# From Metaphor to Method: Cartographic Perspectives on Information Visualization

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## Abstract

*By virtue of their spatio-cognitive abilities, humans are able to navigate through geographic space as well as meaningfully communicate geographic information represented in cartographic form. The current dominance of spatial metaphors in information visualization research is the result of the realization that those cognitive skills also have value in the exploration and analysis of non-geographic information. While mapping or landscape metaphors are routinely used in this field, there is a noticeable lack of consideration for existing cartographic expertise. This is especially apparent whenever problematic issues are encountered, such as graphic complexity or feature labeling. There are a number of areas in which a cartographic outlook could provide a valuable perspective. This paper discusses how geographic and cartographic notions may influence the design of visualizations for textual information spaces. Map projections, generalization, feature labeling and map design issues are discussed.*

## 1. Map metaphors in information visualization

Map metaphors have been associated with the handling of non-geographic information for a long time. They can be traced as far back as the late 19th century when Paul Otlet, regarded by many as the father of information science, made explicit reference to the mapping of intellectual domains [41,44]. Otlet envisioned the use of maps in the exploration of unknown information terrain and even pondered the role of scale in such exploration [44]. Conklin's influential article Hypertext: An Introduction and Survey played a major role in drawing the attention of researchers to the use of graphical browsers, which "display the network graphically" [8]. Navigation was to become the dominant metaphor of hypermedia [1,16,19,34] and graphic browsing consequently became a standard feature in leading hypermedia systems, like NoteCards [18] or Intermedia [56]. Verbal expressions of mapping aspirations were abound and took on almost poetic form [14]. However, few hypermedia researchers realized that there was indeed conceptual and practical insight to be gained from geography and cartography [19,34]. With the advent of the World Wide Web this lack of consideration came to the fore, as the sheer size and complexity of the Web made it all but impossible to utilize previous methods of hypermedia mapping. Graphic browsing, which had been a standard staple in pre-WWW hypermedia, was not implemented in standard Web browsers, and remains absent to this day.

The emergence of the Web has catalyzed a renewed interest in information mapping. In addition to the visualization of Web structures there are other research areas, like content visualization, data mining, and knowledge discovery, that are focusing on the adoption of map metaphors. In the process, the relevance of long-established cartographic principles is being discovered. Good examples are research into the usability of Jaques Bertin's visual variables [2,14,31,33] or the acknowledgement of scale as one of the most important factors in successful information visualization [6]. A number of software packages are now available that specifically tout the virtues of map-like visualizations of non-geographic information. Products like SPIRE (Spatial Paradigm for Information Retrieval and Exploration) and Viscovery SOMine exemplify this.

Nevertheless, research in information visualization rarely makes reference to geographic or cartographic research. A recent collection of state-of-the-art articles, titled *Readings in Information Visualization* [6], only contains very few references to geographic research [26,30,51], while at the same time being largely dominated by mapping metaphors.

## 2. Cartographic methods for information visualization

The geospatial sciences, like geography, cartography, and surveying have developed numerous methods and techniques to capture, process and visualize geographic information. This section highlights a number of ways in which this existing expertise appears relevant to the visualization of non-geographic information spaces. This

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discussion is guided by one idea: if we are to take the mapping metaphor seriously, then we should strive to create visualizations of information space that not only look like maps but whose creation is profoundly informed by existing cartographic approaches. Juxtaposed with geographic maps, graphic examples of ongoing work in the visualization of textual information spaces are presented in this paper. These examples are not mock-ups, but the result of actual implementations. However, their purpose in this paper is mostly to illustrate the discussed ideas, as the detailed discussion of algorithmic and technical solutions is outside its scope.

## 2.1. Distance Model

Thirty years ago Waldo Tobler postulated what he called the *First Law of Geography*: "Everything is related to everything else, but closer things are more closely related" [50]. Much of what geographers and other geospatial scientists do is based on this premise. Maps, as the primary visualization tool of geographers, typically attempt to preserve these distance relationships. Geographic analysis, for instance using GIS, is also fundamentally founded on the premise that distance is an overriding factor in evaluating geographic reality.

