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Designing linked micromap plots for states with many counties

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SUMMARY

This paper describes the design of linked micromap plots for showing county estimates on a state by state basis. The linked micromap template was specifically developed to represent spatially indexed statistical summaries. Each plot shows regional names, spatial patterns and statistical patterns while linking them all together. Thus the design is useful for communicating summaries from a host of health and environmental studies. The specific design challenge in this paper is to create one-page plots for the states with 60 to 120 counties. While the county names and micromaps take up substantial space, the three examples demonstrate that there is sufficient space to represent two variables. The basic design has the potential for showing more. Consequently the new designs are suitable for presenting sophisticated summaries. Copyright © 2001 John Wiley & Sons, Ltd.

1. INTRODUCTION

This paper describes one-page designs that extend linked micromap (LM) plots to the display of states with many counties. Previous LM plot designs [1–4] were relevant to states with fewer than 60 counties. The current extensions are relevant to the remaining states except for the three with more than 120 counties: Virginia, Georgia, and Texas. The examples in this paper show Iowa, a relatively square state with 99 counties, and Tennessee, with a thin parallelogram shape and 95 counties.

The LM plot design provides both a graphical overview and details for spatially indexed statistical summaries [1]. The LM template shows spatial patterns and statistical patterns while linking regional names to their locations on a map and to the estimates represented in statistical panels. In general the LM template allows the display of confidence bounds for estimates and inclusion of more than one variable (see Carr *et al.* [1]). Thus the LM plots provide a powerful template for communicating spatially indexed statistical summaries.

LM plots follow a recently developed template [1–4]. Since LM plots are new, it is helpful for the reader to glance at the figures before reading further. Although some appreciation

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of design considerations and construction details may be required while reading Section 2, the basic notion of juxtaposing small maps, regional names and statistical panels is quite simple.

The use of statistical panels in LM plots reflects a greater emphasis on the statistical estimates than common mapping of statistical estimates. The standard encoding used in the LM statistical panels represents estimates using position along a scale. This has high perceptual accuracy of extraction [5]. Common mapping procedures for statistical estimates use position along a scale to encode political boundaries that may be shown in great detail. The encoding of the statistical estimates is a secondary task. An extreme case is the commonly used classed choropleth map. The process of encoding statistical estimates degrades continuous estimates into primitive class membership and then represents the ordered result using colour. Colour provides a poor encoding for representing ordinal variables [5]. Thus LM plots provide a much better encoding for statistical estimates.

The LM template also extends to the display of multiple attributes. The first published example [2] shows bivariate data and confidence bounds for one of the two variables. Subsequent examples have shown time series, box plots and bivariate box plots [1, 3, 4]. One example [4] represented 159 variables per region using line segment heights (see also Carr and Olsen [6]). However, the previous designs dealt with a modest number of regions. When the number of regions is much beyond 50, easy readability of regional names motivates the use of two columns of names. This takes up precious space and less is available for the statistical panels. While examples in this paper are limited to bivariate data, the designs have enough space to use some previously developed encodings for distributional summaries and multivariate data.

Composite views of spatial and multivariate statistical patterns provide a rich medium for telling data summarizing stories. The patterns and anomalies from the patterns can also raise questions. LM plots are useful for hypothesis generation. The spatial patterns may beg explanation. Maps provide a link to peoples' knowledge about regions obtained through personal experience and scholarship, and lead to speculation about explanatory factors not previously considered. Thus LM plots can provide more than just a summary.

The LM design builds on a foundation established by others. Monmonier [7] promoted juxtaposing maps and statistical panels. Tufte [8–10] advocated the use of small multiples and parallelism. The work of Cleveland and McGill [5] in perceptual accuracy of extract and their promotion of dot plots helped to shape the LM plot design. The LM template also makes extensive use of perceptual grouping. While the origins of this go back to early psychological literature, the specific inspiration came from Kosslyn [11].

The focus of this paper is on the design and production of LM plots for states with many counties. The examples primarily serve to illustrate different designs and to call attention to useful web sites. The characteristic design feature for LM plots in this paper is two columns of regional names. Plate 1 extends an example from Symanzik *et al.* [12] that uses the familiar two-column page layout. This provides a convenient starting example for the description of LM plots in Section 2. The split page layout with micromaps on both the left and right halves leaves little room for statistical panels. Section 3 addresses the design task of making more space available for the statistical panels. Section 4 describes access to boundary files and scripts used in producing the examples in this paper. Section 5 closes with brief comments on usability assessment, template improvements and interactive extensions.

