**      **CONCLUSIONS**

One can say that the topic time has many faces. The classification of time made by Kraak, Edsall and MacEachren (see fig 10), makes it likely that time can be seen as data input with an own classification instead of the usual classification of the level of measurement. At the other hand time can also be seen as a special form of the attributes of an object. In that case time can be classified into the normal classes of measurement level.

The way this information is stored in a GIS is in this context not so evident although a map-maker and a map-reader should be aware of the differences between world time, database time and display time.

Now we are aware of the relevant aspects of time one can go looking for ways to visualise time. Map series and animations are possible presentation products. Map series are well known and before the digital revolution the only effective presentation. Map series were often used to represent locational change, for instance coastline changes. On the other hand animations can be made nowadays and seem to have a large impact on the map 'reader'. Temporal animations show changes in spatial patterns in time. There is a direct relation between display-time and world time and the transition of individual scenes is related to a change in location of attribute. (Kraak, Edsall &MacEachren,1997) However the most effective way of presenting time is not easy to determine. The cartographic rules of Bertin are not designed for time related data sets and even the modifications made by other scientists are not especially focussed on time data sets.

In the next chapter the technical mapping solutions, both traditional and new, to represent time are described. In chapter 6 and 7 the spotlight is focussed on the theory based on the technical possibilities discussed in

the next chapter.

# 5. TECHNOLOGICAL POSSIBILITIES TO REPRESENT TIME

## 5.1 INTRODUCTION

Before computers became commonplace, cartography was an apparently two-dimensional activity, since its traditional products are drawn or printed on paper. Even in this last two years of this millennium 2-D maps are still the base output format for cartographic representations. Traditional time related data sets are in traditional cartography represented in either a single map or in map series. However new possibilities of representing time aspects are generated due to technical progress like multi media software and extensive computer power. In this chapter the technical possibilities of representing time are discussed. First focussed on the traditional mapping solutions (§ 5.2), followed by new technical possibilities like animation and sound (§ 5.3).

## 5.2 TRADITIONAL MAPPING SOLUTIONS

Traditional time related data sets are in traditional cartography represented in either a single map (§ 5.2.1), or in series of maps (§ 5.2.2).

## 5.2.1 Single map

In a single map different expressions of time can be visualised. Either the calculated differences on one spot or the process of expansion. To visualise time-related data in a static map cartographers normally use three different types of maps:

§ Chroropleth map: a single map in which the differences are represented, changes are calculated, classified and represented in

grey scale or colour value /saturation based on the theory of Bertin that ordered data should be represented with a visual variable with the signifying property order.



*Figure 14 Choropleth map*

§   Isoline map or contour map: contour lines indicating the location of the examined object.
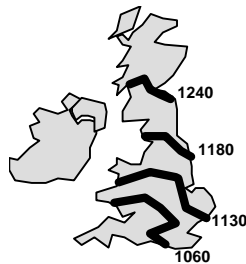


*Figure 15 Contour map*

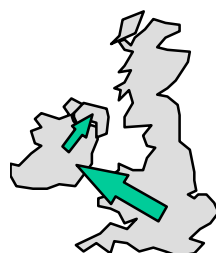§   Flowline map: arrows are used to indicate the direction of the movement



*Figure 16 Flowline or movement map*

Another possible map 'type' is the multi temporal (Red-Green-Blue) map. This kind of map is seldom used but can be used to visualise changes in time like expansion of a city or a desert. Three different dates (e.g.

years) are each represented in a specific colour value and projected on top of each other. When using the three primary colours red-green-blue all possible colours can be generated. Such an image, called image composite, can easily be made with Digital Image Processing software used for satellite images but can also be made with traditional photographically procedures.
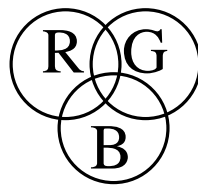


*Figure 17 Multi temporal composite map*

The representation methods used are linked to the measurement scale from the original data set and to the signifying properties of the visual variables.

Recapitulation:

§   change of attribute is represented in grey scale or mixed colour values (value)

§   expansion is represented in contour lines (more or less value)

§   direction of movement is represented in arrows (orientation)

**5.2.2       Series of maps**

Representations of succession of a feature are in traditional cartography visualised in series of maps when it is not possible to combine all feature changes in a single map or to highlight the sequence of the changes. In both cases there is not a locational change but an attribute change.

A well-known example is the changing coastline of e.g. the Netherlands.

The coastline went not only inland but went also backwards, so it is

impossible to make a efficient single choropleth map (see fig 14).

In a map serie each map is of the same type, for instance all choropleth

maps or all contour maps.

Recapitulation:

§   All type of maps can be made. The choice for representation

variables depends on the measurement level of the data.

§   Within a series of maps the type of variables chosen for is constant.
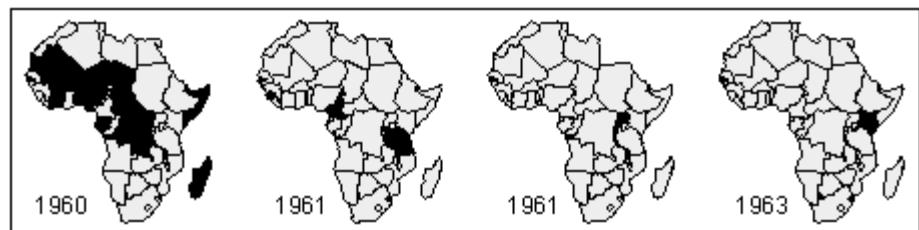


*Figure 18 Example of map serie representing time (ÓKöbben)*

## 5.3        NEW MAPPING SOLUTIONS

### 5.3.1        Multiple dynamically linked views

Within almost all GIS software based on windows it is possible to link

different views to each other. The user will be able to view and interact

with the data in different windows; all windows represent (time) related

aspects of the data. These views do not necessarily contain maps;

charts, sound or video is also possible. Clicking an object in a particular

view will show its time relation in all other views. Monmonier (1990) calls

this 'brushing technique'.

