Miscommunicating With Isolines: Design Principles for Thematic Maps

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Gould and White (1968) introduced the measurement and isoline mapping of regional preferences, producing preference or "isoeutope" maps. As cartographers know, the decision to employ isoline mapping as a cartographic display technique is valid insofar as certain assumptions are met, notably the assumption that the variable being mapped reflects an underlying continuum. This assumption is doubtful in the case of a variable such as regional preference insofar as it is based on rankings or ratings of existing regional units such as states for which human cognition is not continuous. The implications of mapping preference with isolines are discussed, particularly with respect to the attitudes they reflect and the cognitive responses they elicit in viewers. We argue that isoline mapping of data such as state preferences produces misleading impressions of intraregional variation and is neither necessary nor desirable. Alternative methods for the collection and cartographic display of regional preference data are discussed. Notably, we propose the use of "psuedo-Chernoff" faces as an appropriate technique.

Keywords: Isoline mapping, preference maps, spatial interpolation, cognitive cartography, Chernoff faces

Introduction

In a series of articles published during the 1960s, Gould and White (for example 1968) introduced the cartographic display of a people's relative preferences for living in one or another region of a country. This work was subsequently developed most fully in their 1974 book, *Mental Maps*, and its 1986 second edition. Gould and White's cartographic displays provided an early demonstration that subjective, intrapsychic variables (variables that measure thoughts, emotions, attitudes, and so on) could be thematically mapped, much as one maps rainfall, population, or criminal activity.

The notion that subjective variables could be mapped was an important insight. It extended the practice of psychometrics to a geo-referenced context, allowing its cartographic expression. *Psychometrics* is the approximately century-old set of theories and techniques that allow the measurement of subjective variables that do not have direct physical referents; in contrast, *psychophysics*, well explored in cartography for decades (its history is reviewed by Montello, 2002), involves subjective variables that do have physical referents, such as color hue or perceived size (Nunnally and Bernstein, 1994). To many people, it was a revelation that such variables as fear or aesthetic preference could be quantified and mapped,

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and scientifically studied like "objective" variables. In fact, some within geography and cartography apparently still question this (for example, Walmsley and Lewis, 1993).

Early in their research program, Gould and White chose an appealing cartographic technique for displaying their preference data: the *isoline* (or isarithm) map. The isolines in this case represent lines of equal preference or liking for the places they cross; alternatively, they should be interpreted as boundaries between regions of equal preference.[1] Gould and White called them "mental maps," but we believe this term is too general because it implies a mental representation of all beliefs about places (including, for example, spatial layout) rather than a representation specifically of preference. Instead we favor the term "preference maps," or if one wants a precise technical label, we suggest they be called "isoeutope" maps. Our purpose in this paper is to review Gould and White's measurement and isoline mapping of place preferences, review some past criticisms of them, and provide a new critique based particularly on the way they communicate attitudes about preference to viewers of the maps. In the process, we make general observations about isoline mapping, and about the measurement and display of subjective variables like preference. We suggest some alternative mapping methods we think communicate better.

Figure 1 depicts an isoeutope map, based on a sample of 55 students from the University of California at Santa Barbara that we surveyed a few years ago (about 85% of them reported having grown up mostly in California). The map in Figure 1 was constructed following the methods typically used by Gould and White. First, respondents were asked to rank order regions in terms of their preferences for living there; respondents were to assume they had no financial, family, or other constraints to consider. In the case of the states of the conterminous United States, one of Gould and White's most studied areas, this results in a 48 x N matrix of numbers, the numerical ranks 1 through 48 for each of N respondents (we originally solicited rankings of all 50 states, Hawaii and Alaska being popular states, but the continuous interpolation involved in isoline mapping does not work with noncontiguous regions). The matrix was reduced to a vector via the multivariate data-reduction technique of principal components analysis (PCA). That is, each state was assigned a mean PCA score reflecting its average consensus preference by the aggregated sample of respondents. (We have found that using mean ranks instead of PCA scores is simpler, at least as theoretically defensible, and produces nearly identical maps—the two are correlated 0.995 in our data). The PCA scores were transformed and rescaled to range between 0 and 100, the most preferred states being assigned the highest values. Each state's mean rescaled PCA score was assigned to a point location within that state (we used spatial centroids). This spatial distribution of points was then subjected to cartographic interpolation to produce smooth and continuous isoeutopes connecting places of equal preference. This interpolation can be done formally or informally—we used inverse-distance weighted interpolation. On the resulting map, ridges of highly desirable areas and valleys of undesirable areas are evident.

