PRINCIPLES OF CARTOGRAPHIC DESIGN AND THEIR IMPACT ON DIGITAL PRODUCTION METHODS

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Abstract

Absolute truth in maps does not exist. A map can be designed differently according to its purpose and ist aim. It is always an abstraction of the "real world". The design process is interactive, iterative and largely depending on non geometrical, semantic and contextual data. In this paper, examples from topographical maps are presented. The impact on the functionality of modern digital cartographic systems is discussed.

1 Introduction

Today, digital cartographic production methods allow many-sided applications with an output quality level hardly obtained using conventional methods. In spite or maybe because of the availability of comfortable digital cartographic hardware and software, cartographers should concentrate (again) on the principles and the process of cartographic design in order to create user-friendly and better map products.

In this paper, principles of the cartographic design process are surveyed. Based on the conclusions, the impact on modern digital production methods is studied. At the Swiss Federal Institute of Technology (ETH) in Zurich, experience with a digital cartographic production system has been gained during the last six years. The result is an extensive collection of digitally produced maps in various scales and with different thematic contents. Parts of this knowledge now influence an evaluation for a new digital cartographic system at the Swiss Federal Office of Topography (L+T) in Wabern. It is intended to be used for the update and new compilation of the topographical map series of Switzerland and special thematic mapping applications like geological maps, aeronautical maps or thematic atlasses.

2 Cartographic design

2.1 Cartographic objectivity and truth

The greek philosopher Platon stated in his famous "cave allegory" that things we perceive as a part of the "real world" are only projections of unknown facts and relations. In order to obtain a better description of objects, phenomena and processes, methods of scientific modelling are often used. This is also one expression of the insufficiency described by Platon. When compiling and designing a map, it is impossible to represent facts in a completely objective way, too. The one and only objectivity or truth cannot exist. There are always several aspects of these terms to be considered, like e. g. accuracy, completeness, *truth to nature*, etc. Another important factor is the "personality of the cartographer (...). There is not only one good solution but there are several useful solution when generalizing a map" (BAUMGARTNER, 1990). The "art" of Cartography means to carefully weight these features during the map design process. Talking about topographical maps, KNÖPFLI (1990a) says that "at the beginning [of a map project] it is indispensable to determine which properties [of the terrain] have to be visualized". Thus the first question one has to ask when producing a map is the aim of the map. Out of an enormous set of basic data, the important information must be selected. Traditionally, the selection of the map contents and its graphical representation are separated whenever possible. Especially when designing thematic maps, contents and formal aspects interact very closely, however. In this design process, the search for the appropriate representation of the basic data is the major workstep. Focussing on the final map purpose, this is much more than just a simplification and a combination of elements of the basic map or the "realities" (e.g. the earth's surface). Maps are abstractions. "Abstract symbols are those which are most typical for the characteristic to be shown" (KNÖPFLI, 1990a).

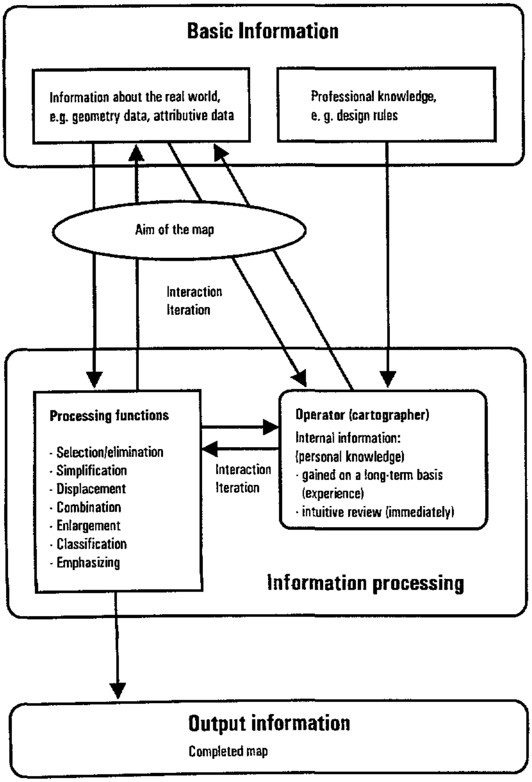

Fig. 1 – The cartographic design process.