*Figure 19 Brushing technique (Monmonier)*

Brushing means that when an object is selected all corresponding elements in other views/graphics are highlighted. Depending on the view in which one selects the object, there is geographical brushing (clicking in the map), attribute brushing (clicking in the diagram or table) and temporal brushing (clicking on the time line). The user gets an overview of the relation among graphical objects based on time, location and attribute. (See figure 19)

### 5.3.2    Animations

Animations are new graphical possibilities for representing time. Basically from the video world, it is now also accessible for cartographers due to the new computer possibilities. An animation is the new version of the time related map series!
Animations can also be used for other purposes like re-expression (e.g. reordering of time moments). However I like to focus on the possibilities of representing time sequences in this report.

Animation is a dynamic visual statement that evolves through movement or change in the display. In cartography, the most important aspect of animation is that it depicts something that would not be evident if the maps were viewed individually. Especially when the display time

corresponds with the world time changes. In that case a single map (=frame) is projected according to the period of time between that frame and the next one. One can say that what happens between each frame is then more important than what exists on each frame.

There are multiple animation classifications, for example:

Based on the kind of time data:

§   Linear

Linear data sets show a continuing change, either slowly or more chaotic.

§   Cyclical

Animations based on cyclical data, for instance weather animations, are related to suggested temporal patterns. Although clouds often show a linear movement, temperature and wind speed show often a regular periodic pattern.

Kraak, Edsall & MacEachren (1997)

Based on purpose:

§   Illustrative animations.

These are animations without interaction possibilities for the spectator.

§   Explorative animations for research purposes.

To explore data sets it is necessary to have the possibilities of interaction. Not only to stop the animation temporally but also to inquire the data at that particular moment.

Koop & Yaman (1996)

Based on technical representation/production method:

§   Frame by frame.

This is the most elementary animation method. Each single image (or frame) is created separately and finally all frames are combined into an animation. Yet this is the most frequently used animation type in cartography.

§ Key frame.

Only the most characteristic images are created (the so-called key frames) and a computer program interpolates the frames in between. This is technique of interpolation is called morphing.

§ Algorithmic animation.

The most powerful animation technique. A computer program defines what will happen during the animation and the creator only defines objects, changes and the movements, which should be made.

(Kraak and Ormeling 1996, p192)

Based on kind of changes:

§ Temporal dynamic.

In temporal dynamic animations it is the map frame, which is fixed, and the action is within this frame. Changes can be either in location or in attribute value. The latest is equivalent to the term temporal brushing.

1980

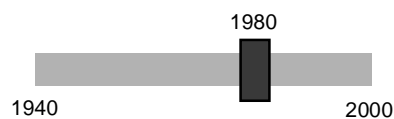1940                                          2000

*Figure 20 Temporal brush*

§ Spatial dynamic.

In spatial dynamic animations it is the action which is frozen and not the map frame. For instance panning and zooming or fly-by in a 3 dimensional animation. Another possibility is re-expression of the data in different ways. This can also be classified as geographical

brushing.

(Ormeling 1995)


Or based on one or multiple views presented to the viewer.

§   Transparently overlapping.

The frames displaying a data set are displayed as transparently overlapping frames on top of an animation of the other data set. If the animation containing the transparent symbols could be manipulated independently of the animation that is running on the base, it would be relatively easy to see whether, where and when the patterns in both animations match.

§   Spatial separated.

The frames of the two animations are displayed in two sequences, which are simultaneously running next to each other. In other to explore the similarity of patterns, tools that allow a user to synchronise the animations are needed.


In all cases user interaction is very important. Without interaction the map-reader can only consume and not control the animation. Buziek (1997) calls animations without or with a very low degree of interaction kinematic maps. Animations with a high degree of interaction possibilities he called dynamic maps.

Another important aspect is the effectiveness of an animation. In general, the maps should be as simple as possible.

A technical qualification for a nice animation is that at least 24 images per second necessary are for an impression of a continuous movement.


**Animation variables**

The variables of animation include both graphical manipulations and

sound (see § 5.3.3.). A distinction can be made between primary and secondary components of an animation. Primary elements make the animation and secondary elements like sound accentuate the animation. (Cartographic Department University of Nebraska at Omaha)

The graphical variables of animation include:

| Animation variable | Description |
|---|---|
| Position | For instance a dot is moved across the map to show change in location. An animation can be used to depict this movement through time. |
| Speed | The speed of movement varies to accentuate the rate of change. For example in an animation that depicts the movement of the centre of a gaz-cloud over a city. |
| Viewpoint | A change in the angle of view could be used to accentuate a particular part of the map as part of an animation. An animation of population change in the Netherlands may use a viewing angle that focuses attention on the western provinces where significant increases in population have occurred. |
| Distance | A change in the proximity of the viewer on the scene as in the case of a perspective view. This can be interpreted as a change in scale. |
| Scene | The uses of the visual effects of fade, mix and wipe to indicate a transition in an animation from one subject to another. |
| **visual variables** | |
| size, shape, colour, pattern | |

An animation covers all the changes that have a visual effect. It thus includes the time-varying position (motion dynamics), shape, colour, and pattern of an object (update dynamics) and changes in viewpoint,
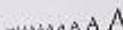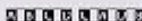
orientation and focus. (Foley, 1990)

### 5.3.3      Sound

Sound is a new phenomena introduced by the possibilities of multimedia personal computers and multimedia software. In a GIS system sound can hardly be connected to a map. The only possibility is to connect it to specific map features. Background music or a typical sound can be played back. In multimedia software packages integrating of sound is easier.

In GIS surroundings experiments with maps in relation to sound are known on topics such as noise nuisance and map accuracy. In both cases pointing at a location on the map controls the volume of noise. Moving the pointer to a less accurately mapped region would increase the noise level. (Kraak&Ormeling,p189)

Krygier (1994) has experimented with sound as an additional variable to visual variables like colour and size. He identified an extensive range of "abstract" sound variables at Bertin's level of visual variables. See figure below.