We believe that isoline mapping is a poor choice for this type of data primarily because it produces misleading impressions of intraregional preference variations among viewers, especially relatively naive viewers. More than once, while gazing at one of Gould and White's maps, students in our classes have remarked that, for example, respondents obviously preferred coastal California to the Central Valley and other points east, or respondents liked the Denver area more than the mountains to the west. Even though these students were told the maps were based on single

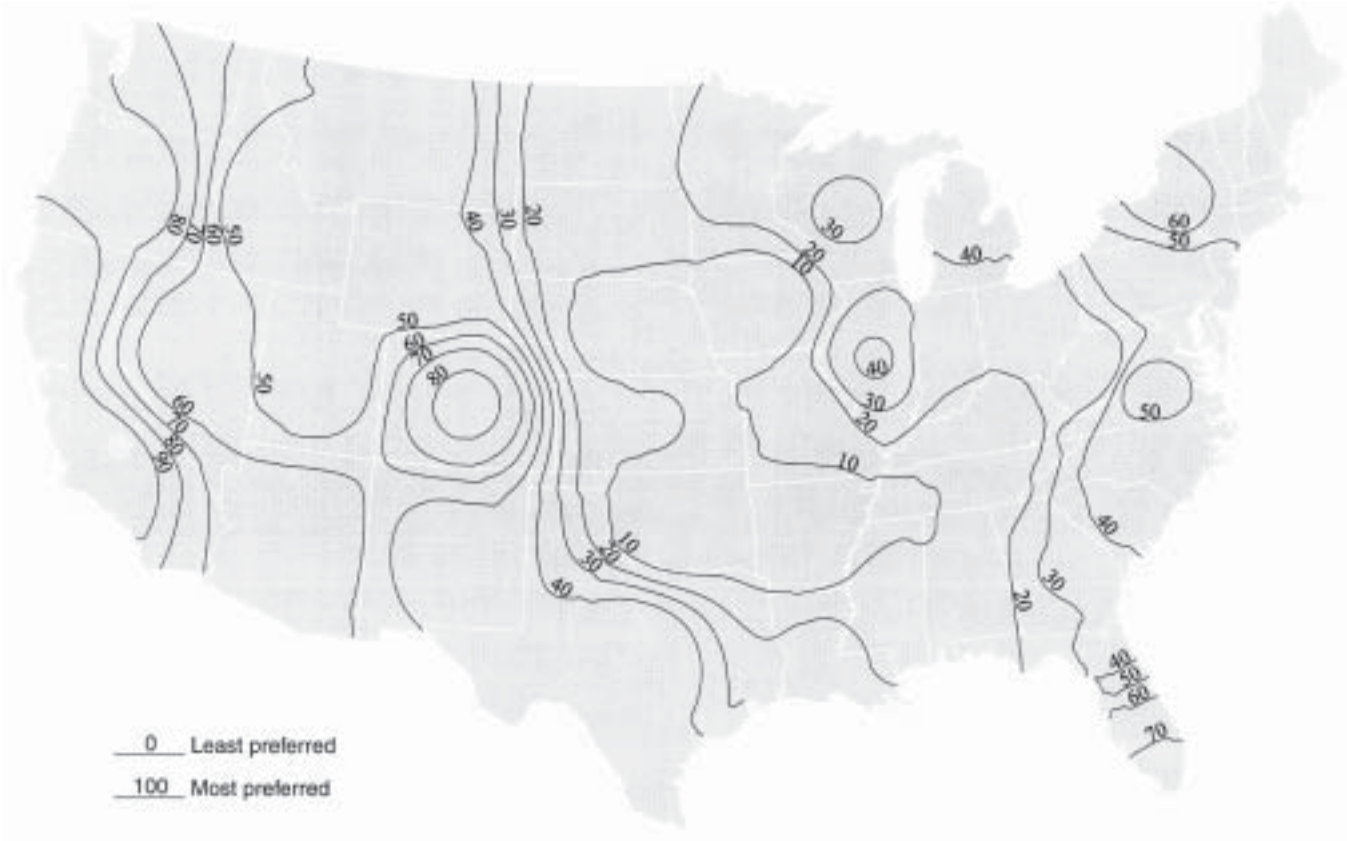

Figure 1. Isoeutope map of PCA scores from state rankings.

rankings of each state, they readily overinterpreted the maps to show variation within states that is not in the data. Being told how the maps were made, students might have realized that the high ranking of California accrues to its western edge, away from the less preferred Arizona and Nevada, while the high ranking of Colorado accrues to its center (the actual northerly location of Denver notwithstanding), away from less preferred states all around. But they did not, as we confirmed in a controlled study that found that 25 of 26 undergraduate students (only a few of whom were geography majors) shown the isoline maps mistakenly identified within-state variation within Colorado, Florida, and California. This was in spite of the fact that the written instructions stated clearly that only one rank per state was assigned, and in spite of the fact that each of the questions gave students the explicit option of answering "can't tell from this map." In contrast, on a choropleth map of the data (Figure 2), an average of 18.3 of the 26 students in fact responded that they could not tell from the map whether there were variations in preference within the states of Colorado, Florida, and California (a handful of students viewing the choropleth map must have overlooked the request to judge variation "from the map"). We find these results to be quite clear, and presume that other naive viewers would respond similarly to isoline and choropleth versions of preference maps.

