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# STRATEGIES FOR THE VISUALIZATION OF GEOGRAPHIC TIME-SERIES DATA

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ABSTRACT Strategies for the visual display and analysis of geographic time-series data may be spatial or nonspatial, single-view or multiple-view, static or dynamic. Labels for place names or other geographic metaphors can describe symbols on aspatial time-series charts. Single-static-map strategies incorporate the temporal dimension through techniques ranging from complex point symbols, or temporal glyphs, to generalized trend-surface or flow-linkage maps focusing on movement. The multiple-static-maps strategy juxtaposes two or more maps for a simultaneous visual comparison of time units, whereas the single-dynamic-map strategy either presents maps in a temporal sequence or shows the evolution of a geographic pattern through a temporally sequenced accretion of symbols. In contrast, the multiple-dynamic-maps strategy provides programmed sequences of multiple views or allows the viewer to interact with maps and statistical diagrams representing different instants or periods of time. Electronic graphics systems have added time to the cartographer's list of visual variables. This paper addresses the graphic portrayal of geographic time-series data. It explores a variety of graphic strategies for the simultaneous symbolic representation of time and space, and summarizes these strategies in a conceptual framework of potential use to cartographers, geographers, and graphic designers. These strategies range from statistical diagrams to maps to video animations to interactive graphics systems with which the analyst might freely manipulate time as a variable.

## GRAPHIC REPRESENTATIONS IN TIME-ATTRIBUTE SPACE

Time-series data traditionally have called for statistical diagrams like Figure 1, with time as the horizontal axis and a single variable as the vertical axis (du Toit, Steyn and Stumpf 1986, pp. 265–274). A separate trend line represents each place, and each trend line requires a label identifying the place represented. The label might be a place name, a directional abbreviation such as 'NE', or some other geographic metaphor.

A logarithmic scale for the vertical axis (Figure 2) is a useful modification that allows the slope of the trend line to portray relative rates of change. With an arithmetic scale the slopes portray only absolute change, not the rate of change. With Figure 1 the viewer should not compare slopes, whereas with Figure 2, he may validly interpret a steeper slope as representing a sharper rate of change than a more gentle slope.

The graphic might also focus attention on time periods, as in Figure 3, rather than upon sample points on the temporal continuum. In this case the vertical axis might show absolute change or the rate of change.

When the data include many places, symbols and labels readily overload the time-series graphic (Figure 4). Assigning each place a unique line symbol might alleviate graphic congestion, but as in Figure 5, a wide variety of qualitative line symbols yields a complex key and makes the graph difficult to read. Even when the number of places is not ridiculously large, crisscrossing trend lines are visually complex and require frequent references to a legend.

Various strategies can help the analyst cope with a plethora of places. As in

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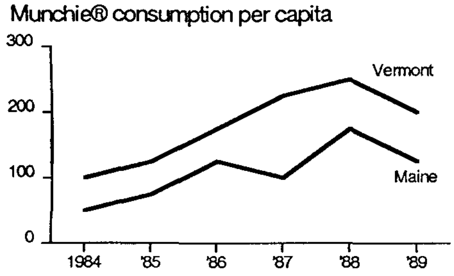


FIGURE 1. *A typical time-series graph, with time scaled along the horizontal axis and the attribute scaled along the vertical axis. Two trend lines, both with a place-name label, illustrate geographic variation in an aspatial context.*

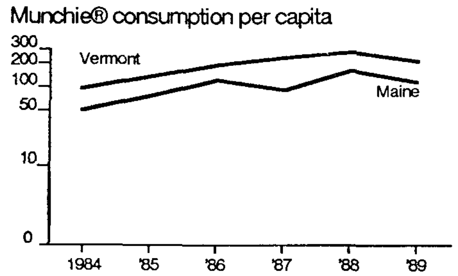


FIGURE 2. *A logarithmic vertical scale replaces the arithmetic vertical scale of the diagram in Figure 1. This adjustment promotes comparison of the rate of change.*

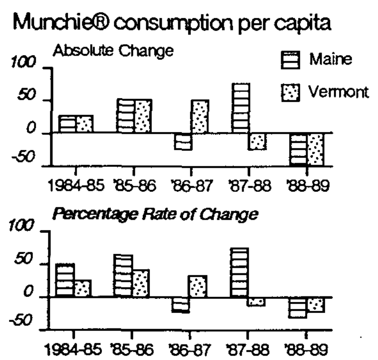


FIGURE 3. *Time-series graphs can use bars, instead of lines, to focus on absolute change for time periods (above) and to focus on the rate of change (below). These graphs are based upon the data for Figures 1 and 2.*

Figure 6, a mean or median might represent all places for each time slice. Adding separate trend lines to show temporal trends for key places, as in Figure 7, can focus the viewer's attention on important departures from the average trend and provide meaningful comparisons for selected places. Figure 8 illustrates how the addition of so-called *error bars*, representing a standard deviation or the interquartile range, can portray variation throughout the region for each time sample as well as temporal trends in regional variation.

