Relational Data Structures: A Rule-based Paradigm of Map Design

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When preparing a map’s design, this paper advocates the use of some type of data preprocessing. More specifically, it recommends Rudolf Arnheim’s rule of order as it helps group the map’s data by ranks and associations. Once identified, these categories can be subjected to rules of taxonomies and cognition to design corresponding hierarchical structures of symbols, colors, patterns and type styles, that mimic a person’s cognitive frameworks or frames of learned real-world information. Several examples of that kind of design are presented and explained. A practical demonstration of designing a relational and compound symbol system is given and discussed. To evaluate the finished design, the use of a design matrix is proposed. Its unique ability to offer quick side by side inspections while allowing swift on the computer screen alterations and reevaluations, points out its ability to refine designs.

Keywords: Arnheim’s rule of order, taxonomies, relational data structures, corresponding symbol structures, compound symbol systems, design matrix.

While the production of some maps starts with putting a pen on paper or moving the cursor on a screen, most cartographers would agree that it should begin like the work of an architect, who collects, evaluates, and processes information before he makes the final plans.

1. Pre-mapping processing

When large sets of numerical data are to be mapped, it is customary to preprocess them into classes, ratios, deviations from the mean, changes between two sets of data and so forth, according to mathematical principles defined in textbooks and guidelines traditionally practiced by cartographers.

While some cartographic research has focused on magnitude estimations of symbol sizes and tones or general principles of graphic design, the preprocessing of qualitative map entities, referred to by A. H. Robinson (1973) as the “feet on the table planning stage” has not received much attention. For simpler maps most professionally trained cartographers practice some form of preprocessing intuitively but many of today’s computer mapmakers rely on the program’s default options of symbols and colors. As the number of maps made this way is increasing, this topic deserves further attention.

If a designer plans to create a clear and intelligible map, the preprocessing of a map’s information should be much more deliberate and guided by cognitive principles. This should start by identifying relational data structures which the designer can transform into an assembly of symbols, colors, patterns and type styles that better matches the viewer’s perception and cognition. Searching the literature for relevant studies singled out a publication by Rudolf Arnheim (1971). In it he reveals one of the most fundamental precepts of good design, the rule of order. As defined below, it provides a general basis for cognitive or relational data preprocessing:
“Order is a necessary condition for anything the human mind is to understand [...]. Arrangements such as layout of a city or building, a set of tools, a display of merchandise, the verbal exposition of facts or ideas, or a painting or piece of music are called orderly when an observer or listener can grasp their overall structure in some detail.

Order makes it possible to focus on what is alike and what is different, what belongs together and what is segregated. When nothing superfluous is included and nothing indispensable left out, one can understand the interrelation of the whole and its parts, as well as the hierarchic scale of importance and power by which some structural features are dominant, others subordinate.” (Arnheim, 1971, p.1)

Whether natural or man-made, “feature description of the real world”, writes Frisby (1980, p. 156), “are segmented into collections of features which ‘go together’ in that they come from the same visual structure. Segmentation relies on processes of grouping, texture discrimination, color perception, movement perception, depth perception, etc.” without which airphoto interpretation would be next to impossible. When order changes to chaos, as we enter an area of complete destruction, we find our skills of orientation and making sense of what we see severely challenged. Likewise, a thoughtlessly designed map presents its user with visual confusion. Unlike the ugly bits and pieces of destruction, these map fragments are a mix of unrelated and meaningless but pretty looking symbols and colors. The user looks for associations and meaning but is hard pressed to find any. Therefore, it is imperative that the order of things perceived in the real world must also be found in maps.

During the slower pace of mapping in the past a designer could study the data. Since the computer has all but eliminated this experience, the mapmaker has become more system-dependent. Therefore, it is suggested that the time saved by automation be invested in a ‘prognostic stage of preprocessing’ where the designer gets to sort out the map’s real-world information. Although objects are identified by their attributes and names, their concepts and definitions need also to be considered when sorting them into classes or categories of related information. In her benchmark study of categorization, Rosch (1978) explains that we form classes because information of the perceived world comes as structured information and that maximum information with least cognitive effort is achieved when categories are formed which coincide closely with the perceived world structure: “In taxonomies of concrete objects”, she writes (p. 28), “there is one level of abstraction at which the most basic cuts are made. Basic categories (like house) are those which carry the most information, possess the highest category cue validity, and are, thus, the most differentiated from one another”. Categories one level more abstract (such as buildings) are superordinate while categories below the basic level (like bungalow) are subordinate. Ranked into hierarchies, superordinate, basic, and subordinate categories form relational data structures which are believed to mimic a person’s cognitive frameworks or frames of learned real-world information (Rosch, 1973, p. 382).

Based on rules of taxonomies, this type of knowledge-based cataloging has probably not been part of the map designer’s training or job description. Hence the awareness of how we actually identify, define, name, categorize, group and rank what we see and the skills to convey these anatomized views on maps should be included in a curriculum of cartographic information science.

The first use of relational data structures for American topographic maps can be traced to the U.S. Geological Survey’s (USGS) decisions to establish map scales and cartographic representations in 1885 (Evans & Frye, 2009). With the advent of color
printing, the agency had to decide which colors should be used to print which map entities.