*Figure 21 Sound variables and syntactics (©Kryger)*

### 5.3.4 Video or images

It is possible in almost all new desktop GIS packages to link a video or
an image to a specific spatial feature in the digital map. A video can give
extra information about the changes of the feature. In an image or in a
chart a more static version of time of that object can be visualised.
Disadvantage is that for each object a video/image and an
accompanying link should be made. An overall impression of time for all
objects is not possible.

### 5.4 CONCLUSIONS

In this chapter the technological possibilities which cartographers
currently and in the past use to represent time are highlighted.
However the effectiveness of the representation is not measurable and
the knowledge rules behind the choice of the optimal representation are
not mentioned yet.

In the next chapter the 'uncompleted' rules made by prominent

researches are considered. These rules should be useful for map- and

animation makers to select the most effective way to represent time.

# 6. CARTOGRAPHIC THEORY TO REPRESENT TIME

## 6.1 INTRODUCTION

Although Bertin believed that movement is an overwhelming variable and would dominate perception, other cartographers continued research on movement and time representation in the nineties. They did research on specific parts of the effects of representation of time but did not construct an easy to use scheme for map-makers. MacEachren, one of the most leading researchers in this field, stated in his book How Maps Work (1995) that "What is probably true is that on a dynamic map things that change attract more attention than things that do not and things that move probably attract more attention than things that change place. The fact that the use of time gives the map designer a powerful new tool is a reason to explore that tool in detail rather than to exclude it from consideration".

In this chapter a compilation is given about the onset of a new cartographic addition to the theory of Bertin. The majority of the research is focussed on the extension of the theory (§ 6.2) and not on a complete new design. The theory is designed for the new graphical possibilities and not on the static, traditional maps or series of maps.

In § 6.3 an overview is given of first onsets of prominent cartographers to join these new aspects with known aspects within cartographic grammar. Their results are compared with each other in § 6.4.

## 6.2 RESEARCH ON REPRESENTATION OF TIME

Recent cartographic research on representation of time is based on the work of MacEachren and DiBiase (1992). They focussed on the theory of

Bertin and were looking on both measurement level and visual variables. Instead of the visual variables, what they called static visual variables, they came with new variables what they called dynamic variables.

### 6.2.1 Dynamic variables

In the early nineties MacEachren proposed together with DiBiase three types of dynamic variables.

These variables were:

§ Duration

§ Rate of change

§ Order

Later he added three additional dynamic variables:

§ Date or moment

§ Frequency

§ Synchronisation

Examples of the dynamic variables:

**Duration**

Duration is the length of time between two identifiable states. Duration can be applied to individual frames of an animation or can be seen as the period between two different states within the animation.
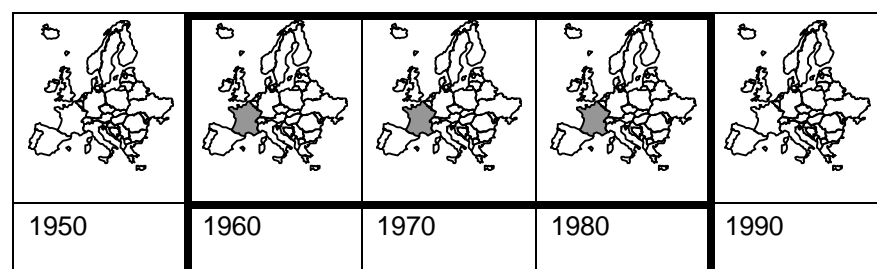


*Figure 22 Duration*

**Rate of change**

Rate of change is the difference in magnitude of change per time unit for

a single frame or for a sequence of frames. The rate of change can be

variable or steadily de/in-creasing.
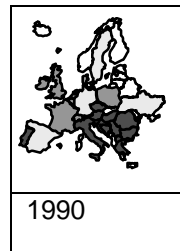


*Figure 23  Rate of change*

**Order**

Order is the sequence of frames or scenes. Time is inherently ordered.

However it is possible to order frames based on another variable as time

and put these frames in a new order and present this.
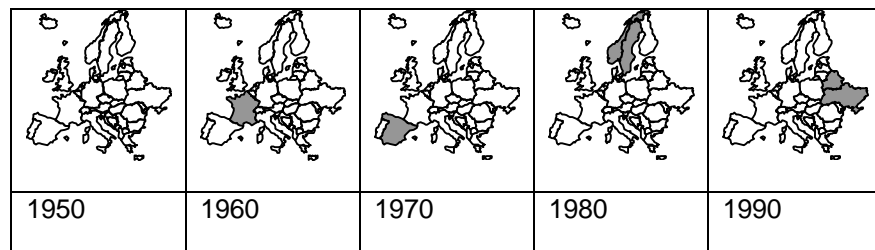


*Figure 24 Order*

**Date or moment**

The time at which some display change is initiated. Display date is

specified in relation to a time span that is either linear or cyclical.

Thinking in maps: the moment that an element in a map changes.
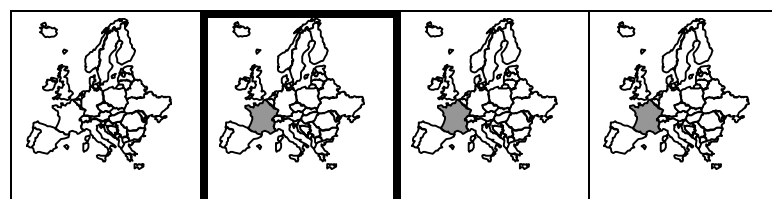
| 1950 | **1960** | 1970 | 1980 |
|------|----------|------|------|

*Figure 25 Moment*

**Frequency**

Frequency is the number of identifiable states per time unit. This temporal frequency is a ratio of two durations. Although it is a calculated variable from other variables it is useful to see it as en extra variable due to the fact that human reception interprets it as an independent variable.

**Synchronisation**

Synchronisation is also called phase correspondence. It is the temporal correspondence of two or more time series. E.g. the correspondence of grow season and rainfall.