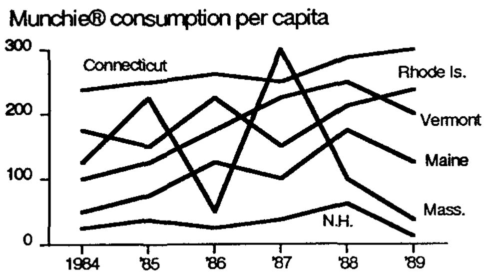


FIGURE 4. *A time-series chart with many trend lines, each labeled with a place name.*

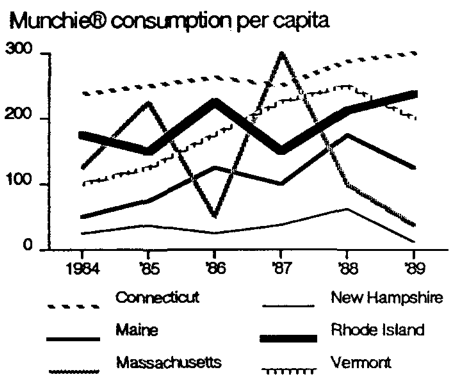


FIGURE 5. *A time-series chart with many trend lines, each with a different patterned symbol.*

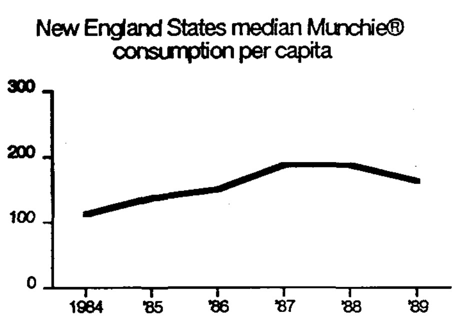


FIGURE 6. *A time-series chart based upon the median value for all places for each recorded instant or period of time.*

## GRAPHIC REPRESENTATIONS IN GEOGRAPHIC SPACE

Thus far, place names and other geographic metaphors have provided the only link with the geographic space, and the phenomena have been univariate, not multivariate. For many applications, though, the analyst must cope with a set of places, each with its own data array (Figure 9), in which the rows, say, represent attributes and the columns represent instants or periods of time. To show relative location, he might also treat these data as sets of maps, perhaps organized as in

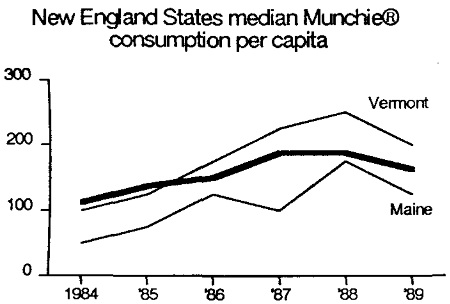


FIGURE 7. *A time-series chart based on median values but including for comparison the trend lines for two significant places.*

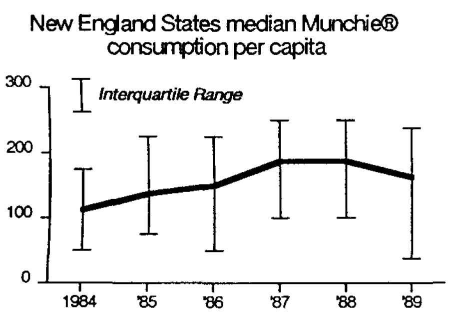


FIGURE 8. *A time-series chart based on median values but including error bars to indicate each value's representativeness.*

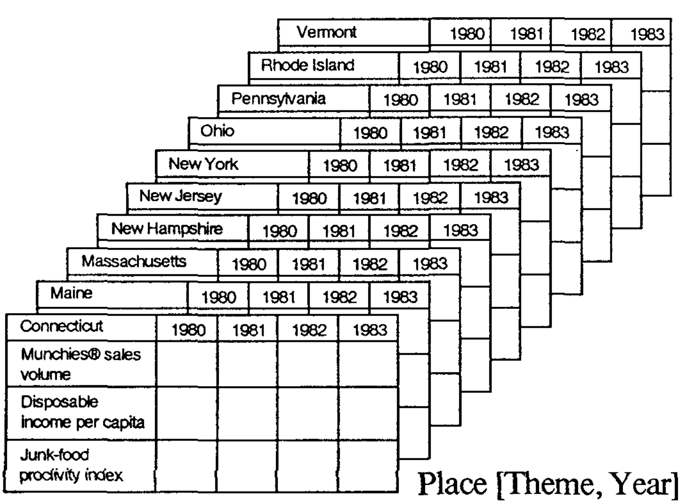


FIGURE 9. *Data arrays, one for each place, with rows representing attributes and columns representing time periods.*

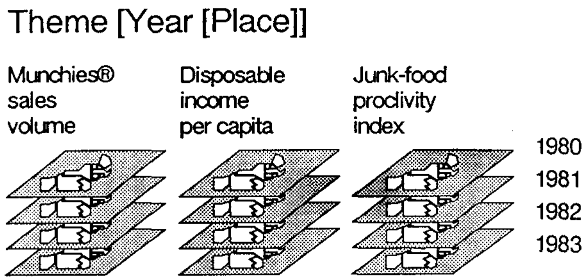


FIGURE 10. *Stacks of maps grouped by attribute and within each attribute, by time.*

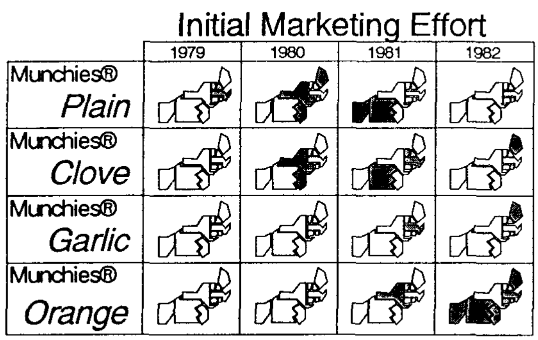


FIGURE 11. *A cartographic cross-classification array, with rows representing attributes and columns representing time units.*

Figure 10, with one set for each attribute subdivided by time sample. Historical atlases based on quantitative data commonly take this form, with each attribute's set of maps arranged on a page or distributed over a sequence of adjacent pages.

