Spatialization

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Information access and dissemination

Efficient and effective access to and knowledge construction from massively growing spatial and nonspatial databases available online have become major bottlenecks for the rapidly evolving information society at large. The rise of the Internet since the 1990s, especially the rapid expansion of the World Wide Web, and the current growth of social-networking platforms brought about the construction of massive, multivariate and multimedia online databases (e.g., Wikipedia, OpenStreetMap, Flickr, etc.). These (increasingly user-generated) databases can include vast amounts of non-numerical, semistructured data (e.g., Wikipedia entries, blog posts, etc.) or nonstructured data (e.g., online books), and these data very often also contain geographically relevant content. Most geographic information systems, however, typically rely on numerical, tabular georeferenced information for space–time data analysis; the kind of numeric data that fit into a table, neatly organized in rows and columns. Analyzing large and complex alphanumeric datasets with traditional spatial analysis methods can become inadequate, as the data may be bound by a priori assumptions (e.g., dependent on a particular data distribution, or a sampling method, and moderate sample sizes, etc.). Due to their inherent complex, multidimensional nature, vast unstructured and semistructured datasets need to be transformed into meaningful chunks of information, and adapted to the limited information-processing and sense-making capacity of humans. With these information science-related developments mostly happening outside of geography, it became apparent to geographic information scientists that methods and approaches that geographers have been using for hundreds of years to model and visualize geographic phenomena could also be applied to the representation of any data record, object, phenomenon, or process exhibiting spatial characteristics (Fabrikant and Buttenfield 2001).

Many different types of spaces and spatial reference frames exist beyond geographical space that could be reorganized, analyzed, and explored with spatiotemporal methods, and mapped using well-established cartographic practices. For example, chemical structures that build up to the human genome, medical records that refer to human body space, or neuronal connections in the human brain are good examples of nongeographic spaces that lend themselves for spatial analysis and mapping. For example, Atkins (1995, 34) depicts the periodic table as a stepped undulating terrain of chemical properties. The higher the hills in this landscape of the chemical elements, the larger the atom diameters of the depicted chemical elements.

Spatialization offers the field of geography, which investigates space and spatial relations, opportunities to apply its rich spatial knowledge to nongeographic, and even nonspatial, data domains (Couclelis 1998). One can also imagine abstract information worlds presented in map-like displays for visuospatial analysis that are not spatial at all. For example, real-time digital

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stock transactions create a space of money flows, and digital interactions of people through online networking platforms form social networks in cyberspace, which could both be mapped in the form of transportation network maps. Songs played on online music sharing websites create a landscape of musical tastes that can in turn be depicted as a relief or terrain map in which musical tastes shared by many people pile up metaphorically to create mountains of popular music styles. Figure 1 depicts a two-dimensional (2-D) space of musical tastes and listening experiences sampled from members of the popular online music sharing website Last.fm. Listeners of this social music media website are invited to share personal information about the music they upload or listen to by tagging songs with additional text information. Based on users' listening patterns, this information is then used by the system to suggest additional musical pieces that users might enjoy listening to.

The music spatialization in Figure 1 renders a meaningful spatial pattern of musical styles, where rock music pieces cluster in the western parts of this Last.fm landscape (Skupin, Biberstine, and Börner 2013), clearly separated from world music, classical music, and jazz, concentrated in the eastern parts of this relational world of musical tastes. Interestingly, funk music, located in the southeast of the space, seems to be seen as a musical transition zone between jazz and classical music.

Spatial metaphors

Spatialization takes advantage of people's familiarity with space in everyday life to produce information spaces that are intuitive and internally coherent. Everyday experience of the real world involves visuospatial perception and memory, spatial reasoning, and communication about features and objects in the environment, their spatiotemporal and thematic attributes, and the relationships between these objects. For example, instead of presenting users with large abstract tables or long lists of queried items from an online archive in text format, information spatializations allow users to visually explore graphic displays of information by means of spatial metaphors, as if they were exploring a real landscape or a cartographic map of a real environment, allowing them to see and experience the "layout" of the information in a single view (Skupin and Fabrikant 2003).