If we extend this idea to information visualization, it becomes necessary to find numerical expressions for relationships within an information space. The latter has to be divided into meaning-bearing units based on a chosen level of disaggregation. For example, in a hypermedia information space one might choose between single nodes or clusters of nodes. As is the case in the sampling of geographic space, the choice of a sampling unit should be driven not only by concerns of computational efficiency. It may also be that an information space exhibits certain scale-dependent structural characteristics, which visualization should preserve. Recent advances in uncovering the scale dependency of geographic data appear relevant in this respect [43]. For instance, the *operational scale* at which a structural feature operates might be matched against the resolution at which the information space is sampled.

Once the sampling resolution is chosen, further fundamental choices have to be made. For example, visualizations of hypermedia information spaces tend to focus on an analysis of hyperlink *structures*. Some approaches represent the structure directly, using point symbols for nodes and line symbols for hyperlinks [18,56]. Others define numerical expressions for structural distance, based on the number of hyperlinks one would have to follow to move between nodes [17,36]. Alternatively, distance expressions can be based on the *content* of information space units [48,49,58]. For textual content, keyword indexing can lead to the assignment of high-dimensional 'locations' and the creation of a vector space model [46,47]. In keeping with the First Law of Geography, the distance between document vectors is then computed based on some notion of relatedness. *Similarity* is one possible interpretation, though one still has to choose among a number of similarity coefficients. One might argue that such freedom in the definition of "distance" is very different from the well-defined geographic notion of distance. In reality, even geographers utilize many different notions of distance. While "as the crow flies" distances are dominant, modern geographic analysis utilizes a variety of *functional distances*. For example, analysis of commuting patterns often involves the use of travel time as a measure of proximity. Functional notions of distance also play a role in simulating movement around barriers and across different types of terrain. Analogously, the choice of distance coefficients in information visualization is influenced by the goals of the representation as well as by the characteristics of the information space.

## 2.2. Map Projection

High-dimensional configurations of information space units are not directly accessible to human cognition. In order to visualize them they have to be projected into low-dimensional configurations. The task is therefore to reduce the number of dimensions while preserving relationships among information space components. This issue is similar to a problem faced by cartographers: how to represent three-dimensional geographic space on a two-dimensional display surface, like a printed map or computer screen. This transformation is performed by map projections. Some of these projections make the earth's entire surface visible in a single geometric configuration, while a spherical representation, as if viewed from space, shows only one hemisphere.

In analogy to this, how could one create two-dimensional, map-like visualizations of complete, yet very high-dimensional, information spaces? Multidimensional scaling (MDS), principal component analysis (PCA), and self-organizing maps (SOM) are the most commonly used methods. In terms of complexity and computational efficiency, MDS does not scale up very well for large data sets [29,58]. PCA also does not fare very well [29]. Self-organizing maps, also known as Kohonen maps, are based on an artificial neural network approach. While they tend to be computationally intensive [20], they can produce meaningful results even for large data sets. SOM have received much attention in the visualization of text documents [29,58].

One issue rarely addressed is the degree to which each projection mechanism distorts the original high-dimensional feature relationships. Changing a few parameters can dramatically alter the character and distribution of distortions. This is already very apparent in cartographic projections, but is more dramatic and less predictable for truly high-dimensional data sets, due to the magnitude of the dimensional change. One also has to consider that the underlying principles and goals of projection methods can differ tremendously. Consider the case of two commonly used map projections: the Mercator projection and the Peters projection. They are identical in terms of the preservation of topological relationships of geographic objects. Both distort relative distances of features (as do all map projections) but they do so in different ways. The Mercator projection preserves angular relationships, making it a preferred choice for navigation purposes. At the same time it distorts relative area sizes dramatically, making it quite a bad choice for the display of such area-related attributes as population density. The Peters projection aims at preserving relative area sizes. This has prompted the United Nations to use it as the preferred projection for its world maps, in an effort to portray the area sizes of countries near the equator, i.e. the majority of third world countries, more justly. Cartographers are aware of the relative advantages and pitfalls of specific projection mechanisms and choose map projection parameters and visualization methods accordingly.