This points to an issue that has been periodically debated at least since the advent of map-design research in the 1950s (Montello, 2002). Should people be educated to understand maps, or should maps be designed so as to facilitate efficient and accurate communication even among naive viewers? We certainly don't see this as an "either-or" question. Of course

we support cartographic education, but we also support the inspiration behind map-design research that cartographers should make maps based on how people who view the maps perceive and think about the maps, and about the world. Even if cartographic education could ensure the valid interpretation of various map symbols like isolines (which is an empirical point that may not be true), maps are viewed by thousands of people who have not and will not receive this education. If anything, inadequate cartographic education is probably becoming more common. Isoeutope representation produces numerous artifactual peaks and troughs within states (or whatever the data-collection region is). These artifactual patterns are sometimes reasonable, by at least partial accident; for instance, the coast of California is generally preferred over the Central Valley, probably even by many people who live in the Valley but what about the Sierra Nevada? In many other cases, these artifactual patterns can be very unreasonable; because California is preferred over Arizona by almost all respondent groups (perhaps by many Arizona residents too), preference within Arizona peaks in the southwest desert and drops off toward the high country in the east and north. A direct attempt to measure preference variation within Arizona would probably result in the opposite average pattern.

Criticisms of Gould and White's Preference Mapping

A variety of criticisms and suggestions for improvement have been targeted at Gould and White's "mental mapping." Thill and Sui (1993) proposed to mathematically introduce uncertainty "fuzz" into the prefer-