2.2 *Cartographic generalization and cartographic design*

The German topographic-cartographic information system "ATKIS" consists of the "Digital Landscape Model (DLM)", containing the basic data, and the generalized "Digital Cartographic Model (DKM)". The transformation process from the DLM to the DKM is settled using predefined rules according to the seven elementary generalization functions (HAKE/GRÜNREICH, 1994): Enlargement, selection/elimination, simplification, combination, displacement, emphasizing, classification. The selection of an object, for example, depends on metrical values (MAHR, 1995). As stated before, such a rule is too simple to cover all possible cases. Additional semantic and contextual information about the aim of the map, the map elements and their interaction, as well as the interaction of the different design functions, play an important role. This is the main problem of all efforts to automatize the generalization process. On a purely geometrical basis, all kind of different generalization algorithms could be applied to a suitable set of data. The necessary additional knowledge can hardly be defined in a useful manner.

As shown in *Fig. 1*, the whole process can be divided into three main parts: The basic information, the information processing and the output information. Starting point of all such workflows is the aim of the map. It can be specified from the beginning or it might change during the work. The information sources are data about the "real world" and the cartographic knowledge which is necessary in order to transmit the thematic data to the map user without any disturbances (KNÖPFLI, 1990b). This is done in the second step by the human operator (the cartographer) using processing functions. In order to use and combine these functions in a significant way, the cartographer needs existing cartographic knowledge and his own, internal knowledge. The second one can be divided into knowledge gained on a long-term basis ("experience") and knowledge gained immediately during the design process by intuitive review. The exchange between the information sources and the processing function is interactive (2-way) and iterative (in several repeating cycles with changing start conditions). At the end of the whole process, the output information (the final map) is integrated in the basic information and can be used for new tasks. As a consequence of this understanding, it seems to be appropriate to replace the term "cartographic generalization", which indicates a simple derivation, by the more comprehensive expression "cartographic design" ("Kartographische Gestaltung").

2.3 *Examples: Design of urban situation*

Example 1: Changement of map scale

The cartographic design process becomes an art in pretentious maps, e. g. official topographical maps. This is especially the case when different map elements have to be combined. In the map legend, the elements are defined like parts of a box of bricks. In the map image however, they appear in their spatial situation, size, shape, extents and distribution and in their side by side and overlay appearance. One of the main and most pretentious tasks of cartography is to properly solve this interaction of the map elements. The cartographic design becomes extremely difficult in a narrow spaced area like an urban situation. *Fig. 2* shows the evolution of such an area in three steps from the original scale 1:2000 to a representation in the scale 1:25'000. The comments added to the three images show the importance of the *additional information* which has to be interpreted from the original data set. The round shape of the narrow lane on the left side has to be emphasized by adjusting the outlines of the buildings on both sides, for instance.

Town of Poros/Greece

Final scale 1:25'000.

Approx. 6x enlarged.

Basic data

Digitized from cadastral plan.

Generalization I

- First simplification of the shapes
- Combination of buildings
- Displacements in order not to affect the minimal dimensions
- Emphasizing the structure of the lanes.

Reduced to the final scale, this representation is still too detailed.

Generalisization and redesign II

- Further simplification and combination of the objects.
- Emphasizing the round lane on the left.
- Emphasizing the irregularly situated buildings in the center.