If the number of instants of time is small, if the number of attributes also is small, and if the number of places is not too large, then a cartographic cross-classification array (Figure 11) might represent all the data in a single graphic (Monmonier 1979). Additional columns might even be inserted for periods between time samples, or additional rows might portray rates of change. The eye can readily slew from map to map, and the analyst can examine spatial and temporal trends simultaneously and even infer cross-correlation between variables. Yet for most data sets, small display screens or small pages render this approach unsuitable.

For a single variable observed for several instants or periods of time, individual cartographic point symbols, or *glyphs*, might portray a separate, spatially-positioned series for each place. Figure 12 illustrates a few typical temporal glyphs. Although tiny time-series line-graphs might be too visually complex for a map with many places, small clock-face, calendar, or framed time-line symbols could be useful for some applications.

Another strategy is aggregation, perhaps the most severe example of which is the center-of-population map used for decades by the U.S. Bureau of the Census. As Figure 13 shows, for each census year, a single point symbol represents the

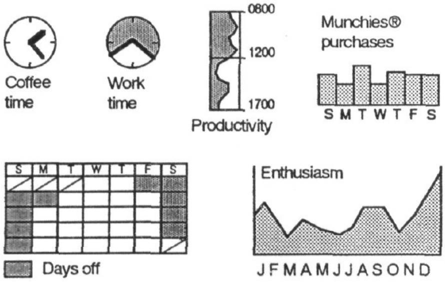


FIGURE 12. *Typical temporal glyphs: the clock face, the calendar, and the framed time-line symbol.*

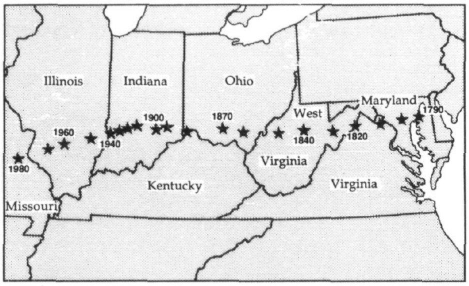


FIGURE 13. *Map similar to the center-of-population map used by the U.S. Bureau of the Census to summarize the general westward shift of the U.S. population since the first census in 1790. [Adapted from 'Statistical Abstract of the United States: 1984,' 104th ed., p. 7]*

center of mass of the national population. By showing these symbols for successive censuses, the map demonstrates most dramatically the westward – and more recently, the southwestward – movement of the nation's population.

Other single-map generalizations include displays based upon single dates for each areal unit. A good example of this strategy is the county-unit map showing census year with peak population. This type of map can shock naive viewers unaware that many counties had more people fifty years ago than they do today.

Another spatial variable well-suited to a single-map portrayal is the time of first settlement. Isochronic lines for a polynomial trend-surface (Chorley and Haggett 1965) provide a concise generaliation of major thrusts in the advance of the settlement frontier, as in Figure 14, a county-level example for New York State. Canonical trend surfaces (Monmonier 1970) might be of use as well, to treat simultaneously the frontiers or innovation waves for several different ethnic groups or ideas.

Flow-linkage diagrams similar to Figure 15 offer a further generalization of advancing settlement. These directed links, which attempt to reveal principal avenues of movement, focus the viewer's attention on corridors and direction, not on the extent of settlement at particular times (Monmonier 1972).

Historical and cultural geographers frequently employ directional symbols to portray change over time. Arrow symbols are particularly useful in showing

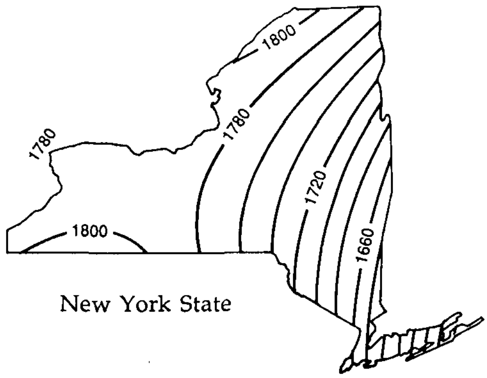


FIGURE 14. *Quadratic polynomial trend surface showing general pattern of the time of first settlement of New York State counties.*

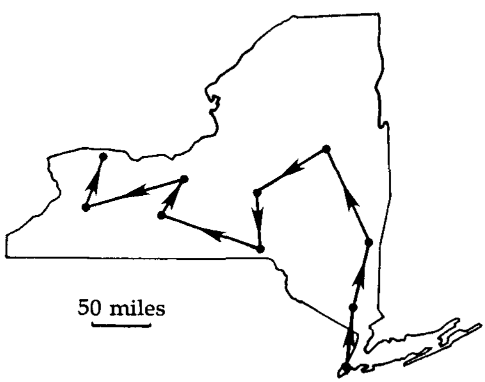


FIGURE 15. *Flow-linkage trend diagram showing general pattern of the time of first settlement of New York State counties.*

migration streams, the spatial diffusion of ideas, the migrations of tribes and refugees, and the advance and retreat of armies. Directional symbols can vary in size to represent relative magnitude, or vary in label, color or pattern to represent a particular group or time period. Edward Tufte (1983, pp. 40–41), in his widely acclaimed essay *The Visual Display of Quantitative Information* lavishly praises Charles Joseph Minard's use of a variable-width flow-line symbol on a map showing the declining size of the Napolean's army in its abortive Moscow campaign of 1812: "It may well be the best statistical graphic ever drawn."