When dealing with the visualization of high-dimensional information spaces it is similarly difficult to make a choice among the different projection techniques and their respective parameters. For instance, multidimensional scaling focuses on the relative distances of objects [27], while self-organizing maps attempt to preserve topological relationships [24]. Awareness of these differences should influence the choice of a particular visualization method as well as the interpretation of its results. For example, while self-organizing maps may have the distinct advantage of being applicable even to extremely large dat sets, relative distances can be greatly distorted in the resulting two-dimensional configuration. This fact is nicely utilized by the popular U-matrix visualization method, which can be used to determine clusters based on the magnitude of distance distortion across neighboring neurons. However, users of a SOM-based visualization have to be made aware of these distortions, so that absolute map distances are interpreted with great caution. This has to be part of responsible information visualizations just like readers of a traditional geographic map should be made aware that the nominal map scale does only apply to a small portion of the map.

## 2.3. Generalization

The visualization of information spaces on a two-dimensional display surface can be severely impeded as the volume and complexity of the respective data set grows. In the context of hypermedia structure visualizations, this issue was recognized early on. Some even identified it as "the dominant problem in hypermedia mapmaking" [1]. Numerous proposals have been made to reduce the complexity of information visualizations. Methods such as windowing [9,11,19,45], fish-eye views [12,13,15,38,39], link inheritance [13,38], tree condensing [9,10], and link typing [38,42] are examples of this effort. Despite the progress made in information visualization, it continues to struggle with complexity as a limiting factor to the success of graphic representations.

Cartography is a field of science that has amassed tremendous expertise in dealing with graphic complexity in the visualization of very complex realities. Cartographers manage to create maps in which geographic meaning is preserved throughout the scales, despite the large number of objects involved. The processes of abstraction that achieve such scale-dependent representation are collectively referred to as *cartographic generalization*. The search for solutions in this subject has so occupied cartographers that whole university courses, monographs [22,54], and article collections [5,37,45] have been devoted to it. The relevance of these efforts is not restricted to some narrow scientific endeavour either. The impact of cartographic generalization is felt by millions of people every day, as they use maps in various forms and with a wide range of scales.

The relevance of cartography is underscored by the similarity that many hypermedia methods have to existing cartographic approaches. Note, for example, the affinity of the hypermedia methods of clustering and link inheritance to cartographic aggregation, as applied in the generalization of settlements and roadways [13,38,57].

Figure 1 serves to illustrate the principal relevance of cartographic generalization to information visualization. Generalization of the displayed maps is based on controlling the number of classes into which features are grouped. In this example, geometric generalization, such as simplification of form, is not implemented.

At the root of the complexity problem lies a conflict between the number of visualized features, the size of symbols and the size of the display surface. Cartographers dealt with this conflict mostly intuitively until researcher's like Friedrich Töpfer [52,53,54] attempted to find quantifiable expressions for it. While Tufte does not make reference to those efforts, he does give special consideration to the issue [55].

In grappling with the complexity problem, information visualization researchers now acknowledge *scale* as “the major usability problem of current interfaces” [6]. Other areas of visualization struggle with this issue as well, though different terms are employed, like the *level-of-detail* (LOD) notion that is used in the context of 3D virtual environments. Cartographic generalization is deeply connected to the concept of scale, which has traditionally been defined as the ratio between the size of a feature in the map to its size in the real world. For a variety of reasons, the digital age has required cartography and related fields to rethink the notion of scale [28,43]. Resolution and granularity stand out among those modern notions of scale

[3], especially in the context of remotely sensed raster imagery.