2. THE STRUCTURE OF LM PLOTS

LM plots have three basic elements: micromaps; regional labels, and statistical panels. As an example, in Plate 1, the micromaps are small maps of Iowa counties and the statistical panels are dot plots [5, 13, 14]. In general micromaps can take many forms, such as diagrams or networks. Typically micromaps are map caricatures that enlarge smallest regions to facilitate colour identification and that simplify regional boundaries while retaining salient regional features. As indicated earlier, the statistical panels may take many forms, such as dot plots, bar plots, and line plots. Variations on these three basic elements make the LM template relevant to a host of applications.

Beyond the three basic elements, the characteristic features of LM plots include sorting of regions, perceptual grouping of regions, and linking of regions to labels and estimates. In Plate 1 the regions are sorted in ascending order (bottom left to top right) by the values of the 1950–1969 mortality rates. Plate 1 illustrates a two-column layout that was the first variation tried when addressing the task of presenting data for more than 50 regions.

Perceptual grouping helps the reader to focus attention on small subsets of the regions. Ideally the subsets should have four or fewer regions [11] but groups of five or six are manageable. The grouping of many regions creates many small groups. The grouping of groups then provides a framework for intermediate levels of comparison and hierarchical access to detailed comparisons. The two-column layout provides an obvious mechanism for the top level of perceptual grouping. Plate 1 places the counties with smaller values on the left side of the page. The second level of perceptual grouping divides the counties into quartiles. Thus each county is easily described as being in a specific half or specific quarter of the counties. The third level of perceptual grouping divides counties within each quartile into panels with around five counties per panel. This last level of grouping enables the use of cyclic colours as a link between corresponding micromap panels, name panels and statistical panels.

The colouring scheme for micromaps serves multiple objectives. These objectives are not transparent to all readers upon first encounter. However, a brief explanation usually suffices. One objective is to allow patterns to emerge (when present) based on regions with similar values. The colouring scheme uses light yellow to call attention to the regions in each quartile. This provides the rough equivalent of a four-class choropleth map and enables ready identification of corresponding spatial patterns. A typical classed choropleth map will have five or six classes and combines the information in a single display. Consequently the classed choropleth maps provide a quicker overview with more spatial contours than revealed by the light yellow in LM plots. However, the additional highlighting in LM plots and the sequence of 20 micromaps provide much more spatial detail than typical classed choropleth maps, even if the visual assessment process is not as fast.

The second colour scheme objective is to sequentially highlight the sorted counties and to link the counties with their names and estimates. A few familiar saturated hues serve as links to corresponding elements in the horizontally associated micromap panel, name panel and statistical panel. Typically the hues appear in a spectral order to provide a familiar ordering (see Brewer [15] for studies of spectral ordering). The grouping of counties into micromap panels allows reuse of the same linking hues in moving from micromap to micromap. Thus a few familiar hues serve as links for a large number of counties. While limiting the number of colours on a page is advantageous, the horizontal linking scheme has one drawback. When readers initially study the vertical sequence of micromaps, they may think there is something in common for counties with the same hue. The only thing in common is the rank order within the different groups. However, the full sequence of micromaps is interpretable once the reader starts paying attention to the shifting locations of the saturated hues.

The third objective of the colour scheme is to facilitate rapid location of a particular county. Locating where a county is highlighted in a LM plot is much faster than a tedious serial search. Light grey is common for all counties not in a quartile. If the particular county appears grey for any panel of a quartile, then that county is not highlighted in the quartile. Thus it suffices to scan the top panel of each quartile. If the county appears as light yellow in a panel then it is in the quartile and a quick scan of panels in the quartile will reveal its location. If the county appears in a highlight hue, it has been found.

Readers can quickly find county locations in LM plots when the names are in alphabetical order. Finding a name in a sorted list is a fast operation. From there the colour link to the county location is immediate. Thus LM plots without the statistical panels can serve as a rapid look-up device for regions in an educational setting.