As a cartographic genre, these maps might be termed *dance maps*, after the choreography diagrams (Figure 16) used to teach the spatial mechanics of ballroom dancing to generations of students. These maps cover a period of time marked by several events, each described by map symbols describing a transition from one place to another. Dance maps are one of the three most common spatial-temporal displays.

The second type is the *chess map* (Figure 17), so called because a separate map presents a snapshot for a discrete instant or period of time. Chess maps are

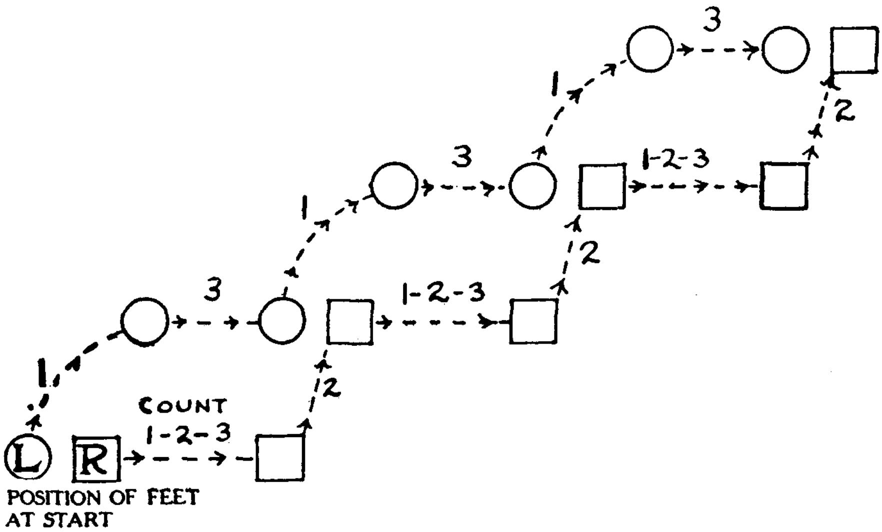


FIGURE 16. *A prototypic dance map showing the woman's steps for the Hesitation Waltz. [Source: Walker, Caroline, 'The Modern Dances: How to Dance Them,' Chicago, Saul Brothers, 1914, p. 46.]*

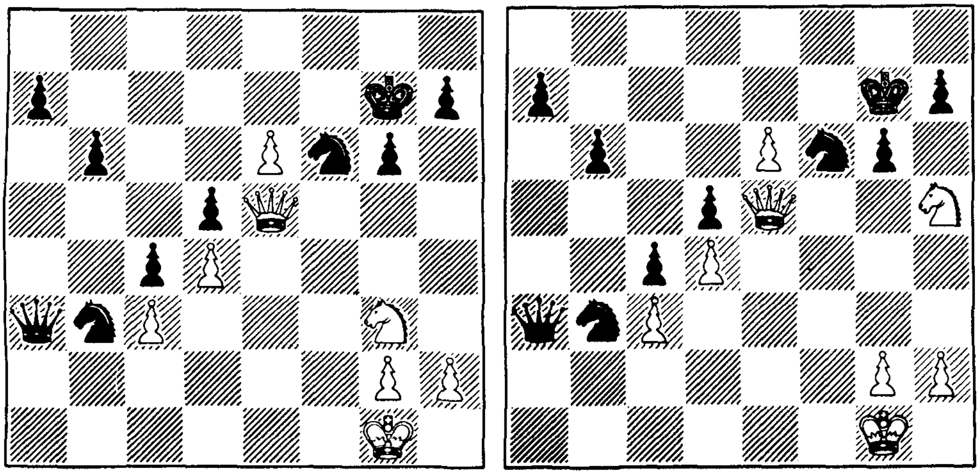

FIGURE 17. *Chess maps are two or more geographic-space displays justaposed so that the viewer can compare spatial patterns for different times.*

juxtaposed so that the user can compare the pattern at time 1 with the pattern at time 2. The visual focus here is on the status of the phenomenon at these particular times, not on change per se. The chess map strategy would include a pair of choropleth maps representing the same population trait for 1980 and 1990, say, or a set of point-symbol maps showing the distribution of military bases for 1945 and 1985.