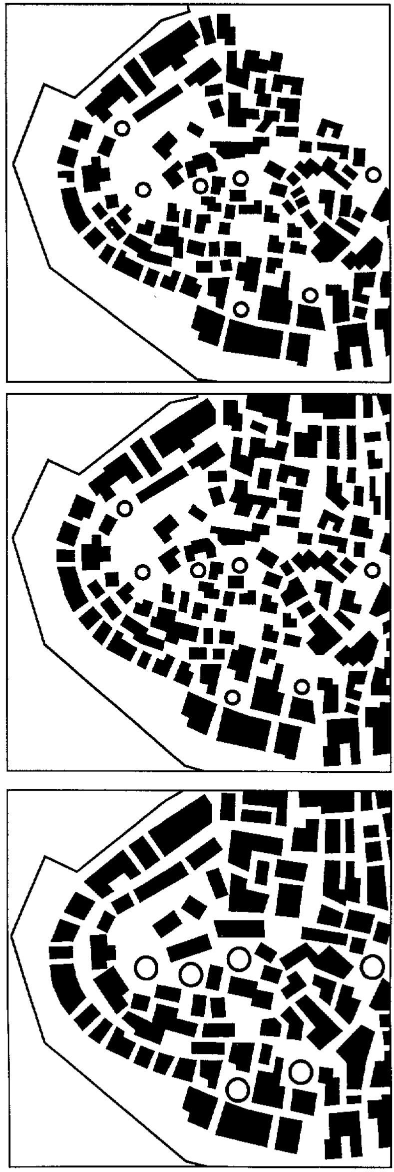

Fig. 2 – Cartographic design of an urban area in three steps from 1:2000 to 1:25'000.

Example 2: Design of cartographic finesses

Fig. 3a and *3b* show two versions of the same situation (L+T, 1993). On *Fig. 3a*, the large scaled "reality" is simplified by enlarging the minimal dimensions of the cartographic objects without any major displacements. The way they are added together injures the readability of the map. The map representation is little interpreted, thus representing an "objective" catalog of the objects. *Fig. 3b* is a more abstract representation with the aim to pronounce the situation of the buildings and the traffic routes, especially the railroad lines. In order to improve the perceptability of the different map objects, precautions have been taken by redesigning the situation. Buildings usually do not touch the railroad line, they are therefore displaced. The effect of this unravelling is obvious. *Fig. 3b* is more modellized than *Fig. 3a*. The result of this design concept is an easily perceptable, scale adequate image. The complete map is a clear representation of selected and interpreted local and regional situations and interactions.

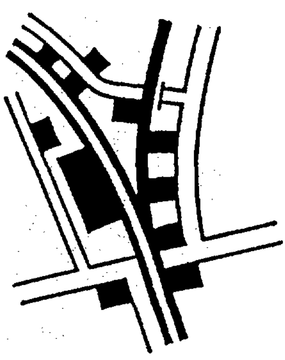

Fig. 3a – "Objective" representation.

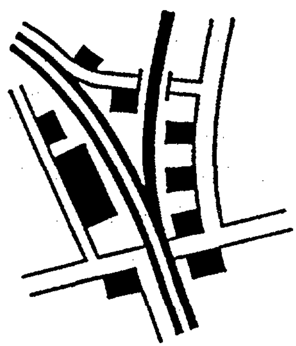

Fig. 3b – Redesigned, abstract representation.

Example 3: Different design solutions for different aims

Based on the survey of planimetry in *Fig. 4a*, different map extracts representing a mediaeval town in Switzerland are shown. Each one is designed to answer different questions *(Fig. 4b–d)*. Obviously, additional information is necessary in order to design the map according to its use and aim.

3 Impact on digital cartographic production methods

The principles of cartographic design have an important influence of modern digital cartographic production methods. For over 30 years, such methods have been used. First, less pretentious and monotonous tasks like cadastral plans have been automatized using vector systems which are able to process point and lines with a reduced possibility of symbolization. The map elements area and colour could only be fully included in the digital workflow by raster systems. Today, hybrid Systems which allow to process both type of data are widely used. An ideal system would allow to use the editor which is most suitable for a specific task. In order to preserve the consistency, a raster and a vector data set would be updated simultaneously (SPIESS et al., 1988). This configura-

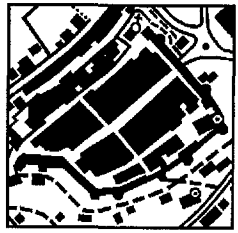

Fig. 4a – Topographical map of Switzerland 1:25'000 (extract, 3x enlarged): Mediaeval town of Murten, with typical lanes.