Plate 1 shows two variables and is a more interesting design than the single variable dot shown in Symanzik *et al.* [12]. The dots represent the age-adjusted mortality rates for cervical cancer for the period 1950–1969 and the arrow tip shows the rate for 1970–1994. The data source is a new National Cancer Institute web site (www.nci.nih.gov/atlas/mortality/index.html, January 2000). Representing a second variable takes little additional space when the variables have the same units. Subsequent examples involve variables with different units and require the use of a second axis.

Most counties in Plate 1 show a clear decrease in mortality rates and the two notable exceptions draw immediate interest. Thinking about the figure leads towards designs that show mortality rates as time series for smaller time intervals and towards designs that relate the mortality rates to other variables. Plate 3 provides a simple example relating mortality rates to per capita income. More complicated designs are beyond the scope of this paper.

There are stories behind the cervix cancer mortality data. The positive story is that the development and use of the pap test has had a tremendous impact on early detection and the reduction of mortality. Other stories concern regions of the nation where the rates were slow to decline. Access to medical care is an obvious factor. Some explanations, such as tests being withheld from the poor because of the potential cost of treatment, cannot be confirmed by simple graphics.

3. ALTERNATIVE ONE-PAGE DESIGNS FOR STATES WITH MANY COUNTIES

This section illustrates two one-page designs that provide alternatives to the two-column layout in Plate 1. The particular goal is to represent two variables using a scatter plot as the statistical panel. Both of the new designs retain the Plate 1 feature of using two columns for the county labels. However, the new designs get by with one column of micromaps. This makes additional space available for the statistical panels.

Plate 2 shows an early attempt to use scatter plot panels. The plate, with complex linking and overplotted points, illustrates the design challenge and motivates the compromises reached in Plate 3.

As shown in Plate 2, the shape of Tennessee allows the display of 16 micromaps in one column on a single page. Since Tennessee has 95 counties, highlighting six counties per micromap accommodates all the counties in the usual LM plot fashion. While colour discrimination is more complicated with six colours than five, six is still within the generally accepted bounds for map design. In Plate 2, colour (and not the symbol shape) links the county names to the county polygons in the corresponding micromap.

The ordering of county names within two columns must change to accommodate the single column of micromaps. In Plate 2 the ordering for names is from left to right and then from top to bottom. The design for Plates 2 and 3 aligns the county names in the two columns. In Plate 3 the names could be staggered to match the 10 vertical plotting positions for the dots in the dot plots. However, staggering the names makes the plot appear more complicated.

The key challenge in using scatter plot panels is to have enough height to provide good resolution for the variable represented on the y-axis. Each scatter plot in Plate 2 obtains its height by using the composite height of four micromaps.

The scatter plot height in Plate 2 spans 24 county names. This complicates the task of linking names to highlighted points in the scatter plot. The linking in Plate 2 uses the combination of four symbols and six colours to provide 24 unique links. The white background dots provide a scatter plot of all counties. The colour and shape linking symbols overplot the dots when highlighting the counties in a particular quartile.

The symbol choice might be refined for Plate 2. Open symbols, while not carrying colour as well as filled symbols, can cause less overplotting problems. Symbols such as '$+$' and '$\circ$' have easily discriminated features and hold up well in an overplotting context. However, it is not immediately obvious what combination works best for four shapes and six colours. Plate 2 suffices to draw attention to the two basic design issues. The first is that obtaining space for the y-axis conflicts with keeping a simple linking scheme. The second is that while sorting counties by one of the scatter plot variables brings out spatial patterns in the micromaps, it conflicts with the goal of minimal overplotting in the scatter plots.

One alternative design (shown on my web site, www.galaxy.gmu.edu/~dcarr/index.html, January 2000) orders counties by the values represented on the y-axis. This is a self-consistent design in that the counties highlighted at the top of the LM plots are highlighted at the top of the scatter plot. Similarly, counties highlighted at the bottom of the LM plot are highlighted at the bottom of the corresponding scatter plot. However, this approach only helps a little in terms of overplotting. The most suggestive scatter plots show a strong functional relationship between the two variables. When there is a strong functional relationship, especially a monotonic relationship, the overplotting tends to be problematic no matter which variable is selected for sorting. The overplotting tends to be modest when the scatter plot shows little relationship between the variables. While null patterns can be informative, the plots do not usually make it to publication.