The third type (Figure 18) is called simply the *change map*. It refers to a single

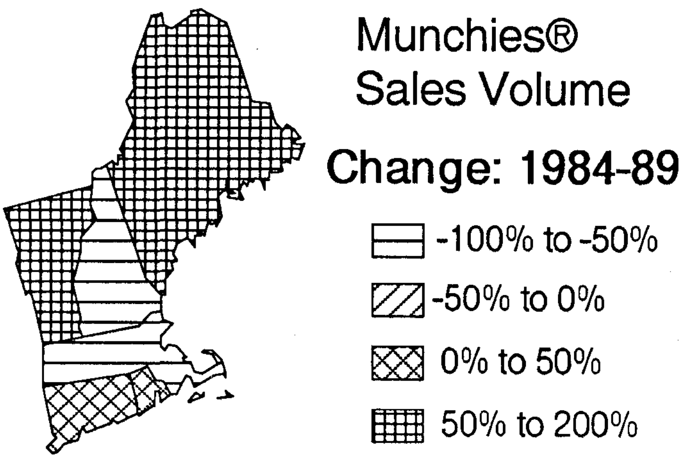


FIGURE 18. *A change map showing rate of change by state.*

map on which symbols vary in value, size, or some other appropriate visual variable to represent the direction, rate, or absolute amount of change.

Multivariate data-compression techniques such as principal components analysis (Johnston 1978, pp. 127–182) or canonical correlation (Davis 1986, pp. 607–615) might prove useful in reducing the number of variables that need to be displayed. As Palm and Caruso (1972) have aptly demonstrated, labeling factors is often problematic, and map titles such as 'Factor 1' or 'Socioeconomic Status' can be confusing. Indeed, multivariate statistical methods are seldom suitable if the audience does not understand the underlying statistical and geometric principles. Yet for the analyst well-grounded in both statistical and graphic analysis, multivariate methods – including classification techniques – can be highly effective for identifying redundant measures and for extracting summary maps from spatial-temporal data.

### HYBRID REPRESENTATIONS WITH SPATIAL AND TIME-ATTRIBUTE AXES

No multivariate analysis should be attempted without a prefatory univariate analysis. Statisticians advocating *exploratory data analysis* call for graphing the frequency distributions of each and every variable. Statistician John Tukey (1977, p. 56) warned that "We have not looked at our results until we have displayed them effectively." When the data are geographic, though, we need to display them in both the attribute space familiar to the statistician (Figure 19, right) and the geographic space that provides the necessary sense of place and relative location (Figure 19, left).

Treating just a single variable measured at two different times calls for an array of graphics (Figure 20) in both attribute space and geographic space. As a minimum, this array would include separate maps portraying the spatial variance at each of the two times, a map of change or the rate of change, three separate univariate histograms or cumulative frequency diagrams showing frequencies for

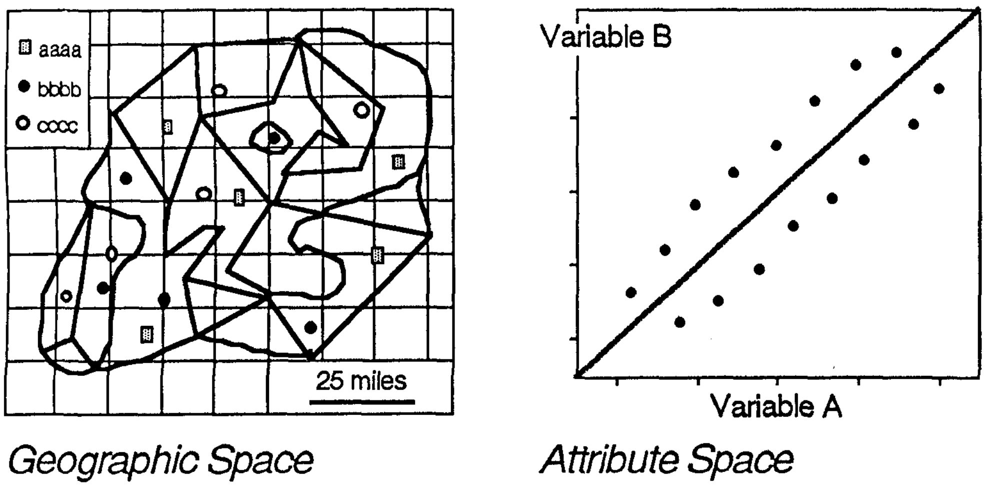


FIGURE 19. *A comparison of attribute space and geographic space.*

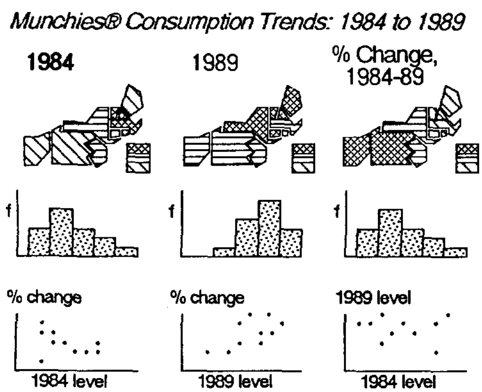


FIGURE 20. *An array of graphics for exploring a single geographic attribute measured at two instants of time.*

each time as well as for change, and three separate scatterplots portraying in attribute space the bivariate relationships between the two sets of values and between each set of values and the rate or amount of change.