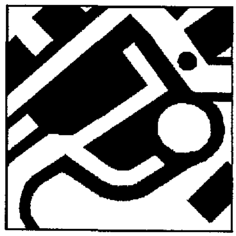

Fig. 4b – Topographical map of Switzerland 1:200'000 (same extract as *Fig. 4a*, enlarged): One of the towers is very dominant.

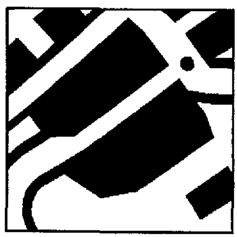

Fig. 4c – Variant of *Fig. 4b*, pointing out the typical structure of the town with narrow buildings and the major transit lane.

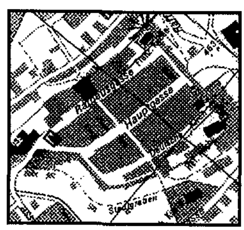

Fig. 4d – Tourist map containing street names, public buildings, etc.

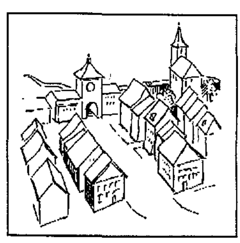

Fig. 4e – Schematic view of the main lane with the town-gate, the church and the city-wall. Compare with *Fig. 4a*.

tion does not yet exist on any commercial cartographic system. However, there are some software packages available which allow to symbolize the vector elements on the monitor using the same parameters and algorithms as for the final, print-ready plot. This "dual" visualization principle is also called "WYSIWYG" ("What You See Is What You Get").

In the following paragraphs, the different map elements of topographical and thematical maps are examined keeping focus on cartographic design aspects and its consequences for the digital environment.

3.1 Situation: Roads, paths

The situation elements (cultural features) are an important part of every complete topographical map. They represent most of the human constructional intervention in a landscape. The making of a high quality situation drawing is especially difficult. The different aspects of cartographical design, as presented before, already have an influence on the production in larger map scales.

Roads and paths usually have to be redesigned by the cartographer using photogrammetrical data or large scale maps. Modern cartographic software allows onscreen-digitizing on top of the basic data. Very often, photogrammetrical compilations tend to have a «shaky» appearance which cannot be removed by filter algorithms without significant changes of the object's shape.

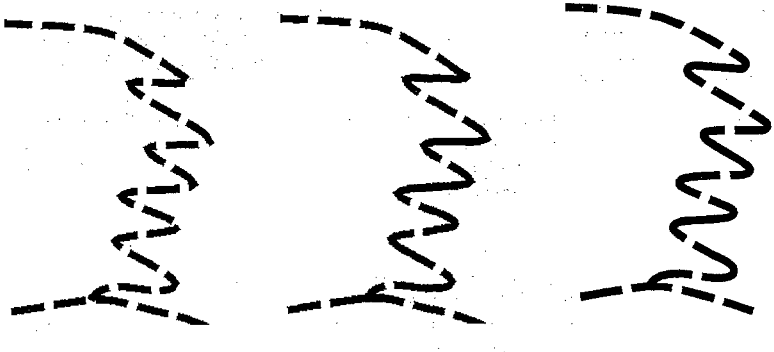

Fig. 5a
Automatically drawn footpath with a constant length of dashes. (Rasterized)

Fig. 5b
Elimination of misplaced gaps by covering with small line patches. (Rasterized)

Fig. 5c
Ideal, conventional solution. (Vector display)

Special design problems arise with dashed lines (e. g. footpaths). CAD-Programs usually place dashes with a fixed length, instead of adjusting them to the geometry of the object and other elements according to cartographic design rules. *Fig. 5a* shows an automatically drawn footpath with a constant length of dashes. Many gaps are (mis)placed on knees and forkings. In *Fig. 5b*, the worst cases are eliminated by covering the gaps with small line patches. *Fig. 5c* shows the ideal "handmade" solution. A fully automated solution should be built on the following set of rules:

- Gaps should not occur on the beginning or the end of a line.
- The length of the last dashes on both ends of the line must be choosable.