A substantially different design, also available on the same web site, controls overplotting by systematic sampling. The design highlights every fourth point along the x-axis in a particular quarter section of the LM plot. For example the plot highlights the first, fifth, ninth, etc. points in the bottom quarter panel. The remainder, after dividing the county ranks by four, partitions the counties into four groups. Counties with a remainder of 1 appear highlighted in the bottom quarter of the page and appear in rank order. Similarly, the next to the bottom panel highlights counties with a remainder of 2. The third panel highlights counties with remainder 3 and the top panel highlights counties with a remainder 0. Overplotting remains only for those situations where more than four points are closely located on the x-axis and have similar y-values.

The colour scheme for the systematic sampling design uses class intervals for the county ranks based on the x-axis variable. The 16 counties with smallest estimates are violet and the 16 counties with the highest estimates are red. The merit of this class interval colour scheme is that the highlighting colours in the micromaps indicate class in membership. Thus the collection of micromaps serves as a classed choropleth map. However, the linking is still complicated. In each quarter of the LM plots there are four counties shown in red, four in orange and so on. The design requires four symbols to discriminate among the four counties with the same colour within the same quarter of the LM plots. Further, the four separate scatter plots with systematic sample highlighting provide neither local focus nor an ideal overview. Thus the sequential sampling designs do not meet all the design objectives.

All three variations of LM scatter plots discussed above have drawbacks. A fourth variation in Carr *et al.* [1] utilizes multiple columns of scatter plots. This, however, is not compatible with a large number of counties and a one-page constraint. These drawbacks motivate the compromises reached in Plate 3.

Plate 3 illustrates additional data, so a brief comment on the Plate 2 data is appropriate before continuing. Both variables in Plate 2 are from an interesting web site (web.utk.edu/~chrg/hit/main/index.html, January 2000) that distributes Tennessee health data. The motivation for putting the two variables together in a scatter plot was a conjecture that the same societal conditions that lead to births for very young women may also be associated with higher mortality rates per 1000 births of all women. Plate 2 shows that the variables are only mildly associated. In Plate 2 neither variable is considered an independent variable. Plate 3 provides an example that treats one variable, per capita income, as an independent variable.

Plate 3 shows per capita income and age-adjusted cervical cancer mortality as two juxtaposed dot plots. Since the counties are sorted by income, the full column of dots representing cervix cancer mortality can be viewed as a modified scatter plot that has been rotated 90 degrees clockwise. Before this rotation the (x, y) pairs were (income rank, mortality rate). The scatter plot modification consists of plotting the income rank rather than the income. Note that the per capita income dot plot provides the actual income values and shows the spacings between adjacent incomes.

The scatter plot has two enhancements. The first is addition of a loess curve [9] that is shown as a black line. Adding such a curve is appropriate when the mortality rates are thought to be a function of per capita income. The second enhancement is the explicit display of residuals from the curve. The line segments between the points and the curve explicitly show the residual magnitudes.

The goal of simpler appearance promotes the use of fewer micromaps than in Plate 2. The design of Plate 3 illustrates the use of 10 micromaps rather than the 16 in Plate 2. Note that with roughly 100 counties and 10 counties per micromap an approximate description refers to the counties as belonging to a particular decile. Thus the 10 counties at the top of Plate 3 are in the top decile for per capita income. Plate 3 also simplifies the light yellow encoding. It highlights counties as being either above or below the median county per capita income.

Decreasing the number of micromaps allows a corresponding increase in the vertical size of each micromap. The larger micromaps appear closer to the reader and facilitate colour recognition for small counties. A first thought might be to also increase the width of the micromaps in order to preserve the general shape of the state. However, micromaps are caricatures that serve the LM plot as a whole and the width can be adjusted to objectives such as to reserve space for statistical panels. There is no requirement that the micromaps retain a particular aspect ratio or conform to a particular map projection. The key micromap requirements are ready recognition of counties and a collective shape that is not too distressing.

The number of linking symbols required for LM plots depends upon the number of counties highlighted per panel. Plate 3 calls for 10 linking symbols. Map design guidance limits the number of linking hues to six or fewer [16]. Consequently Plate 3 introduces a nested colour-linking scheme. For each group of 10 counties there are two dots for each of five hues (red, orange, green, green-blue and violet). A small overplotted black or white dot discriminates between the two counties with the same hue. This discrimination scheme uses only five hues (not counting black and white) and only one symbol shape in the statistical panels.