Given the solutions shown in figure 1, one question that arises is whether there are inherently appropriate scales at which each of the generalized solutions should be shown. Again, existing cartographic expertise may provide a starting point. Cartographic generalization is notoriously difficult to automate, due to the large degree of subjectivity involved. However, some aspects of information visualization could be automated more easily, especially with respect to the relationship of feature counts, symbol sizes, and display scale. One good example for this is what has become known as the *Radical Law* [53], which aims at uncovering the quantitative foundations of what cartographers would subjectively call "good" generalization.

## 2.4. Feature Labeling

In two-dimensional information visualization as in cartographic representations, feature labeling is problematic for a number of reasons.

First, text labels tend to occupy relatively large portions of the display area and thus contribute greatly to the problem of *graphic complexity*. In the case of point features, labels take up much more map space than the symbols they refer to. Generalization procedures should thus make consideration of text labels by either reducing the number of displayed features or labeling only a subset of features. In either case, labeling becomes integrated with a generalization routine.

Second, visualization procedures have to make decisions about the *choice of label positions*. This is especially problematic in two-dimensional displays containing dense feature clusters. Conflicts are inevitable if large numbers of closely neighboring features are to be individually labeled. The problem is related to the generalization issue since one way of addressing it would be to reduce the number of labeled features. On the other hand, one may want to search for optimized positions at which labels are legible and clearly associated with map features. Cartographers have developed a number of principal rules regarding label placement. A significant body of cartographic research has been devoted to the subject [20,21,61,35,60]. Some of these studies prescribe preferred label positions based on cartographic experience [21,61]. Imhof's article [21] has been one of the most influential among cartographers. Besides describing a hierarchy of point feature label positions he also discusses the treatment of area and line features. Other researchers have attempted to verify such label position preferences by analyzing the labeling solutions of existing maps in a quantifiable manner [60]. While existing cartographic labeling rules can be reasonably learned and applied by human mapmakers, their automation is a non-trivial task. Two dominant approaches can be distinguished. One is based on the employment of expert system techniques [32]. The other approach views labeling as a combinatorial optimization problem [7,62]. This is one of those areas in which a cartographic problem has found great interest in the broader graphics community. For example, Christensen et al. [7] reports on an implementation of various optimization routines. Sophisticated automated labeling routines are only starting to be implemented in cartographic packages, with varying success. There are also areas outside cartography in which feature labeling has been found to be a problem. For example, psychometric studies have confronted it when dealing with the results of multidimensional scaling procedures [25,40].

Third, the *choice of label terms* for information space units can be challenging in itself. In the case of vector-space models this is unproblematic, if single terms are being visualized. This is similar to the labeling of geographic place names, like settlements, where label terms typically correspond to the real world names of features. On the other hand, if documents themselves are visualized, the choice of label terms is more difficult. A weighted ranking of keywords can help to automate the process. This principle can be extended to label whole clusters of documents and was used to computationally extract the cluster labels shown in figures 1 and 3.

The use of feature labels in information visualization requires recognition of interrelations among these three aspects. Furthermore there may be various other relationships at work, especially in more complex visualization. Cartographic labeling aims not only at the prevention of labeling conflicts, as they might occur between labels of one feature class, labels of different feature classes, or between labels and the features themselves. As with the generalization issue, cartographers utilize labels to convey geographic locations and distributions at various levels. For example, the labels of towns and cities on a map of Africa allow even the casual map reader to draw conclusions about their colonial history: There are clusters of French names, clusters of English names, Portuguese names, etc.. "Good" maps consider geographic reality in label placement. The names of coastal cities are supposed to be always placed completely inside the water area while cities that are located near the coast are supposed to be labeled inside the land area [21]. In some cases, the place and shape of labels may actually substitute the direct representation of feature geometry through line or area features. This is often done for such features as species habitats and sub-oceanic ridges. One important thing to remember about the use of text labels in complex, map-like information visualizations, is that labels do not merely serve as fixed identifiers of map symbols. In addition to this role, they serve as counterparts to other map elements, "overlapping their content and spatial domains and echoing their iconic properties" [59]. The recognition of this complicated relationship of iconic and linguistic codes might help in the evaluation of information visualizations. For example, one might ask whether a continuous, terrain-like visualization is appropriate, when the associated text labels suggest that *meaning* is restricted to the ridges and mountaintops, while valleys and pits remain without labels. Especially useful in the investigation of meaning in map-like information visualization are efforts within cartography to outline a theoretical framework of map design and map use, like MacEachren's *How Maps Work* [30].