- Gaps should not occur on knees of a line.
- Gaps in small curves should be avoided. They should be placed in the inflection point between two curves.
- Small pieces between two knee points, which have roughly the same length as the dash, should be free of gaps.
- Gaps should not occur near forkings.
- Gaps on a "zigzagged" path must not be aligned. They have to be displaced where necessary.

Generally, cartographic systems should be able to change the attributes of line elements within the same vector.

3.2 *Situation: Buildings, single map symbols*

In the whole world, buildings appear in various sizes and shapes. It is very difficult to set up general rules for their representation in a map. The scale and the minimal dimension are the major keypoints. The graphical minimal dimension is 0.3 x 0.3 mm for buildings and 0.15 x 0.15 mm for the gaps between them. In conventional cartography, the working scale is usually the same as the map scale. The cartographer always keeps the overview over the whole work and the working area. In digital mapping, this ability is restricted because of the limited resolution of the computer screens. One always has to work in enlarged views. This is an advantage for detailed cartographic work, but a major disadvantage in order to keep the overview and the "feeling" for the final map scale. One solution can be the placement of a rectangle in the working area, representing the minimal dimension. It might be possible to include such tools in future cartographic systems, for example an edge lock which disables the placement of edges below the minimal dimensions.

Single map symbols are integrated in the map according to the same rules as the other situation elements. They are defined by a fixed geometry which should not be changed, except for scaling and simplification in other map types. It should be possible to rotate them in order to increase their meaning.

3.3 *Aera features*

Classical topographical maps contain only little area features, except forest areas and area patterns like a swamp. Modern digital cartographic systems allow to easily include such features. Areas can be defined as vector polygons. The filling and the patterning can be accomplished both in vector (e. g. Postscript) and in raster mode. A function which, up to now, is only implemented in objectoriented, dynamical GIS (without extensive graphical capabilities), is the possibility of modifying the borderline of an area without loosing its attributes and links to other elements. On a geological map, for instance, it should be possible to automatically adjust the filling of two neighbour areas after the modification of the boundary line. Usually, the line and the two areas have to be changed separately.

3.4 *Analytical shading*

In a topographical map, the 3-dimensional shape of the terrain has to be shown 2-dimensionally. An important part is the presentation of terrain heights. The most common features used for this task are contour lines and spot heights. They can be imported in a cartography system from a photogrammetrical device and might also be used to create a digital elevation model in order to compute an analytical shading. Most

CAD systems offer the possibility to render a given surface assuming a specific angle of incidence of the light. Usually, the contrast of such a shading must be increased. Compared to handmade shadings, analytical shadings often do not clearly enough show morphological details and the difference between large structures on the light and on the shadow side (HURNI, 1993).

3.5 Digital cliff drawing

The cliff drawing is one of the typical cartographic tasks, which is depending on traditional manual techniques. This work requires long experience and talent. A completely new drawing of a map sheet using the manner of cliff drawing applied on the Swiss national maps, requires between 2000 and 6000 working hours. It can hardly be executed any more under the present economic circumstances. In a research project at ETH Zürich, a computer program has been developed. It allows to create a simplified cliff drawing based on morphological structure lines according to the following aspects and rules (HURNI, 1995):