Successful interface metaphors create explanatory theories for users interacting with a system (Kuhn 1996). That is, users can map the processes and relations of a real-world source domain (e.g., geographic space) onto the processes and relations of the target domain (e.g., an information space), allowing them to use their knowledge of familiar source domain operation to predict the unfamiliar, often abstract target domain operation. What is common to geographic and nongeographic spaces (e.g., body space) are fundamental spatial concepts such as location, distance, arrangement, hierarchy, scale, and so on. A fundamental assumption is that spatialized displays work because users can understand them intuitively (Wise *et al.* 1995). If this assumption is generally true, understanding the fundamentals of geographic space (the metaphor's source domain) as understood by display users will help to construct cognitively adequate information displays based on meaningful spatial metaphors (target domains). Location and distance (i.e., arrangement) on the Earth's surface are among the most fundamental geographic primitives, and both are reflected in the distance–similarity metaphor, that is, more similar items should be placed closer to one another in a spatialized display because closer items will be seen

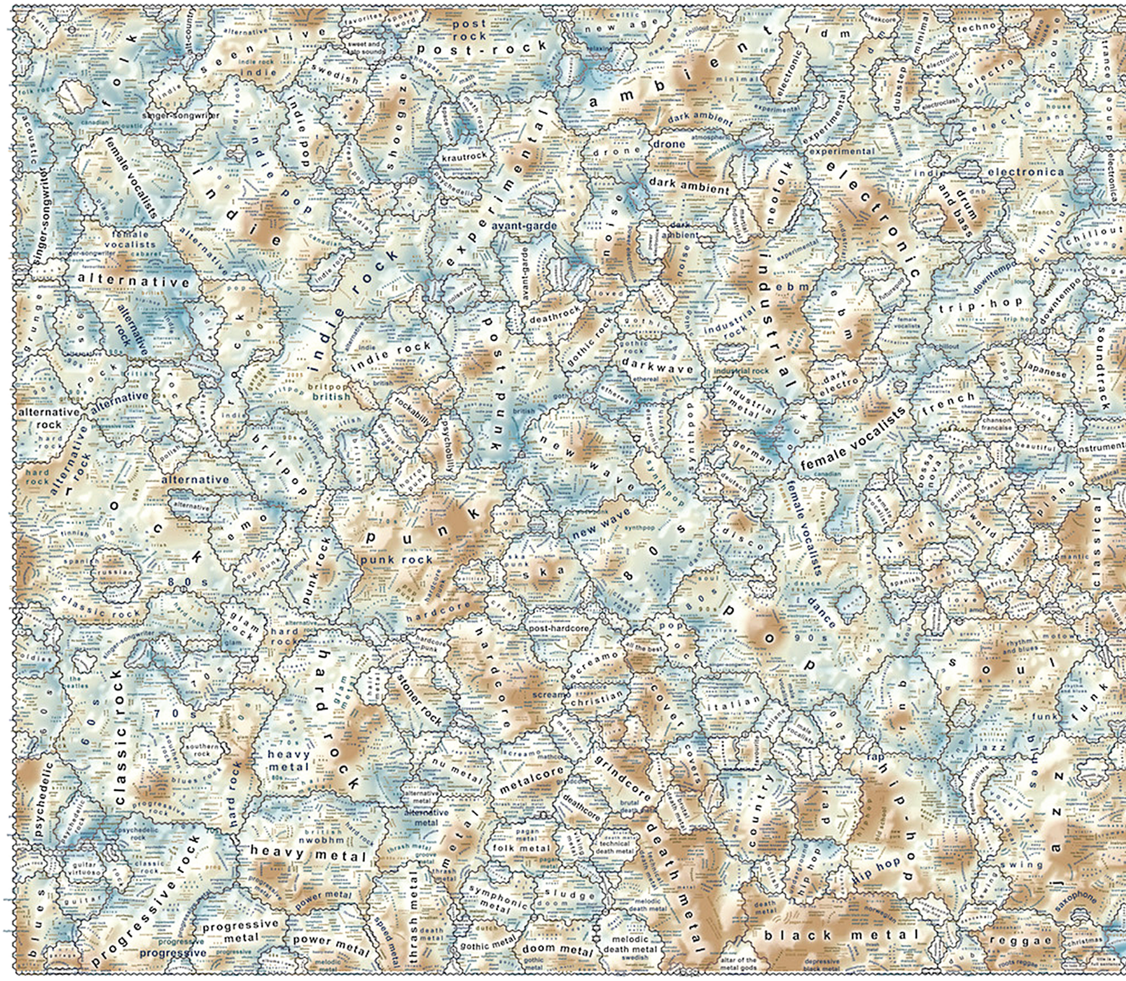

Figure 1 The landscape of shared music on Last.fm. Skupin, Biberstine, and Börner 2013. Reproduced from PLOS.

by people as more similar than distant items. Montello *et al.* (2003) have called this principle the first law of cognitive geography, as a consistent result of a series of empirical studies with various types of spatialized displays. This research provides empirically validated evidence to support Gatrell's (1983) proposal for using a broader conceptualization of space in geography, and thus to employ a variety of distance metrics beyond Euclidean geometry to analyze and visualize a multitude of spaces of interest to geographers. The current popularity of ordination methods utilized to reorganize and mine vast amounts of spatial and nonspatial data, for example, by using nonmetric multidimensional scaling, principal component analyses, and self-organizing map techniques in various subfields of geography (i.e., physical geography, remote sensing, and behavioral geography), is another good example of the analytical power of the distance–similarity metaphor.