If the geographic space can be reduced to a single measure, such as distance from the equator or distance from the center of town, a single hybrid graph might combine elements of both geographic and attribute space. The non-spatial axis might be the rate of change or even time itself. Graphic train schedules can employ this concept to reveal at a glance relative rates of travel between stations and the length of stop-overs at terminals. As Figure 21 describes, each train starts at the top of the graph and moves downward and toward the right. Fast trains have a steep descent, and slow trains a comparatively gentle descent. A horizontal terrace represents layover time at a station. A graph with many trains, some fast and others slow, can show differences throughout the day in frequency, the relative

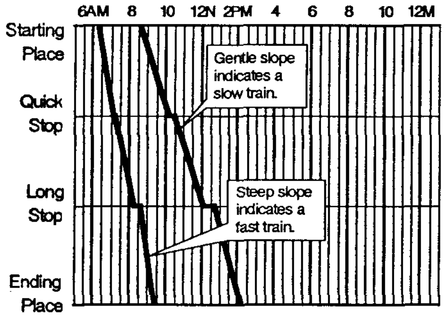


FIGURE 21. *A graphic train schedule, with time scaled horizontally (from left to right) and distance shown vertically (from top to bottom).*

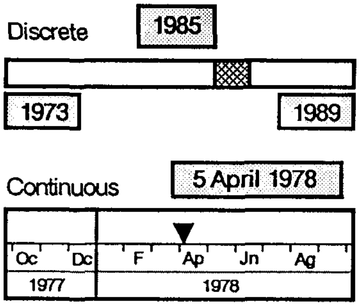


FIGURE 22. *Temporal scroll bars can provide discrete (above) or relatively continuous (below) references to time.*

advantages of express service, and trains that cover only a portion of the route (Tufte 1983, pp. 115–116). For commuter routes with generally frequent service and many stops, a graphic train schedule providing a quick overview of train service might be more useful than a cumbersome numerical schedule consisting of lengthy tables and numerous footnotes.

## TIME AS A VISUAL VARIABLE

Computer graphics can elevate time to its proper place in graphic analysis. Graphics systems can do this in one of two ways. The first strategy is the interactive graphics system that allows the user to manipulate time freely, as with a *temporal scroll bar* (Figure 22), for moving between time periods. The viewer uses a mouse to point to the box in the scroll bar, and to change the time displayed on the map by 'dragging' this box to the left (to select an earlier time) or to the right (to select a later, more recent time). A discrete temporal scroll bar (Figure 22, above) might address time in years or decades, whereas a continuous scroll bar might provide a graphic scale and reference time more precisely, for example, in days, hours, minutes, or even seconds. As Carter (1988) notes, the map viewer often needs to flip back and forth through a sequence of maps, and to move at his or her own pace. The second strategy is *animation graphics*, which provides a temporally-ordered sequence of views so that the map becomes a scale model in both space and time.

Over the past three decades a number of geographic cartographers have addressed the uses of animation techniques for dynamic maps (Berlyant 1988, Moellering 1980, Thrower 1959 and 1961, Tobler 1970), and in the 1980s videotex and microcomputers provided dynamic sequencing for the categories displayed on choropleth maps (Slocum *et al.* 1988, Taylor 1982). Dynamic maps can range in complexity and sophistication from a simple temporal sequence of complete maps, as might be shown in sequence with a single slide projector, to dynamic symbols that move across the map in the manner of video games. Other intriguing animation effects are possible, of course, including dramatic fades or dissolves of multiple views, progressive zooms, and rotating oblique views of statistical surfaces approached gradually, in the manner of an airplane circling an airport. Fading, fuzzy, or blinking symbols might be particularly useful in dealing with data whose accuracy varies over time.

Another form of animation is the meaningful program or succession of views. In the 1970s statisticians addressed the problem of exploring graphically a database with a large number of variables with a technique called *projection pursuit* (Friedman and Tukey 1974, Huber 1985, Tukey and Tukey 1981). Projection pursuit leads the analyst to one or more potentially significant scatterplots by selecting a small number of optimum two-dimensional 'interesting' views chosen for their degree of clustering or 'clottedness.' The *grand tour*, a more recent elaboration of the projection pursuit model, seeks an optimal sequence of such interesting views (Asimov 1985, Buja and Asimov 1986). Both highly promising techniques are still largely experimental and little used.

An obvious extension, of course, is the addition of an optional geographic-space viewport. This approach, called 'atlas touring' and currently under development, integrates maps and statistical graphics through the use of *graphic scripts*, composed using basic sequences called *graphic phrases* (Monmonier 1989b). A graphic phrase for the visual analysis of spatial-temporal data might, for example, partition the screen into four windows and generate an animated sequence of juxtaposed chess maps for pairs of individual years at the top of the display, a change map for the period in question at the lower right, and a time-series statistical diagram for the entire period of analysis at the lower left. Other graphic phrases might explore the spatial trends on a particular map or the spatial correlation among two variables. A map author might use several such graphic phrases to develop a graphic script examining the spatial-temporal trends, geographic trends, and spatial covariation of an electronic atlas in the form of a large spatial-temporal data set. Monitoring the script-writing behavior of map authors should provide data to support the development of a still more advanced system – a system able to generate automatically a meaningful sequence of graphics that serve as a guided tour of an electronic atlas.