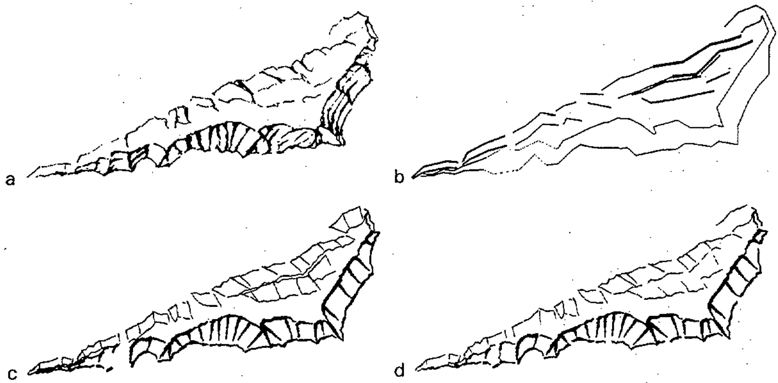

Fig. 6 – Computer aided cliff drawing:
a) Conventional cliff drawing.
b) Digitization of upper and lower edges of cliffs (program input).
c) Raw program output (rasterized vectors).
d) Manually edited output (raster mode).

- Digitization of the upper and the lower edges of the cliff (two vectors with the same number of vertices).
- Lighting model:
  - Light/shadow side: Attributation during digitization (lighter or darker appearance).
  - Different line weights according to aspects.
  - Variation of line weight within the same edge line according to lighting model.
- Edge lines (upper/lower edge) and vertical structure lines:
  - Automatic generation from digitized vertices.
- Roughness of lines:
  - Artificial "shaking" by random function.
  - Local changement of line weight by random function.

- "Cavity" (round cliff shapes due to erosion effects).
  - *Attributation during digitization. 8 possible radii (positive or negative).*

The fine tuning of the software is done by about 50 parameters. From this we can also postulate the need for "Tunable Cartographic Software" for other complex cartographic problems like displacement of elements, etc. It might be possible to develop modules which could be adjusted to specific tasks according to the aim of the map. Though, the amount of necessary parameters seems to be fairly high.

Fig. 6a shows a conventional cliffdrawing according to structure lines. On *Fig. 6b*, the upper and lower edges are digitized. The degree of "cavity" is represented by the line weight (Thick line: no cavity). These vectors are used as input for the program. *Fig. 6c* shows the raw output (rasterized vectors), which is finally edited by hand using a raster software (*Fig. 6d*). The production of this example took about 10 minutes!

4 Conclusions

It is impossible to represent map data in a completely objective way. The cartographic information must be presented in a well organized manner in order to allow an optimal perception of the map contents. This again implies the basic need for selection and structurization. Additionally, aesthetic aspects are considered to be very important for the whole process. A cartographer designing a map is largely depending on non-geometrical, semantic and contextual information. It must be gained from the basic data, either by experience or immediately in an interactive and iterative way. It is even appropriate to replace the term "cartographic generalization" by the more comprehensive expression "cartographic design".

These conclusions have an important influence on the requested functionality of modern digital cartographic production systems. In the following list, based on the call for tender at L+T, the main functional demands are presented:

- The graphical representation of the map contents must be definable by the user. Limitations by the system must be excluded.
- The system must be able to record analog maps with an adequate, high resolution.
- The system must be able to import existing data without any loss.
- Hybrid processing of raster and vector data must be possible. The system must allow overlaying, registering and editing of both data types as well as vector-to-raster and raster-to-vector conversion with a short response time.
- "WYSIWYG" in order to allow an optimal representation of symbolized vector data in combination with raster data is a prerequisite.
- All symbols, line styles and area features must be definable according to the map legend. Changements and additions must be possible.
- It must be possible to structurize map elements according to their meaning and color. Combinations of different groups of elements must be easily definable.
- The system must allow to register and simultaneously present several vector and raster layers. Selective editing must be possible.
- The cartographic design process requires extensive raster and vector editing functions, especially to solve problems of displacement and to work out graphical finesses.

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