There are some drawbacks to the linking scheme. The nested approach involves a second stage of discrimination. In common applications, lightness of the hues is not finely controlled. Thus black and white dots will not be equally salient against the same hue. For example, a black dot on a dark blue background is hard to see while a white dot is obvious. Any uncertainty may foster checking the other region of the same hue just to make sure which region is which. This slows the processing of information. In general, nested linking is not as fast as simple colour linking. Another drawback is that some readers may wonder if the little dots on the maps refer to cities. Despite these drawbacks, designers may be hard pressed to develop a more effective alternative for 10 linking symbols for readers with full colour vision.

In terms of the variables, the cervix cancer mortality data used in Plate 3 is from a convenient source (www.nci.nih.gov/atlas/mortality/index.html, January 2000). The decrease in mortality rates for counties across the nation is a testimony to the power of early detection and medical treatment. An examination of yearly mortality rates is distressing from the viewpoint that the rates in some counties were so slow to decline. The connections between mortality rates and health service access and between access and income motivated obtaining per capita income [17] for Plate 3.

More focused data could provide a stronger picture than shown in Plate 3. The time period for the mortality rates is large and reflects a composite of changing yearly rates. While the county per capita income rankings are fairly stable over the time, there are some notable exceptions. The selection of 1985 as being representative of the long time period is an arguable choice. Looking at smaller time intervals could help. Also per capita income refers to the whole population. Specific data on white female per capita income is desirable but not available for 1985. Since the data for Plate 3 is not optimal for showing the conjectured relationship, the figure serves primarily to illustrate the design.

Despite the data limitations, Plate 3 reveals spatial and statistical patterns. The light yellow in the micromaps calls quick attention to regions of adjacent counties with above (and below) 1985 median per capita income. At a glance one can also find the counties in the top and bottom deciles. The right column of dot plots reveals substantial variability in mortality rates. However, the curve is strongly suggestive. The curve begins to bend toward higher rates around Jackson County in the third panel from the bottom. The corresponding per capita income is close to $7000 and drops below this as the smoothed mortality rates increase. Low income is a surrogate for limited education and the lack of access to the health care. Low income may also be a surrogate for other variables such as increased risk life styles. In Plate 3 patterns are evident despite the variability and other limitations of the data.

4. PLOT CONSTRUCTION RESOURCES

The plots in this paper were produced using S-plus [18]. The S-plus scripts for these plots are available (at www.galaxy.gmu.edu/∼dcarr/index.html, January 2000). This site includes LM plot scripts for an increasing number of states as well as LM plots for other geographic regions such as ecoregions and Organization of Economic Cooperation and Development nations. The collection of graph designs includes a set of instructive experiments including graphics described but not shown in this paper.

The simplified county boundaries are a key part of the state LM plots. The above web site provides access to S-plus objects that include the county boundaries, names and state outlines. The boundary files are also directly available as American Standards and Code II files for those who might want to use them in other software.

This paper develops layouts that build upon the simplified county boundaries that were developed from previous research [12]. That research developed interactive tables and LM plot methodology for estimates of concentrations for each of 480 hazardous air pollutants at state, county, and census tracts levels (www.epa.gov/CumulativeExposure). The completed interactive methodology has potential use in many applications, and the development of LM plot methodology is in progress.

5. IMPROVEMENTS AND INTERACTIVE EXTENSIONS

As graphics capabilities evolve, there will be a movement away from generic graphics to data set specific graphics [19]. The task of developing templates for the counties of each state must take into account the shape of the state, then the number of counties and the relative size of the counties. This laborious process is still in progress. Fortunately, once a design is developed it can be used repeatedly.

Even the best graphs are subject to improvement. The LM plots proposed in this paper are subject to improvement and usability tests will help. The results of comparative testing often depend on the task selection. Other graphics serve some tasks better than LM plots. For example choropleth maps provide quick overviews and make it easy to compare a region's coarsely represented estimates to those of its immediate neighbours. On the other hand, LM plots can answer questions that are difficult or impossible to answer with competing graphics. For example, classed choropleth maps contain no information about the ranking of counties that appear in the same class interval. Another comparative criterion is the breadth of applicability. Statistical panels can show counts, distributional summaries and time series. Classed choropleth maps are used for showing ratio estimates and not counts [20]. They were not designed for showing distributional summaries or time series. Such comparative considerations apply to other representations of statistical summaries including tables. While subject to improvement, LM plots provide a valuable addition to the designs for representing spatially indexed statistical summaries.

