Visualization of Processes of Spatial Diffusion and Spreading

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Processes related to diffusion and spreading over space are of particular interest to many applications, as diverse as the analysis of the diffusion of innovations over space, air transport of toxic gases, accessibility of locations in space, or the spread of forest fires. The visualization of such processes, because they usually proceed in an uneven fashion and eventually "fill" the entire space, is particularly demanding. Given the tools of computer graphics and digital cartography, however, many new options are open to exploration. This paper gives a systematic overview of possible visualization methods and presents new techniques for space-filling diffusion processes; diffusion and spreading along networks is not the focus of this work.

Visualization of spatial diffusion can be based on five design elements. The *first element* relates to the variable that is depicted. Two options are possible: visualization of the progress (or duration) of the spread process across geographic space (i.e., how far has the "wave" spread forward at time t_n); and display of the amount of the mapped variable that is reached at a certain time t_n (e.g., the amount of population living within a travel distance of 10 minutes about a railway station). The *second design element* involves the dimension of the visualization: 2-D (i.e., planimetric mapping of the spread process); 3-D (mapping diffusion as a surface, or adding time as a third dimension, alternatively); or 4-D (achieved through animation of 3-D maps). The *third design element* relates to the map type that is used for the visualization. Situation maps depicting time slices, or isochrones for 2-D maps, perspective surfaces, or space-time cubes for 3-D visualization are some of the map types that are available among various others. The *fourth design element* involves the use of animation. While static displays capture time slices of a diffusion process, animation allows to represent sequences of time slices, hence the progress of diffusion expressed by a time series. A similar effect can also be achieved through pseudo-animated displays such as color cycling (e.g., changing colors of isochrones in a cycle around the color wheel suggests motion). Finally, the *fifth design element* involves distortion of geographic space and its transformation into temporal space. Distances are then no longer represented in units of length, but in units of time (i.e., travel distances). This leads to a visualization type we call "temporal cartogram", which displays isochrones as concentric circles, while geographic objects such as boundaries are distorted.

The paper describes the algorithm to construct temporal cartograms in detail. It consists of two major parts: the computation of the diffusion process across space, and the distortion of geographic objects according to the resulting travel times. The diffusion is computed on a raster basis by means of cost surfaces which model obstacles or frictions to the diffusion process (e.g., waterbodies in cross-country movement). The resulting raster map of travel times is used to interpolate displacement vectors for each of the coordinates of the original geographic objects (e.g., the vertices of a boundary line). Finally, the original map is distorted using a piecewise linear rubber-sheeting transformation over triangulations of both the original and the displaced coordinates.