### 6.2.2     Relation dynamic variables and time

Although MacEachren and DiBiase give the impression that these variables are totally new, they are directly related to the classification of time as shown in § 4.2.

| Time classification | Dynamic variables |
|---------------------|-------------------|
| Time span *(how long?)* | Duration |
| Rate of change *(how fast?)* | Rate of change |
| Sequence *(What order?)* | Order |
| Temporal location *(When?)* | Moment |
| Temporal texture *(How often?)* | Frequency |
| Periodic time | Synchronisation |

All cartographic researchers adapt this although it is disputable because they put the dynamic variables in the context of visual variables. They are then a kind of the dynamic version of the static visual variables. On the other hand the classification of time in chapter four is almost identical

however based on type of data and not on representation level (=visual variables)!

The differences between the type of data (measurement level) and the possible way of representing issues are placed on the same level and seem now even comparable, although they are clearly different.

At least four prominent cartographers (Kraak, MacEachren, Ormeling and Köbben) tried to work out these new dynamic variables in relation to cartographic grammar. None of these new theories, as discussed in the next section, give a complete overview of the relation between the three major parts in cartographic grammar: level of measurement, signifying properties and variables (either static or dynamic).

## 6.3 EVALUATION OF SUGGESTED THEORY MODELS

### 6.3.1 MacEachren

MacEachren suggested the following relation between dynamic variables and the level of measurement:



*Figure 26 Dynamic variables in relation to level of measurement (MacEachren)*

MacEachren suggests that display date is clearly a nominal variable. It

can be used to show that a feature is or is not in a location at a particular point in time. He also suggests that due to the fact that duration is a quantity, which can be precisely controlled with most animation software, duration of a scene can be used to depict ordinal or quantitative data.

Remarkably, he links the scale of measurement to the dynamic variables. He skips the fact that signifying properties are also essential in map design.

MacEachren also introduced new techniques for representation of periodic duration; colour cycling. Which colour cycling, a range of colour values or hues is "cycled" through the symbol. Colour cycling results in apparent movement or flow through the symbol in a particular direction. Beside duration he suggest that frequency is also clearly a variable in the technique of colour cycling.
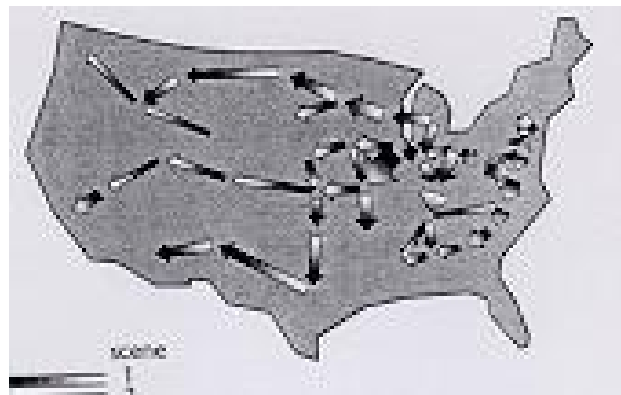


*Figure 27 Colour cycling*

### 6.3.2      Ormeling

Ormeling (URL:Ormeling, 1998) stated that time as general attribute is an ordered variable. It can be rendered by ordinal visual variables, here size, value or texture as suggested by Bertin.

| | Numerical | Ordinal | Nominal | |
|---|---|---|---|---|
| | | | Selec-tive | Associ-ative |
| Size | | | | |
| (colour)value | | | | |
| Texture | | | | |
| Colour hue | | | | |
| Orientation | | | | |
| Shape | | | | |

Legend: Good / Marginally effective / Poor

*Figure 28 Visual variables in relation to signifying properties (Ormeling)*

However in animations there are added variables that affects the visual impression of the map-reader. The way these dynamic visual variables affect one has hardly been analysed. A first result can be seen in figure 29.

| | Numerical | Ordinal | Nominal | |
|---|---|---|---|---|
| | | | Selec-tive | Associ-ative |
| Display date | | | | |
| Duration | | | | |
| Order | | | | |
| Rate of change | | | | |
| Frequency | | | | |

Legend: Good / Fair / Weak

*Figure 29 Dynamic variables in relation to signifying properties (Ormeling)*

Besides the first steps in theory he also looked at the use of animations. In his opinion the reasons stated why one should use animated maps are

still scanty. Suggested reasons are:

- **§** the information is conveyed quicker
- **§** better performance of users
- **§** map-readers like them.
- **§** trends are easier detected
- **§** determine rate of change
- **§** explanation of physical processes like erosion is easier.

Ormeling suggests that "animations are effective however the theory behind is not clear yet".

### 6.3.3      **Köbben**

Köbben also looked to the possible cartographic rules for representing time. (URL: Köbben, 1998). He tested the perceptual properties of the dynamic visual variables apart from the well-known perceptual properties of the (static) visual variables.

He called the dynamic variables of DiBiase and MacEachren dynamic *visual* variables.

Köbben also started, just like Ormeling, with the theory of Bertin concerning the static visual variables:

*Figure 30 Perceptual properties of static visual variables (Köbben)*

The columns Quantity and Order are identical to the columns in the table of Ormeling. There are little changes (poor becomes marginal effective) in the column Selection (Orientation) and Colour Hue is stated as 'marginal effective' in the column Association instead of the qualification 'good.'

He crossed the visual variables with the perception or signifying properties instead of Ormeling who crosses the visual variables with the level of measurement.

Köbben stated that it should be clear that it is important to know the perceptual properties of the dynamic visual variables as well. He arranged tests to research the reactions of viewers on the use of dynamic visual variables in cartographic animation. In the test he first tried to isolate the dynamic variables from the traditional visual variables. At the end he also tested the combination of a dynamic variable with a visual variable because he had the strong suspicion, from literature and common sense, that a combination of dynamic visual variables with one or more static variables would improve the impact of the animation.