The primary competition to LM plots will likely come through the world of interactive mapping [21–27]. 'Mousing' on maps can reveal values of a region and link to additional information. Interactive class boundary selection allows flexible exploration of spatial patterns in classed choropleth maps. Pan and zoom with progressive disclosure can provide both overview and access to detail. LM plots also become more powerful in interactive in contexts, with pan and zoom, drag and drop panels, variable selection and sorting control. The emerging designs offer many possibilities.

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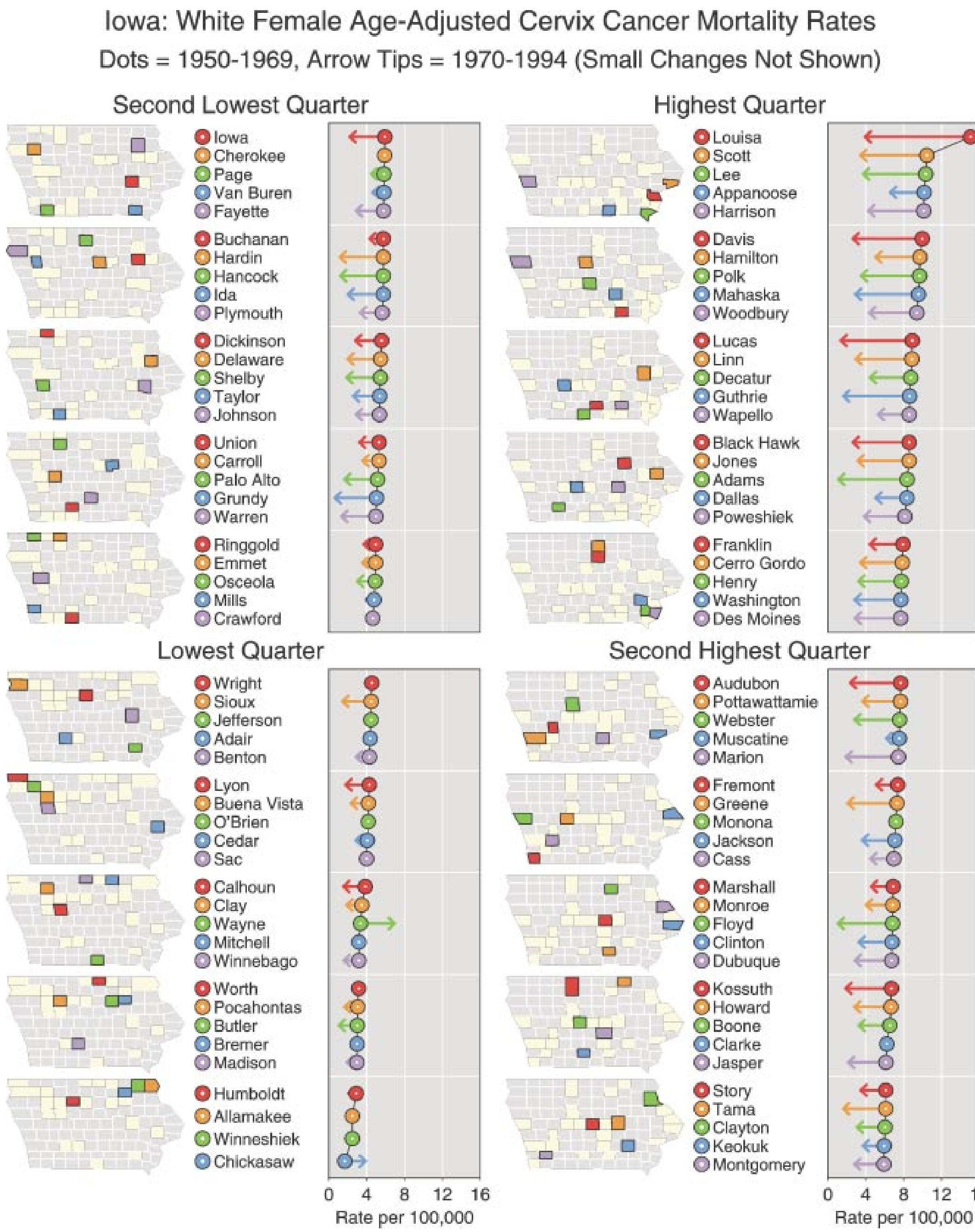

Plate 1. A split page LM design for Iowa counties. The light yellow in the maps and perceptual grouping emphasizes quartiles. The dot plots panels show the mortality rates for two time periods and the change in rates.