These techniques beg the question of how best to define and measure the meaningfulness of a map or scatterplot or the interest it might hold for a viewer. As statisticians associate inherent interest with the clottedness of a point cloud, geographic cartographers might regard as interesting a map that resembles a known set of regions, demonstrates a straightforward spatial trend, or otherwise exhibits a moderate to strong level of spatial autocorrelation, the geographic-space equivalent of clottedness in attribute space. But for some distributions, a

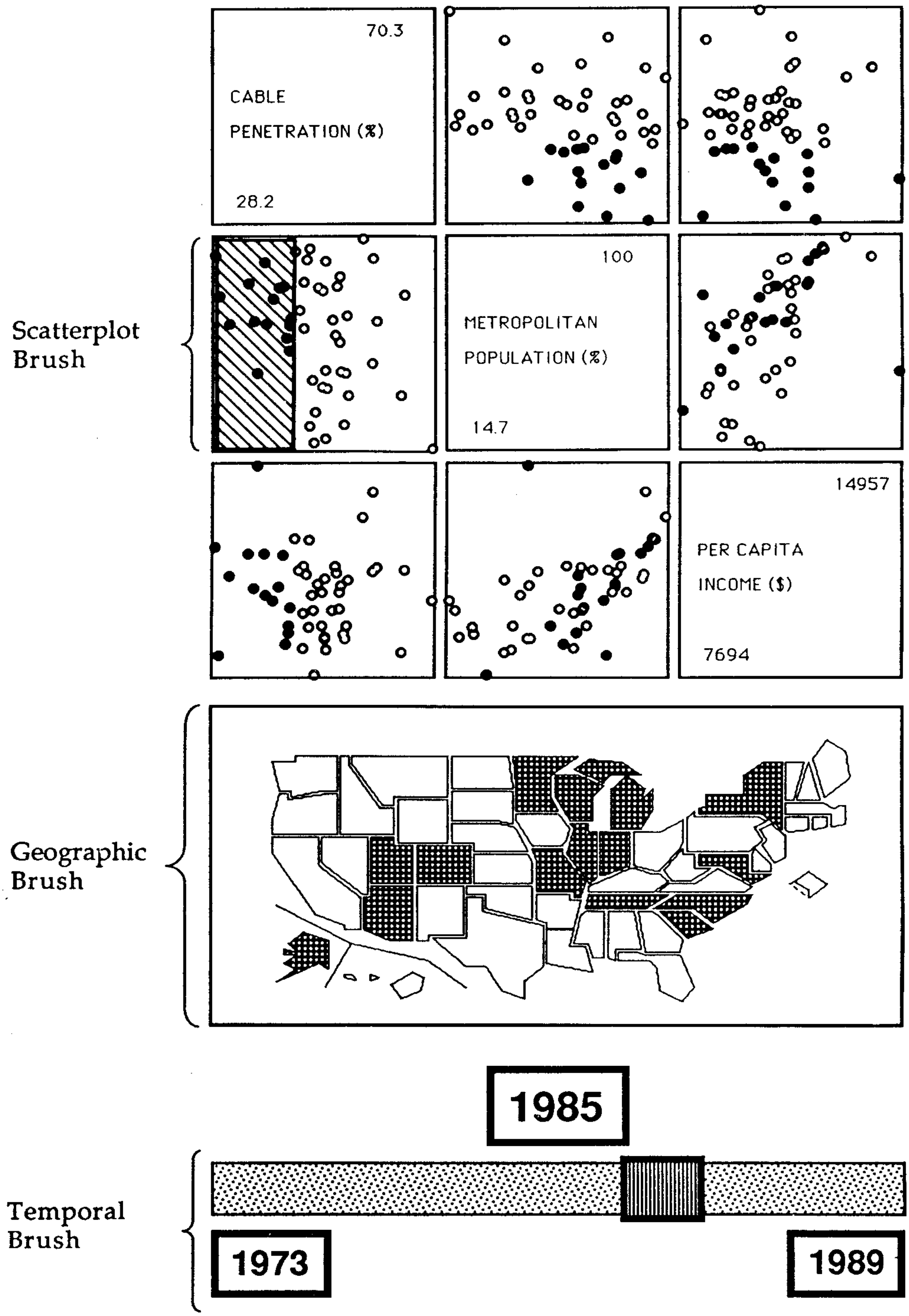


FIGURE 23. *A scatterplot matrix with a scatterplot brush, a geographic brush, and a temporal brush.*

pattern that exhibits no discernable trend or lacks regional homogeneity might be more intriguing and noteworthy than one that meets such expectations.

*High-interaction graphics* avoids this issue by allowing the user to search the data for views he or she finds interesting. High-interaction graphics requires a high-resolution display, a pointing device, a 'friendly' direct-manipulation graphics interface, and a high-speed processor that allows the analyst to interact creatively with the display (Becker, Cleveland and Wilks 1987). The software must be flexible and the response time minimal. Historians and geographers have demonstrated the pedagogic utility of interactive systems tht allow the user to juxtapose maps and frequency diagrams and to classify distributions portrayed on choropleth maps (Miller and Modell 1988).

Interactive systems for studying spatial-temporal data might incorporate *scatterplot brushing* (Figure 23, top) and a modification, the *geographic brush* (Figure 23, center), with which the analyst highlights areas on the map and views them as well on the scatterplot matrix (Monmonier 1989a). The viewer might use a scatterplot brush to select a number of places by enclosing with a variable-size rectangular frame the points that represent them in any of the nine scatterplots; the dots representing these places would be highlighted (darkened in this case) within the rectangular brush on the scatterplot in question and also highlighted in each of the other eight scatterplots as well as on the accompanying map. With a geographic brush, the analyst could select and highlight places by pointing to them on the map, by drawing a polygon around them, or by choosing one or more established regions, such as the Northeast, from a pull-down menu. For spatial-temporal data, addition of a *temporal brush* (Figure 23, bottom) is appropriate as well. The viewer might manipulate the time represented by the display by using the temporal scroll bar to call up the point clouds for some other time unit.