Reactions of the test persons to the use of duration were mostly positive. Animations using duration conveyed a strong sense of order and some sense of quantity was attained especially when a legend was included. A distinct drawback was the long durations that were sometimes necessary to distinguish the classes, resulting in comments about 'boredom' and 'fading interest'.

*Frequency* was mostly regarded as fairly effective. Most subjects found it hard to grasp the meaning of these animations at first and with these animations especially, it was found important that users could control them, i.e. stop and 'rewind' on demand.

The dynamic visual variable *order* seems to be most effective for depicting quantitative or spatio-temporal data that actually was ordered. When used for qualitative data, most subjects where so confused, they thought that the order depicted some (non-existing) order in the data.

*Rate of change* proved to be very effective in communicating a sense of order and, to a lesser degree, of quantity. However the maximum number of classes that can be used seems quite limited.

Perhaps the most important conclusion has to be that selection, which is so important in making cartography a strong tool for communication, can not be effectively attained by using dynamic visual variables alone. Therefore it seems that dynamic visual variables will only render favourable results in the use of cartographic animations when combined with the traditional static visual variables.

The tests resulted in the following table:

| | Quantity | Order | Nominal | |
| | | | Selection | Association |
| --- | --- | --- | --- | --- |
| Display data | | | | Weak |
| Duration | Fair | Good | | |
| Order | | Fair | Weak | Fair |
| Rate of change | Weak | Good | | |
| Frequency | | Fair | Weak | Fair |

Legend: Good, Fair, Weak

*Figure 31 Dynamic variables in relation to perception property (Köbben)*

Except from the column names this table is identical to the table of Ormeling.

He sympathies with the statements of DiBiase (1992) and Koussoulakou & Kraak (1992) that static visual variables can indeed be used on the individual frames of an animation in such a way that these images gives the message an extra dimension and "new" energy. He also give his approval to their conclusion that animations helped users to grasp the contents of a message in a more effective manner compared to using traditional static maps or map series.

### 6.3.4    Koop

Koop is lecturer in Cartography at the University of Utrecht in the Netherlands. In 1995 he tested the signifying properties of animations with help of a panel of test persons. He uses the definition of animation as stated by Foley (see § 5.3.2).

His research question was:

"How can the temporal component in animations be used to gain an effective process of cartographic communication?"

In his research he focused on the signifying properties of the dynamic variables as mentioned by MacEachren and DiBiase. Just like Köbben he tried to isolate the dynamic variables from the traditional static visual variables.

The test persons got two different questions to answer:

§    Are in this animation different areas with distinct classes?

§    Is a pattern recognisable?

They used these questions to find out of the signifying properties

association and selection are recognised.

First he started again with his interpretation of Bertin's theory.
The relation between the visual variables and the signifying properties is
given in the following scheme.

| | Quantity | Order | Nominal | |
|---|---|---|---|---|
| | | | Selection | Association |
| Size | Good | Good | Good | Poor |
| (colour)value | Poor | Good | Marginally effective | Poor |
| Texture | Poor | Good | Good | Good |
| Colour hue | Poor | Poor | Good | Marginally effective |
| Orientation | Poor | Poor | Marginally effective | Good |
| Shape | Poor | Poor | Poor | Good |

Legend: Good / Marginally effective / Poor

*Figure 32 Visual variables in relation to signifying properties (Koop)*

Except from a slight different insight in the selectivity possibilities of
colour, value and texture, it is identical to the scheme of Köbben.

He also made a scheme, based on his tests, of the signifying properties
of the dynamic variables, which is identical to the scheme of Köbben and
Ormeling.

| | Quantity | Order | Nominal | |
|---|---|---|---|---|
| | | | Selection | Association |
| Display data | | | | (Poor) |
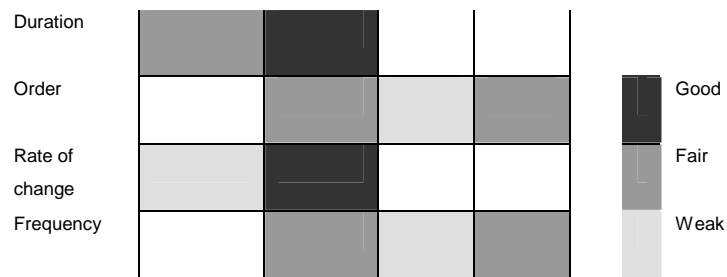
*Figure 33 Dynamic variables in relation to signifying properties (Koop)*

In his conclusions he referred to the possibilities to combine the dynamic variables with static ones. Keynotes are:

§    The dynamic variable display date (or moment) is not especial effective. However in combination with static visual variable colour it is more or less well appreciated by the test persons.

§    Representing categories of qualitative data by use of the dynamic variable frequency was at first confusing but with interaction possibilities better.

§    The dynamic variable order seems to be usable for quantitative data.

§    Rate of change is very effective when using only a small amount of categories to represent order. It is less effective for quantitative data.

§    Selection is easy to gain with static visual variables, however difficult to gain with dynamic variables. It seems to be recommendable to use a combination of those variables to achieve the signifying property selection.

§    Sound and interaction can be used to intensify the animations.

### 6.3.5 Kraak

The last cartographer quoted here is Kraak. Kraak (1996,p193) stated that the traditional graphic variables should be used to represent the spatial data in each individual frame. The dynamic variables can be seen as additional tools to design an animation. They can control all visual

manipulations.

Beside, Bertin's graphic variables each have a match with one of the animation variables (§ 5.3.2). From the dynamic variables only order and duration have a match. The dynamic variables can be seen as additional tools to design an animation. Most prominent are duration and order, which have a strong impact on the animation. They define the order of the images and the time they are visible. Since the other dynamic variables are a functions of or dependent on order and duration (display date and frequency) or more or less data dependent (rate of change, research concentrates on effects of duration and order. In literature describing animations the same pattern can be found: In sixteen animation descriptions found only four explicitly use other variables then duration and order.