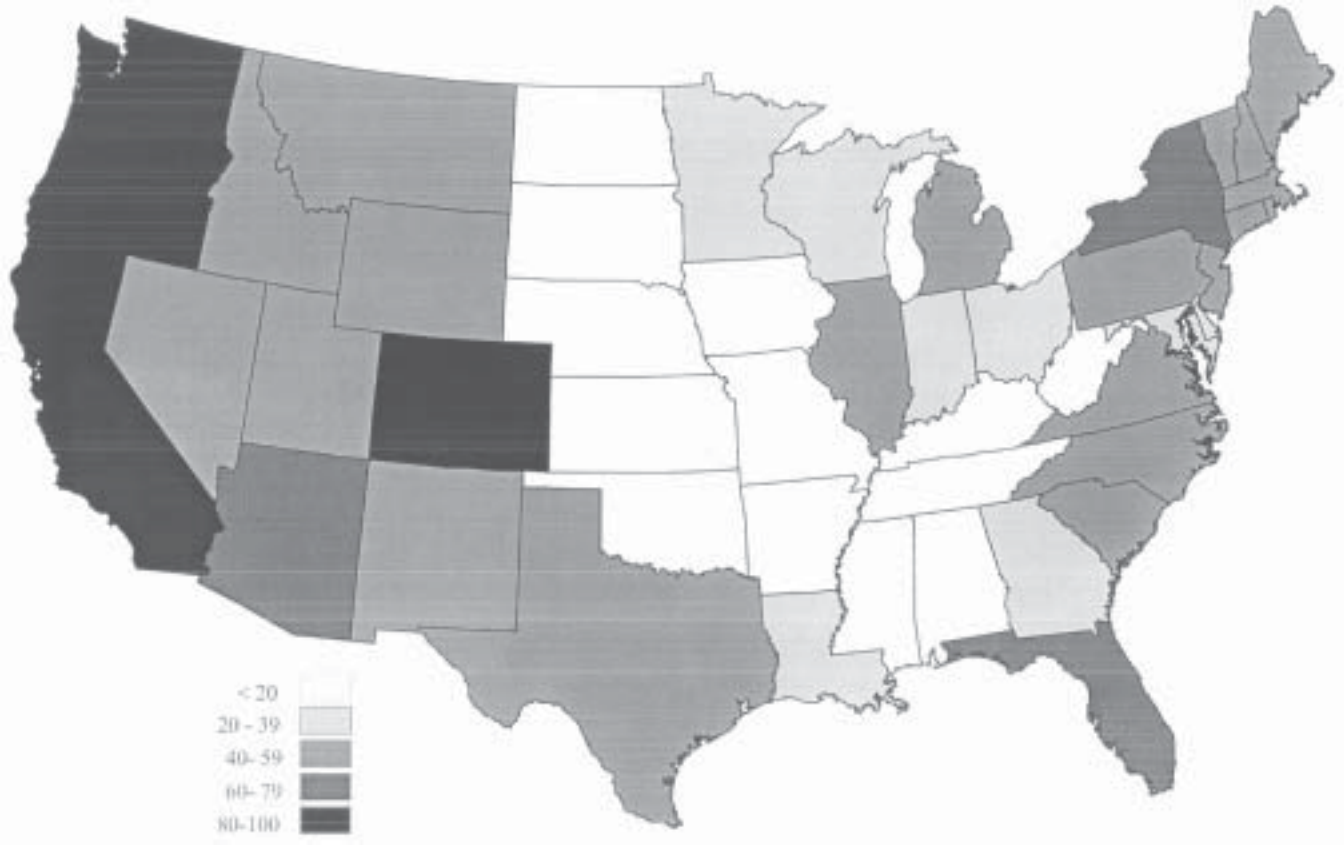

Figure 2. Choropleth preference map of PCA scores from state rankings, based on five equal-interval classes.

ence rankings used to construct the maps, to reflect the fact that people are less certain about intermediate regions than highly favored or disfavored regions. We agree with this proposal, but note that it is rather elaborate and does not alter the basic patterns of the maps much. A simpler and more straightforward approach to the problem of ambivalent rankings, as Thill and Sui in fact suggest, would be to use a "rating" task instead of a ranking task. A rating task directly generates metric (interval-level) data and allows preferences that are nearly equal to be expressed as ratings that are nearly equal. Other writers have also focused on the meaning of the ranking task used to generate preference data. "One of the most common criticisms pertains to the expectation...to rank geographic entities in order of preference" (Thill and Sui, 1993, p. 264). Tuan's (1974) opinion was that the ranking task is a game that is unusual or unrealistic to subjects, though he believed "the maps...are an appealing way to display data" (p. 591). Gould and White themselves noted, in the preface to their second edition, that "criticism [of the first edition] focused on the viability of the ranking of spatial preferences and the representativeness of the sample of respondents" (1986, p. ix).