### 2.5. Map Design

The value of maps largely stems from the successful marriage of esthetic and utilitarian components. It is through a process known as map design that raw geographic data are turned into visual representations that are both attractive and useful. While this necessarily involves a degree of subjectivity, there are a number of widely accepted map design principles. Many of these are also of use in the visualization of non-geographic information. A good case in point is the use of *graphic variables* to encode quantitative and qualitative data variables. For example, size is a graphic variable whose use should be restricted to quantitative data, while variations in symbol shape can be used to encode qualitative data. Formalized by Jacques Bertin [2], these principles are now being recognized as being at the root of information visualization [6] and have been investigated by the graphics community in various contexts. Tufte particularly contributed to the popularization of cartographic ideas about turning quantitative data into visualizations. Most of his numerous graphic examples do in fact depict geographic space [55].

The establishment of *visual hierarchies* through intelligent symbol choices is one important aspect of map design. Figure 2 illustrates this for administrative divisions of geographic space. Note how the inherent hierarchy of the mapped features is supported visually. Higher-level area objects are delineated with thicker lines and are labeled with a larger font size. Using the same color for labels and borderlines further supports the association of labels with the respective area features. Similarly, one could create visualizations of non-geographic information, in which multiple levels of a hierarchical classification are simultaneously displayed. In figure 3, a portion of a visualization of newspaper articles is shown, in which three levels of a hierarchical clustering tree are projected onto a two-dimensional base map. The use of visual hierarchies to express multi-level classifications is not restricted to such hierarchical classifications. For example, one could simultaneously display k-means clustering solutions for a varying number (k) of clusters.

*Color* is one of the most effective tools to convey meaning in graphic representations and has been a natural focus of attention for cartographers as well as the broader graphics community for some time. Brewer [4] provides a set of guidelines for the use of color in the encoding of quantitative and qualitative information for cartographic purposes. These guidelines also provide a good starting point in the two-dimensional visualization of non-geographic information. One example is the visualization of quantitative information, like single SOM layers. When applied to a vector-space model, these layers contain information about variations in the influence of individual terms on different parts of the map. It is common in information visualization packages to employ a full spectral color scheme to convey these quantitative differences. This is frowned upon by traditional cartographers who view differences in hue as being more appropriate for the encoding of qualitative variables [2]. In addition, use of the full spectral scheme is especially problematic due to the position of a bright, saturated yellow at the center of these schemes [4].

## 3. Outlook

Cartographers are increasingly involved in activities of the graphics and visualization community. Examples are efforts towards the incorporation of cartographic principles into VRML or the Carto project within ACM SIGGRAPH. These activities are typically restricted to the visualization of geographic phenomena. When it comes to the visualization of non-geographic information, little reference is made to existing cartographic expertise and geographic notions. However, information visualization has more to gain from cartography than a superficial appreciation of the value of map-like representations of high-dimensional information spaces.

This paper presented a cartographic interpretation of some of the major issues related to the map-like visualization of textual information. It is part of an ongoing research agenda that includes an investigation of the relative merit of geospatial data models for information visualization and the joining of traditional cartographic generalization routines with contemporary level-of-detail (LOD) approaches.

**Note to the reader:** The figures referred to in this paper can be accessed at the following Web location:
www.geog.uno.edu/~askupin/research/infovis2000/figures/

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