Another application of the dynamic variables is called dynamic symbolisation. Here they are used to strengthen the visual variables. Maps with blinking symbols (use of frequency) are good examples. (URL: Kraak 1, 1998)

### 6.4    COMPARISON OF THEORY MODELS

The models of MacEachren, Koop, Ormeling and Köbben can be joined together in one table to get a better overview of the similarities and the differences.

| | Numerical | | | | Ordinal | | | | Nominal | | | | | | | |
| | | | | | | | | | Selective | | | | Associative | | | |
| | MacEachren | Ormeling | Köbben | Koop | MacEachren | Ormeling | Köbben | Koop | MacEachren | Ormeling | Köbben | Koop | MacEachren | Ormeling | Köbben | Koop |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Display date | ░ | | | | ▒ | | | | ▓ | | | | ▓ | ░ | ░ | ░ |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Duration | | | | | | | | | | | | | | | |
| Order | | | | | | | | | | | | | | | |
| Rate of change | | | | | | | | | | | | | | | |
| Frequency | | | | | | | | | | | | | | | |
| Synchronisa-tion | | | | | | | | | | | | | | | |

Legend:
- Good
- Marginall effective
- Poor
- No effect
- Not teste

*Figure 34 Overview of theory models*

It is striking that the results of Ormeling, Köbben and Koop are exactly the same. I assume that these Dutch researches all refer to the results of the same test, although they do not refer to each other.

Beside the fact that the observations of Ormeling, Köbben and Koop are identical, still some similarity with the observations of MacEachren can be noticed. MacEachren is however far more optimistic than his Dutch counterparts.

Beside these similarities other important points of difference can be made. For instance the fact that MacEachren links the level of measurement of the data set with the dynamic variables. The Dutch researches however link the dynamic variables with a mixture of measurement level (numerical, ordinal) and the signifying properties at the image level (selection, association)! The latest combination looks like to be very inconsequent.

Geels (see par 3.4.3) clearly distinguish the level of measurement to the image level in relation to the signifying properties and the static dynamic variables.

It looks like the fact that MacEachren uses the name dynamic variables for two different cartographic items. Sometimes he uses the names to

Caroline Pennekamp                                                    May 1999

classify the type of data, like it is a way of classification of the level of measurement. On the other hand he uses the same term to indicate a way of expression -as the extension of the visual variables.

(See par 6.2.2 and 6.3.2).

The Dutch researchers see the dynamic variables also as an extension to the static visual variables and concentrate on the signifying properties of these variables. They do not mention the –direct- link between the type of data (time classification) and the dynamic variables at all. Also the choices made by them to represent the dynamic variables is not clearly stated. How did they, for instance, represent frequency?

On reflection, it can be said that none of the researchers designed a full scheme with all relevant items (level of measurement/time classification, signifying properties, static visual variables, dynamic variables and animation variables) included. Also the relation to the time triangle (time-place-attribute) is never mentioned or referred to.

## 6.5 SUMMARY

In this chapter key items in the cartographic research field on visualisation of time are mentioned and discussed. First the dynamic variables as classified by MacEachren and DiBiase are explained and illustrated with example maps. Then the onsets of prominent cartographers to incorporate these new variables to the theory of Bertin are shown, and a comparison between their interpretation is made. In the evaluation the conclusion is made that the cartographic researchers put the dynamic variables in the same category as the static visual variables of Bertin. However this does not fit with the insight of other scientists like Langram and Kraak. They made a similar classification of time, but classify the time data set itself and not the representation of the data.

A second conclusion is that the first group of cartographers tried to make a crossing between the dynamic variables on one side and on the other side the signifying properties. Two remarks can be given to these schemes. The first one is that most of them mix the signifying properties with the classification of the data set (=level of measurement). The second one is that these schemes are not complete, for instance the static visual variables does not have a place in it, and the scheme can not be used as guide for map-makers who want to represent time related data sets.

In the next chapter a first attempt is made at a more complete and easier to use scheme to select an effective presentation method for time related geographical data sets.

# 7. EXTENDED GUIDELINES TO REPRESENT TIME

## 7.1 INTRODUCTION

In chapters 4, 5 and 6 aspects concerning the representation of time in a geographic information system are considered. However the interrelation between all these aspects is still not clear. In this chapter I will try to link all aspects to each other. Result is a first guideline for mapmakers who want to represent time in using either conventional static map techniques or with help of more sophisticated new animation software.

In section § 7.2 aspects of the overall procedure of making maps, which represent a time-related issue, is represented in a scheme. In § 7.3 six different selection steps are mentioned which should be clear before one can choose the right representation method within one of the two tables in §7.4.

## 7.2 GLOBAL SELECTION SCHEME

Representation of time in a map or in map series is always based on a geographical related question. This question, together with the required impression of the map reader ("What do I want to say and to whom?") are the basis for making decisions in map making process. To represent either the time question and the geographical objects concerned, a selection should made out of three different kind of variables. The final representation should be confronted with the initial intended goal of the representation.