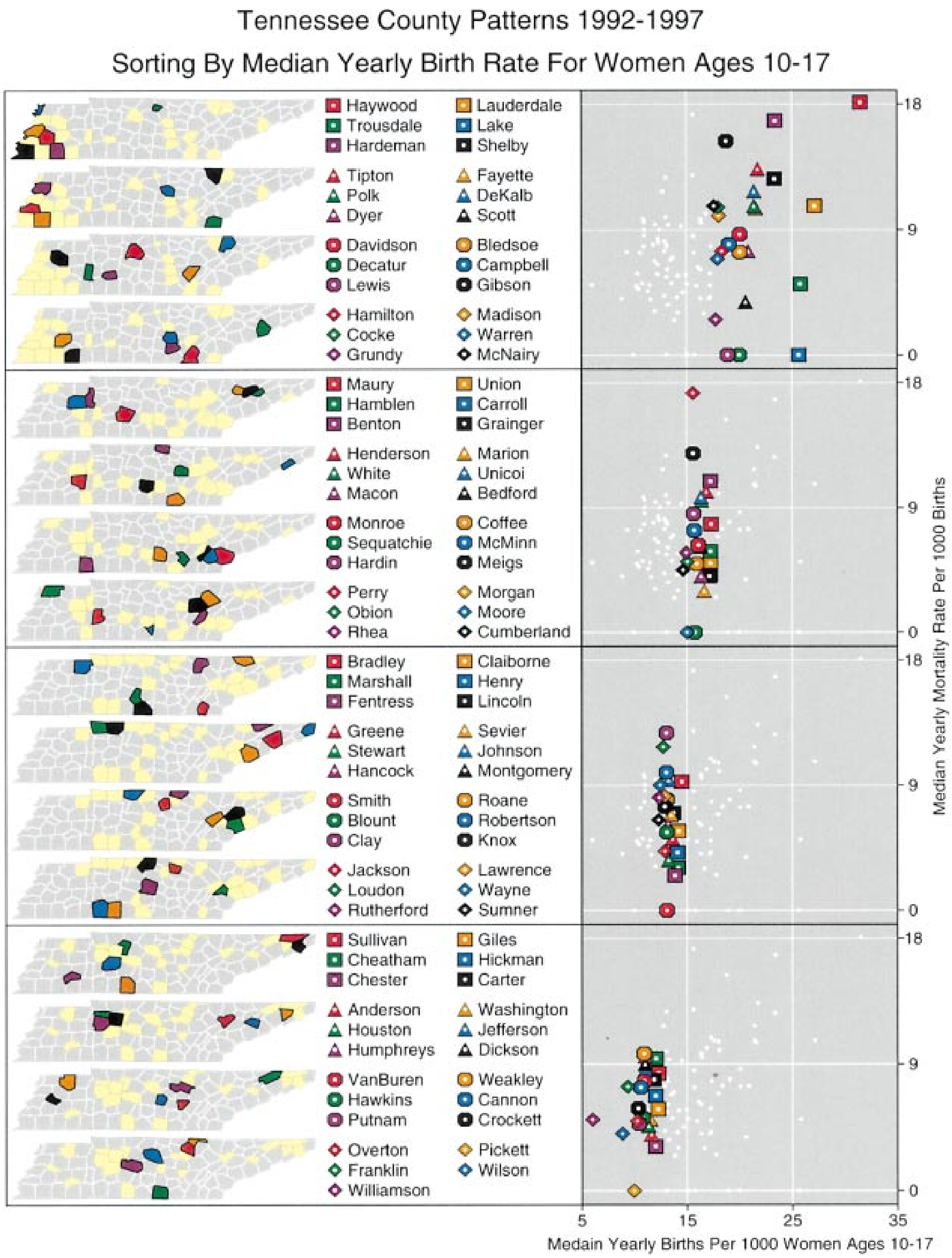

Plate 2. An LM design for Tennessee counties. The design features a single column of micromaps. The light yellow in the maps and the perceptual grouping emphasizes quartiles. The statistical panels are scatter plots. The complete labelling of scatter plot points utilizes complex linking that involves simple shape and hue.