Metaphors are also successfully employed in everyday communication, because they encapsulate so-called image schemas that have been hypothesized to be at the core of human cognition. Image schemas are fundamental cognitive structures shaped by bodily interactions with the real world that allow basic human reasoning and understanding (Lakoff and Johnson 1980). For example, the spatial image schema MORE IS UP is the basis for understanding any type of linguistic, auditory, or graphical metaphor to communicate the magnitude or quantity of an item of interest. Examples of this image schema are in everyday language: "Her appreciation for beautiful maps keeps rising every day." When one is pushing up a lever on a vintage analog stereo system this typically increases the volume of the played sound source. Also, in any statistical charting software, when creating a graph of analysis results, the higher the bar, the higher a point or a line in a graph, and the larger the slice of pie in a pie chart, by default, the greater the magnitude of the depicted data. The use of metaphors in user interfaces is also inspired by Gibson's (1979) ecological theory of visual perception, which postulates that a human observer can intuitively grasp *affordances* in a perceived environment, resulting in appropriate human action and behavior in that environment. Hence, a perceived sound lever on the analog stereo system, or a depiction of a sound lever in a graphical user interface to play digital music, affords a user to push it up or down to change the sound volume. To be cognitively inspired, and thus intuitively understood, the appropriate mapping of more or less sound to yield the predicted result should in turn be based on the MORE IS UP image schema, with a higher/lower sound lever (source domain) for more/less sound (target domain), respectively. Similarly, on a mobile device, the spreading of two fingers, that is, the increase of distance between the thumb and the index finger, typically increases the size of objects perceived on the graphical user interface and the distances between them in the display, and also the level of graphic detail shown in the interface.

The graphical "desk in an office" interface to run a personal computer is another everyday example of the integrated application of spatial metaphors based on (spatial) image schemas and affordances that spatialize an abstract multidimensional digital data environment. This graphical user interface, initially developed by Xerox's Palo Alto Research Center in the 1970s, and later popularized in the 1980s by Apple Inc. for its Macintosh computer, is still the dominant interface metaphor and user interface spatialization to this day. The 2-D view of a computer operating system as an office desk covered with writing tools, documents, and folders, in an office equipped with filing cabinets and a trash can (a table-top source domain), enables a user to visually create, process, store, and delete data in a digital filing system (target domain). Using spatial properties such as proximity (i.e., NEAR–FAR image schema), users typically regroup related files or applications, by putting them into a common folder (CONTAINER image schema). Consequently, hierarchies of folders can be created to simplify navigation through "data space" (VERTICAL ORIENTATION image schema). Deeper into the hierarchy, more detailed information about the data is revealed, thus relating to scale dependence in the real world (PART–WHOLE image schema). Moreover, by surmounting distance with the "drag and drop" option (SOURCE-PATH-DESTINATION image schema), we are able to perform actions within the computing environment, such as copying or deleting files. Files that have to be deleted are carried to a specific place on the desktop, to be put into a trash can. Typically the trash resides somewhere at the edges of the desk, neither obstructing our working environment, nor being too close to important files (CENTER–PERIPHERY image schema).

Applying the distance–similarity metaphor (i.e., NEAR–FAR image schema) to a spatialized digital online library, one can couple document locations with distance, and thus two documents may be cross-referenced by a linear connecting transect (i.e., SOURCE-PATH-DESTINATION image schema). Items falling along this transect may be characterized as being more similar to one item (endpoint) or the other. Documents within a given (radial) distance of a central thematic location form clusters of related information (i.e., CENTER–PERIPHERY). Clusters may be nested hierarchically and build up document ontologies. Introducing the concept of scale, clusters can be explored at different levels of detail. One level of detail provides an overview of the entire information space. Other, more detailed levels "zoom in" on a specific theme or a specific document, and so on.