This process can be put in a scheme that represents the map making process for time issues.
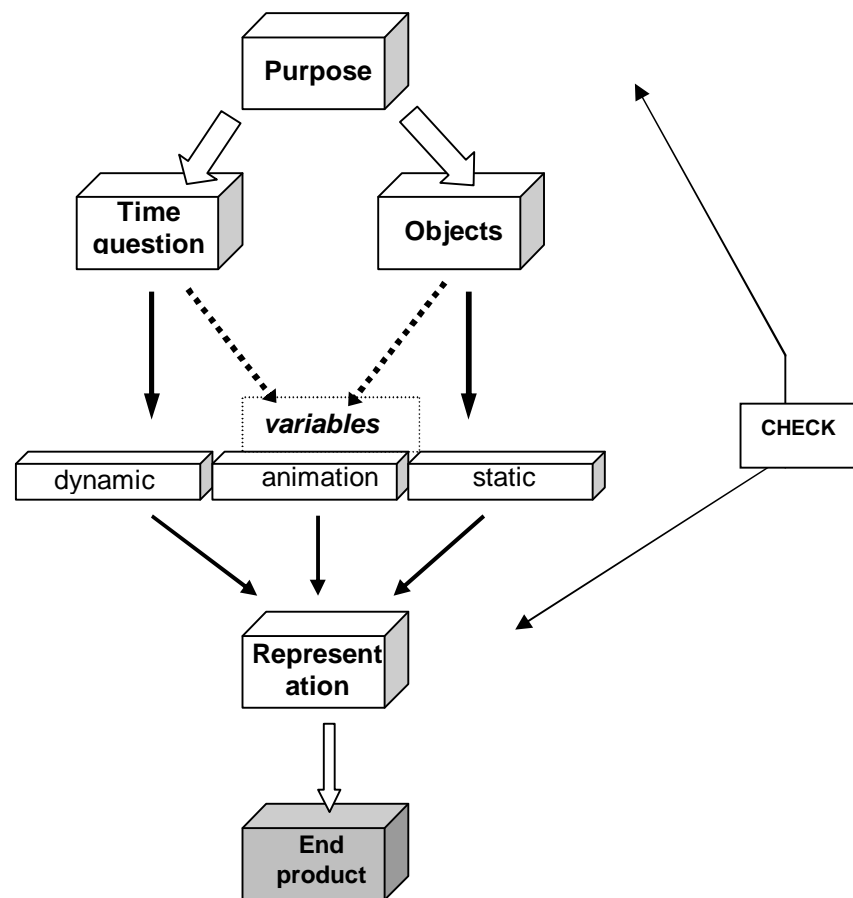
*Figure 35 The selection process*

## 7.3    THE INVENTORY STEPS

The selection process can also be divided into five different selection steps.

**Step 0**: The purpose

The overall purpose, or "What do I want to say?" of the complex time question is the bases of the representation. This question equals to the

term 'image level' and is directly related to the signifying properties of the static visual variables. The answer on this question influences the choice of the selection of visual variables due to the direct connection of the purpose and the signifying properties of the variable. It also influences the choice of the correct dynamic variables by reason of the sometime slight differences between the time classifications.

| Signifying properties of visual variables |
|---|
| Selection/Differential |
| Association/Similar |
| Order |
| Quantity/Proportional |

**Step 1**: Change in place or in attribute?

The choice to make is the classification of the time issue in locational change or attribute change.

| Change in: |
|---|
| Location |
| Attribute |

**Step 2**: Selection of time classification

The next selection is to classify the time series that should be represented in one of the six possible formats based on the time question. This results directly in the classification of the related dynamic variable.

| Time classification | Dynamic variables |
|---|---|
| Time span *(how long?)* | Duration |
| Rate of change *(how fast?)* | Rate of change |
| Sequence *(What order?)* | Order |

| Temporal location *(When?)* | Moment |
| Temporal texture *(How often?)* | Frequency |
| Periodic time | Synchronisation |

**Step 3**: Select level of measurement of object to represent

The level of measurement of the original data in combination with the

purpose of the representation is important for the selection of the most

appropriate visual variables for the representation of the time data.

| **Level of measurement** |
| --- |
| Ratio |
| Interval |
| Ordinal |
| Nominal |

**Step 4**: Select possible static visual variables based on measurement

level of data and kind of time question. See Bertin or Ormeling.

| Static visual variables |
| --- |
| Size |
| Value |
| Texture |
| Colour |
| Orientation |
| Shape |

**Step 5**: Animation facilities possible?

When an animation can be made extra animation variables and dynamic

variables for the representation of the data set are available.

## 7.4    THE SELECTION

The inventory steps can be found in the next two schemes and guide the

map maker to a representation based on the time question and on the subject concerned. Due to the essential difference between the change in location and the change in attribute, two different tables are made according to step 1.

The selection of the representation method of the main **subject** is based on the regular scheme of Bertin. The representation of the **time** question (=dynamic variables) depends on the technical choice of the representation possibilities. The representation **possibilities** are split in one or multiple maps; with or without animation.

Step 2, the selection of the time class and dynamic variable, can be found in column 1 and 3.

Step 3, the selection of the level of measurement of the object, can be found in column 2.

Step 4, the selection of the appropriate visual variable, can be found in column 4 and 6.

Step 5, the available of animation facilities can be found in column 5 and 7.

**Read instructions**

  ---              =    Not possible/bad representation

## Change in location:

| Input | | | Representation | | | |
|-------|-------|-------|-------|-------|-------|-------|
| Time question | Level of measure-ment original data | Dynamic variable | One map | | Multiple maps/views | |
| | | | Static map | Animation | Series of static maps | Simul-taneous animation |
| What way/ direction went … | Nominal | | Orientation | Orientation + Colour cycling | Shape/ colour | - |
| | Ordinal | | - | - | - | - |
| | Quantitative | | - | - | - | - |
| Change of one specific feature during sequence of years | Nominal | Order + duration | Contour map | Colour + order + (colour cycling) | Colour | - |
| | Ordinal | | - | - | - | - |
| | Quantitative | | - | - | - | - |
| Change of two related features during sequence of years | Nominal | Order + duration + synchro-nisation | - | - | 2 series of choro-chromatic maps | Colour + synchroni-sation |
| | Ordinal | | - | - | 2 series of choropleth maps | Value + synchroni-sation |
| | Quantitative | | Chart map with 2 series | - | 2 series of choropleth maps | Value + synchroni-sation |
| Change in speed of an object | Nominal | Rate of change | Orientation (value and/or size) | Orientation + colour cycling or blinking or sound | Shape/ colour | - |
| | Ordinal | | - | - | - | - |
| | Quantitative | | - | - | - | - |