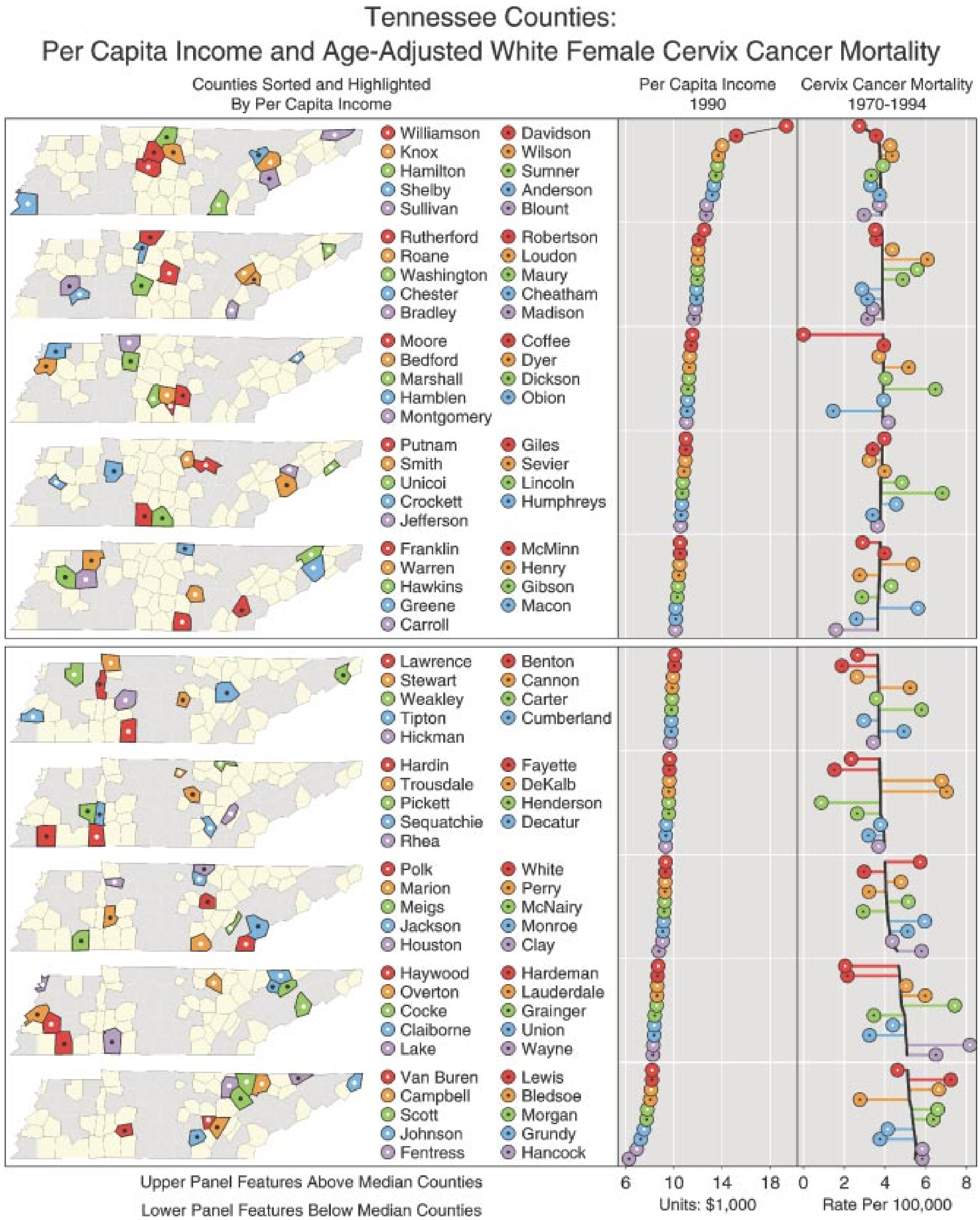

Plate 3. An LM design for Tennessee counties with tall micromaps. The design features a single column of micromaps. The light yellow highlights counties above and below the median. The perceptual grouping subdivides each half into five parts to emphasize approximate deciles. The juxtaposed dot plot columns show two variables. The mortality rate dot plot shows estimates, smoothed estimates using per capita income as the independent variable and explicit residuals. Nested colour linking connects names with regions and estimates.