The power of metaphors in spatialization is its strength, but can also be one of its greatest weaknesses. It is important to realize that a metaphor is only *like* the real thing, not the thing itself. This means that a metaphor may include some but not all characteristics of the mapped source domain, and may in fact have additional (magical) or counterintuitive properties in the target domain. Consider a digital folder to store files as mentioned above. The digital folder (target domain) exhibits similar properties to an analog manila folder (source domain) in that "files" can be stored in it. However, the digital folder cannot be bent, and files never fall out if it gets too full. The digital folder also exhibits "magical" powers in that it can hold many hierarchically stacked folders, and potentially store an infinite number of files (provided an infinite amount of digital storage space is available). In fact, the manila folder might not even be recognized as such outside of the United States, because in many parts of the world the cream-colored folder with tabs to write on is not known or used at all.

Empirical research suggests that a continuous landscape metaphor to represent document collections is not as self-evident as information designers seem to believe. Like visualization designers, lay users reveal a similar naive understanding of geomorphological structures and processes used as source domains, and thus have difficulty interpreting and fully grasping the very popular continuous terrain metaphor to depict a news article collection (Wise *et al.* 1995). On the one hand, the spatial metaphor might be taken literally; viewers interpret depicted features as islands, mountains, and so on, because of their graphic appearance, even after they have been specifically told that the display is an abstract information space of new stories. On the other hand, once the abstract news concept is applied by users, it is mixed with naive conceptions about landscape forms, because spatialization users are not familiar with the true nature of geomorphic processes (e.g., more information is accumulated in the valley) and do not share commonsense/naïve ideas about topography suggested by spatialization designers (e.g., higher mountain means more information) (Fabrikant, Montello, and Mark 2010).

Spatialized views

Spatialization is related to geographic visualization and geovisual analytics in the sense that powerful interactive map-like displays and interfaces are used to gain insights into massive databases that are spatialized. These spatialized views are typically the result of applying sophisticated data mining and exploratory multivariate data analysis approaches, including dimensionality reduction techniques (i.e., factor analysis, multidimensional scaling, principal component analysis, etc.) to large multivariate databases of interest. Such advanced multivariate statistical methods themselves are based on spatialization, that is, they reorganize and visualize massive and complex high-dimensional databases based on the distance–similarity metaphor (e.g., any type of mathematical ordination method), with the goal to uncover interesting patterns and gain an overview of latent relationships buried in the data, which in turn can be further analyzed statistically in more detail.

A spatialized view differs from ordinary data visualization and geographic visualization in that it may be treated *as if* it depicted geographic information. Armed with the arsenal of long-established cartographic visualization techniques, information spaces can be visualized in various ways, for example, as simple point maps, network maps, or continuous terrains. The more cognitively supportive the employed spatial metaphor, and the more perceptually salient its depiction, the more intuitive the spatialized view, and eventually the more effective the use of spatial analysis techniques for data exploration and knowledge construction. While technical developments and analytical innovations in spatialization research have continuously and rapidly advanced, theory development, empirical evaluations, and validations of design principles for spatialized views have received much less attention. Early empirical findings suggest that spatialized views should be based on sound spatial theory and principles, and adhere to cartographic design guidelines to be cognitively inspired, usable, and useful (Fabrikant and Skupin 2005). For example, empirical evidence shows that 2-D point and surface spatializations are equally effective as their 3-D equivalents. This is probably due to the fact humans rarely experience 3-D space directly (e.g., flying or diving), and thus human perception and cognition are closer to 2D than to 3D (Gibson 1979). The strength of a similarity relationship between spatialized items is most effectively depicted by connecting lines between items, and by varying line width, akin to showing the magnitudes of flows on quantitative flow maps. This is because the visual variable size is based on the MORE IS UP image schema, and the links between nodes on network maps encapsulate the SOURCE-PATH-DESTINATION image schema (Fabrikant *et al.* 2004). Groups of related items are shown either in clusters on point-display spatializations (Montello *et al.* 2003), similar to a dot density map (i.e., NEAR–FAR image schema), or as distinctly colored regions in region display spatializations (i.e., CONTAINER image schema), akin to area class or choropleth maps (Fabrikant, Montello, and Mark 2006).

Ongoing spatialization research focuses on how to effectively and efficiently depict multivariate, increasingly non-numeric, and nonspatial data stored in massive online databases, so as to provide aesthetically pleasing, perceptually salient, and cognitively supportive displays for effective and efficient sense-making and knowledge construction.

SEE ALSO: Mapping cyberspace; Space; Spatial concepts; Spatiality; Spatiotemporal analysis; User-centered design

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