Unfortunately, the publication does not mention how and why these decisions were made. Evidently, the deciding criteria were relatedness of entities and colors associated with such entities. Figure 1 shows an example of some entities sorted by category and color. All water related entities were printed in blue, all mapped varieties of vegetation in green, all entities related to relief in brown, man-made entities in black and survey and road classifications in red. This logic was extended further to deal with cross-category entities by giving their symbols two colors.

![Figure 1: Symbolic color categories of U.S.G.S. topographic maps](image)

A selection of symbols, seen in Figure 2, includes the symbol for wooded marsh, which is a combination of the blue marsh- and the green wooded area symbols. The fact that designers of topographic maps in other countries had chosen similar color-category designations is undeniably remarkable.

As the entities of each color category were engraved in separate copper plates, printing just one plate could produce a record of the mapped category’s information. Thus a cartographic relational database had been created and the success of using color to visually segregate categories while defining all members of the same category, i.e.: belong together, had been instituted.

It is of interest that the architects of Geographic Information Systems (GIS) had identified relational data structures as the core component around which they designed the structure of their system’s databases and analytical operations.
2. Design stage

While there are similarities between the proposed cartographic relational data structure approach and the database of a GIS, the former would be compiled for a single purpose mapping project, while the latter is designed to perform a great variety of purpose-driven analyses. This explains why GIS databases, containing a huge number of features and their attributes organized in themes and sub-themes, represent a major investment of time and money. For this very reason GIS users should guard against losing the data’s relational structure in the mapping process by making sure that their graphic designs preserve and visibly depict it. Unfortunately, a perusal of GIS produced maps does not always show this to be the case.

The proposed method of design can be defined by two steps (Stolle, 1984).

A. Use the meaningfully sorted and ranked data structure, created by cartographic preprocessing or a GIS database, to visualize an equally meaningful, sorted and ranked graphic structure.
B. Establish a set of rules that will achieve the following objectives: 1) Convey order by identifying entities that belong to the same category and 2) communicate each entity’s essential characteristic and rank with a meaningful symbol.

In his paper “The Methodical Base of the Standardization of Signs on Economic Maps”, Ratajski (Figure 3) proposed a similar approach by using guiding signs to signify objects that belong to the same category. (Ratajski, 1971).

As many of today’s maps are produced and printed in color, using one appropriate color for each symbol, fill and text that belong to the same category is an effective way to create visual and meaningful order. Color shades and mixes can symbolize degree and mix of category membership while the appearance of symbols conveys the meaning of their entity. Even an abstract design, that uses color that way, will out-communicate an elaborately illustrated design that has no visual order. Ideally, good cartographic designs, like the symbol system of United States Geological Service (USGS) topographic map, geological maps and other established map series, address and meet both objectives.
Once learned, the human mind can correctly identify the real-world’s entities. For example, a ship's gunner must know every important detail of an airplane’s shape of fuselage, wings, tail, and number and placement of engines, etc. to correctly identify a fast approaching plane before deciding to commence firing or not.

A glance at small but detailed drawings (symbols) of plant or animal taxonomies show a great wealth of information. An inspection of fish species, taken from a map legend in the Angler’s Guide to the United States Atlantic Coast (National Oceanic and Atmospheric Administration, 1976, see figure 4) displays an overwhelming variety of distinguishing characteristics. Not just the shape of each fish’s body, but its head, mouth and tail (silhouette) as well as the shape and size of their Dorsal, Pelvic, Pectoral and Anal fins, makes each image, even at that scale, an information-loaded compound symbol. While these entities at the subordinate category level are known only to specialists, the minute variations of details demonstrate the design possibilities of differentiating related map symbols. As the use of most learned distinguishing attributes has become fully automatized even a designer finds it often difficult to describe them and he/she must attempt to rediscover them.

Since the design of individual symbols has been discussed elsewhere (Stolle, 2015), this paper concentrates on the design of relational and compound symbol systems.

Focusing on how the human mind perceives, recognizes and identifies objects, a scheme of color-symbol systems, whose structure mimic the mind’s frames or mental constructs is aimed for. By applying the concept of composite symbols one example of mining design, shown in Figure 5, is presented (Stolle, 1984, pp. 122-129).

Figure 4: Legend of fish species of an U.S. Atlantic Coast angler’s guide (after Freeman, B.L. & Walford, L.A. (1976).
After all the entities to be mapped have been sorted out, they are searched for meaningful identifiers, which are grouped into categories. After superordinate symbol outline shapes, which stand for all members of a particular category, have been designed, individual symbols and/or variations, representing specific characteristics of basic or subordinate category levels, are designed and placed inside the outline. Entities having no prototypical appearance are more difficult to portray and challenge the designers who may have to choose some suitable abstract symbol forms. To optimize the design and information content of compound symbols, this concept needs to be further tested and developed.

Once the design of the symbol system has been completed, it can be tested with a design matrix, Figure 6. Its rows and columns can be constructed quickly with a drawing program. Filling each row with one symbol or type style ordered by category and rank and each column with one area fill of color or pattern will complete the matrix. Its overview affords a side by side comparisons of symbols, text, and fills, which can point out unwanted similarities and incompatibilities, circled with a black outline. It also allows testing for visual contrast and differentiation of overprinted symbols, texts and colors. Any alterations can be made quickly on the computer matrix, permitting instant reevaluation as well as making any other changes.
3. References


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