The bulk of these criticisms are based on intuition rather than evidence, and we find them a bit overstated. Instead, we find it surprising that so little criticism has focused on the cartographic display of the preference rankings, including the way interpolation of data at the state level has been used to construct continuous isoline maps of preference. Our primary concern with the isoline representation of ranked preference data is that the "landscape" of underlying preference is not suitably continuous, particularly given the coarse resolution at which such data are collected. Such isoline maps communicate invalid impressions of continuous variation and intraregional variation to viewers. As is well known, interpolating a continuous surface from discretely sampled data is valid insofar as the underlying variable being mapped varies continuously across space. Put another way, the underlying variable must exhibit considerable autocorrelation, typically positive, across the surface: "The critical assumption is that events in one geographical area influence those in adjacent areas" (Tobler, 1979, p. 526). Existing literature on cartographic interpolation focuses primarily on questions of the relative validity of various sampling schemes and interpolation techniques in constructing isoline maps (for example, MacEachren and Davidson, 1987). As Lam (1983) put it in her overview of interpolation methods: "The fundamental problem underlying all these interpolation models is that each is a sort of hypothesis about the surface, and that hypothesis may or may not be true" (p. 130).

Of course it is at least as important to consider when continuous mapping techniques are valid in the first place as it is to choose the right interpolation technique. Our main thesis is that the hypothesis of an underlying continuum is sufficiently untrue in the case of regional preferences as to make isoline interpolation a poor cartographic choice for their display. There has been research on the variables underlying regional preference, much of it discussed by Gould and White in their second edition. Some of these variables (climate, topography) do vary more or less continuously. We concede that states discriminated primarily on these variables are validly mapped with isolines, although one could still criticize the sparseness of sampling only once per state when the isolines are based on state rankings (cf. MacEachren and Davidson, 1987). Other variables (laws, political climate) do not vary continuously. But more importantly, people can and do express preference rankings for regions about whose internal characteristics they know very little. A majority of

respondents from California don't know much about variation within the state of North Dakota, for instance; informal surveys taken in our classes regularly show that very few students have ever been to North Dakota. In such cases, and they are likely to be commonplace, we believe that people fall back on place attitudes and stereotypes that vary from discrete region to discrete region, but do not vary within regions. This does not invalidate the expression of preference. It does invalidate the use of discrete regional preference rankings to interpolate intraregional preference variations. Nor does the stability and consistency of the preference map patterns (noted in Gould and White's second edition, p. 63) demonstrate the validity of the interpolation procedure. It demonstrates the reliability of the preference rankings.

Regions are spatial categories. Humans commonly organize knowledge categorically in order to simplify a complex world. As such, intracategory variation is minimized and extracategory variation is exaggerated. Everyone is familiar with the inflated distinctions border residents draw between themselves and "those people over there." An apocryphal tale recounted by Muehrcke and Muehrcke (1992) nicely exemplifies categorical reasoning about regions. A man living near the Canadian-Alaskan border wasn't sure on which side of the border he lived. So he hired a surveyor, who determined that the man lived in Canada. "Thank God!" the man cried, "Now I won't have to live through another of those terrible Alaskan winters!" Anecdotal and apocryphal evidence aside, many empirical studies have demonstrated the categorical organization of geographic knowledge, whether based on maps, language, or direct experience of various kinds (Friedman and Brown, 2000; Hirtle and Jonides, 1985; Maki, 1981; McNamara *et al*., 1989; Stevens and Coupe, 1978). In these studies, reasoning is distorted in a variety of ways (including spatially and thematically) because of its dependence on the categorical organization of geographic knowledge.