# Change in attribute:

| Input | | | Representation | | | |
|---|---|---|---|---|---|---|
| Time question | Level of measure-ment original data | Dynamic variable | One map | | Multiple maps/views | |
| | | | Static map | Animation | Series of static maps | Simul-taneous animation |
| Change of … during sequence of years | Nominal | Duration/ order | - | Colour + duration + dissolve | Colour | - |
| | Ordinal | | - | - | - | - |
| | Quantitative | | Size -> Chartmap (serie per year) | Chartmap + duration + dissolve | - | - |
| Order of … | Nominal | Order | - | Colour/ shape + (*blinking /dynamic value change*) | Colour | - |
| | Ordinal | | - | Value + order | Value | - |
| | Quantitative | | Size -> chart map | Size + order | Size | - |
| Situation of an area on time x | Nominal | Moment | Colour | Colour + moment | - | Dynamic linked views |
| | Ordinal | | Value | - | Value | |
| | Quantitative | | Size | Size | Size | |
| Possible synchronisa-tion of .. and .. | Nominal | Synchroni sation | - | - | Colour or shape (2 series) | Colour or shape |
| | Ordinal | | - | - | Value (2 series) | Value |

| | Quantitative | | Size -> Chartmap (serie per year) | - | Size (2 series) | Size |
|---|---|---|---|---|---|---|
| Absolute change of .. | Nominal | Rate of change | - | - | - | - |
| | Ordinal | change | - | - | - | - |
| | Quantitative | | Size | Size + duration Max 2 frames | Size | - |
| Relative change of .. | Nominal | Rate of change | - | - | - | - |
| | Ordinal | change | - | - | - | - |
| | Quantitative | | Value | Value + duration(+ blinking + sound) | - | - |

The representations mentioned in the four most right columns in the tables above suggest suitable static, dynamic and animation variables for representation of the selected time question in relation to the type of data. In the scheme below a transition is given of the visual variable into a more common used object like map-type.

| Use of: | Results in a: |
|---|---|
| Colour | Chorochromatic map: A map with different colours for each unique value. For instance soilmap, topographic map of countries. |
| Orientation | Flow map (see § 5.2.1) |
| Value | Choropleth map (see § 5.2.1) |
| Size | Chart map or figurative map A map with symbols whose size depends on the numeric value its represents. For instance bars or circles. |
| Graphs | Chart map A map with in each area a multi item chart (bar/pie). |

## 8. DISCUSSION

Although chapter seven is full of clear selection points and with extended selection tables, the most important step in that chapter is a diffuse one: "did the map-reader understand what I wanted to show?".

Some of the representation methods mentioned in the selection tables are tested in a scientific environment (see for instance § 6.3), however most of them are only suggestions partially based on the theory and partially based on the combination of experience and imagination.

The two tables in chapter seven are not complete: the signifying properties have no place found in the tables although explicitly mentioned as an important issue in the selection steps. As a reason, the check of the endresult with the original goal of the representation have to be made later and has no place in the schemes.

However the schemes are easier to use then the schemes made by the cartographers as mentioned in chapter 6. The only steps that can be found in those schemes are step two, the selection of the dynamic variable, and a misty combination of level of measurement with signifying properties (step 0 and step 3).

I believe that the signifying properties of the visual variables (selection / association / order / proportion) are not the most suitable terms to use for time data. In my opinion the link between dynamic variables and the signifying properties (Koops, Ormeling, and Köbben) or the level of measurement (MacEachren) is non-usable. The schemes they made look nice but are almost impossible to understand and to imagine. For most map-makers the schemes are therefor non-usable schemes.

## 9.     CONCLUSIONS

In this report an extensive walk-around is made on the subject visualisation of time related geographical data sets.

Bertin's idea that visualisation of movement is to complex and to overwhelming is partially right (it is complex) but I do not subscribe his opinion of "to overwhelming".  Of course, time is more than movement; however animation of time issues is a kind of movement that is a very attractive possibility in modern cartography. Also the additions that fellow cartographers made concerning dynamic variables in relation to the famous cartographic theory of Bertin are very interesting, however not easy to interpret.

The scientific controlled tests as mentioned in chapter 6 do not cover all possible visualisation aspects however what they found was that animation helped people to interpret time issues quicker than without a visual representation of the time (Ormeling § 6.3.3). Map-readers could easier detect trends and physical processes like erosion were easier explained to non-professionals.

The selection steps and the selection tables in chapter seven are new guidelines for non-professional cartographers to select variables (static, animistic or dynamic) in their creative process. However, still a basic knowledge of cartographic grammar is very helpful especially to select the correct level of measurement, and to convert the visual variables in the correct map type. Basic cartographic knowledge is also very useful to design an attractive, balanced and easy to read map.

The realisation of my idea that it should be possible to construct an easy to use simple scheme seems to be too difficult. It was to complex to put all information in one scheme without repetition of same issues. More time and an open mind is needed to optimise the schemes or even better construct a single –new- scheme.

Also, further research on this issue is important to test the effectiveness of the proposals and to understand what really is the visual impact of movement on the map-reader. Test sites like the ITC Web Cartoforum site (URL: Blok, 1999) and Pennekamp (URL: Pennekamp, 1999) are the first steps to gather new data on the effectiveness of cartographic animations.

Other aspects like the impact of new technical opportunities such as sound, multi-views and animation should also be tested in an academic environment.

A last topic that requiers further research is the callibration between animation, grammar rules and map-reader perspectives -like analysis and exploration.

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Caroline Pennekamp                                                                    May 1999

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**INTERNET SOURCES**

URL:

Blok: http://www.itc.nl/~carto/webcartoforum/paper.html

Buziek: http://visart.ifk.uni-hannover.de/~buziek/COMVIS/ifkvis.html

Fli/FLC: http://crusty.er.usgs.gov/flc.html

ICA: http://www.geog.psu.edu/ica/ICAvis.html.

Köbben: http://www.itc.nl/%7Ekobben/publications/madrid_paper.html

Kraak: http://nvkserver.frw.ruu.nl/html/nvk/ica/madrid/kraak.html

http://www.itc.nl/~carto/kraak/visualization.html

Ormeling: http://nvkserver.frw.ruu.nl/nvk/ica/madrid/ormeling.html

Pennekamp: http://www.gis-larenstein.nl/pennekamp/hoofd.html

Peterson: http://maps.unomaha.edu/books/IACart/book.html

Other: http://www.siggraph.org/~rhyne/carto/carto98.html