'Atlas touring' and geographic-temporal brushing can be complimentary. Data collected with an interactive system can be helpful in refining or tailoring definitions and measures of interest or meaningfulness. And a programmed series of views, which the analyst can interrupt at will, might serve as a useful introduction to the data – a graphic pump-primer, of sorts, to initiate analysis and encourage the generation and testing of hypotheses.

## CONCLUDING REMARKS

Table 1 is a conceptual framework that summarizes the range of options for the graphic display of quantiative spatial-temporal data. It demonstrates that the principal tools available for the visualization of spatial-temporal data are:

1 multiple views, either in sequence or simultaneously in the same window;
2 time scaling, as well as space scaling;
3 interaction with the data and the display; and
4 integration of maps and time-series graphics.

Cartographic research must turn away from its search for the single optimum map, and begin to deal with sequences of maps and the need to integrate maps

TABLE 1. A CONCEPTUAL FRAMEWORK FOR THE VISUALIZATION OF GEOGRAPHIC TIME-SERIES DATA

*Time-series graphs with place names or other geogrpahic metaphors*

*Single static maps:*
- Temporal symbols
- Temporal aggregation
- Focused measurements (e.g., peak-year maps)
- "Dance Maps" (movement)
- "Change Maps" (rates, absolute change)
- Generalized maps focusing on transition and or diffusion

*Multiple static maps (and graphs)*
- "Chess Maps" (juxtaposition)
- Cartographic cross-classification arrays (with maps and statistical graphics)

*Single dynamic maps*
- Sequenced symbols (accretion)
- Temporal sequences of views
- Symbols suggesting motion (pulsating directional symbols)

*Multiple dynamic maps (and graphs)*
- High-interaction graphic analysis
  - Scatterplot brushing
  - Geographic brushing
  - Temporal brushing
- Programmed sequences of "interesting" or "meaningful" views
  - Authored video animation
  - "Projection Pursuit" (not geographic)
  - "Grand Tour" (not geographic)
  - "Atlas Touring" (geographic)

with statistical diagrams and text blocks containing definitions and other relevant information.

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**RÉSUMÉ** Les stratégies pour l'affichage visuel et l'analyse de données géographiques reliées au temps peuvent être spatiales ou non, à vues simples ou multiples, statiques ou dynamiques. Ainsi, des étiquettes pour le nom de places ou d'autres métaphores géographiques peuvent décrire des symboles sur des cartes non-spatiales reliées au temps. Les stratégies de carte unique et statique incorporent la dimension temporelle par des techniques allant de symboles ponctuels complexes, ou glyphes temporels, à des cartes de surfaces de tendance généralisées ou de lien de flux se concentrant sur le mouvement. La stratégie de cartes statiques et multiples juxtapose des cartes, deux ou plus, en vue d'une comparaison visuelle simultanée d'unités de temps, alors que la stratégie de carte dynamique et unique présente soit des cartes en une séquence temporelle, soit encore l'évolution d'un modèle géographique par un accroissement séquentiel de symboles dans le temps. Quant à elle, la stratégie de cartes dynamiques et multiples fournit des séquences programmées de vues multiples ou permet à l'usager d'interagir avec cartes et diagrammes statistiques représentant différents instants ou périodes de temps. Les systèmes graphiques électroniques ont ainsi ajouté le temps à la liste des variables visuelles du cartographe.

ZUSAMMENFASSUNG Verfahren für die optische Anziege und Analyse von geographischen Zeitreihendaten können räumlich oder nicht-räumlich, statisch oder dynamisch, mit Einzel- oder Mehrfachsicht sein. Etikette für Ortsnamen oder andere geographische Metaphern können Symbole auf nichträumlichen Zeitreihendarstellungen bezeichnen. 'Einzel-Statisch-Karten'-Verfahren vereinigen die Zeitdimension mittels komplexer Punktzeichen (Zeitglyphen) bis hin zu generalisierten Trendflächen- oder Fließkopplungskarten, die sich auf Bewegungsfolge konzentrieren. 'Mehrfach-Statisch-Karten'-Verfahren stellen zwei oder mehrere Karten nebeneinander zwecks simultanem optischen Vergleich von Zeiteinheiten, während das 'Einzel-Dynamisch-Karten'-Verfahren entweder Karten in zeitlicher Folge darstellt oder die Entwicklung eines geographischen Musters durch zeitlich aufeinander-folgenden Zuwachs von Zeichen. Im Gegensatz dazu liefern die 'Mehrafach-Dynamisch-Karten'-Verfahren programmierte Folger von multiplen Sichten, oder sie gestatten dem Betrachter, sich mit Karten und statistischen Diagrammen zu befassen, die verschiedene Zeitpunkte oder Zeitperioden darstellen. Die elektronischen graphischen Systeme haben zur Reihe von optischen Variablen für Kartographen die Zeit hinzugefügt.

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