Preferred Approaches to Preference Mapping

We believe preference rankings should be displayed at the regional level at which they are collected. By and large, Gould and White discussed their maps only at the regional level; they may well have recognized that the impressions of intraregional variation created by their displays could readily be misinterpreted. In both editions of *Mental Maps*, Gould and White reported some of their earliest work on residential desirability in European countries. In these early preference maps, they did not use smoothed isoline contours to map preference rankings—they used choropleth mapping. Choropleth mapping has some communication problems of its own. The choice of intervals is often ad hoc. Especially problematic is the choropleth mapping of variables based on counts or densities of people; the "standard" red-blue choropleth maps of recent U.S. presidential elections is very misleading in this way. But preference data are not measures of person variables; they are measures of attitudes about portions of the earth surface. And in this case, we think the use of equal intervals is straightforward and defensible. So we find choropleth mapping to be an appropriate cartographic technique for these data (the data in Figure 1 are choropleth mapped in Figure 2). We agree with Sol's conclusion in a paper presented at the 1994 meeting of the Association of American Geographers: "Isolines are appropriate only when data have geographic volume and are continuous phenomena.... If a question asks for a preferred residence by state, then the data should be mapped areally, using choroplethy." The balance of her talk was a demonstration of the

use of graduated circles to depict rankings of cities. Symbols such as graduated circles (and cartograms) are less appropriate than choropleth shading because preference is an interval, not a ratio, variable.

Ironically, Chernoff faces (Chernoff, 1973) might be an unusually appropriate display technique for regional preference data. Chernoff faces were originally proposed as multivariate data symbols; different parts of the face icon (eyes, eyebrows, mouth, head shape, etc.) can be independently varied so as to represent different variables. Cartographers (for example, Slocum, 1999) have proposed their use as multivariate point symbols on maps. However, in most cases the faces would probably communicate poorly because face perception is special. Upright human faces are recognized more holistically, less by part decomposition, than other types of objects, such as houses or words (Farah *et al*., 1998; Young *et al*., 1987). The powerful tendency to holistically perceive faces as stimulus configurations may make it difficult for viewers to extract independent values of multiple variables from the display and may lead to perceived configurations that artifactually suggest multivariate data patterns. Although the holistic perception of faces can be a strength is some cases, they probably mislead more than illuminate when particular combinations of variables cannot readily be associated with particular emotional evaluations. In an empirical study of Chernoff faces, for example, Nelson and Gilmartin (1996) found they did not work well, and concluded that research and debate leaves the question of the efficacy of Chernoff faces "still far from resolved" (p. 195). Chernoff (1973) himself anticipated "that the faces would have relatively little usefulness as a communication device" (p. 364).

The perception of unitary emotional expressions from faces is rapid and powerful, probably one reason they have been considered useful for the difficult problem of multivariate communication. A symbol system that so immediately communicates positive and negative emotions would, therefore, be exceptionally effective for communicating regional preference as a single quantity (Figure 3). Because these symbols are not functioning multivariately, we call them "pseudo-Chernoff faces."

Conclusion

Place preference is a useful geographic concept that deserves continued investigation; its assessment is a valuable exercise to geographers. Place attitudes, even when stereotypical as they often are, are part of human interaction and engagement with the Earth and with geographic information, and should help predict and explain spatial behavior such as tourism and migration. Gould and White deserve much credit for originating its systematic study by geographers. We believe this to be true even if the ranking task is difficult in some cases, or if disregarding family and fiscal constraints is, to some degree, unrealistically hypothetical.

However, if one wants to investigate and display *intra*regional variation in preference, different data-collection methods should be used. One could collect discrete rankings of subregions within the larger regions. Stimson's research on preference for suburbs in Adelaide provides an example of this approach (Golledge and Stimson, 1987, p. 288). Alternatively, one could design some type of continuous task that would allow respondents the freedom to indicate their own preference boundaries on a base map without state boundaries (for example, freehand drawing of areas). One interesting outcome of such a method would in fact be evidence of the degree to which respondents' preference boundaries ignored or attended to state boundaries.

Figure 3. Pseudo-Chernoff face preference map of PCA scores from state rankings, based on five equal-interval classes.

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NOTES

[1]These two interpretations of isoeutopes reflect the distinction between *isometric* and *isoplethic* (or pseudo-isoline) mapping, based on whether the mapped variable can be considered to exist at a point (like elevation) or not (like population density) (Dent, 1993; Imhof, 1972; Muehrcke and Muehrcke, 1992). Arguably, preference maps are isoplethic. However, we do not believe this distinction has any relevance to the arguments we make against any form of isoline mapping for preference data collected as state ranks.

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