Comment

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In the course of studying representations for many-dimensional data, I have found only a small handful of good, original ideas. I think Beat Kleiner and John Hartigan have introduced another one of them in their paper. On closer inspection, though, I find that their method really comprises two separate ideas—one somewhat better than the other. The paper does not make this distinction, but, by doing so, I will show it is possible to isolate the better idea and use it by itself to good effect.

There are two steps one must go through to construct a two-dimensional graphical display for multidimensional data points: first, one must choose a two-dimensional graphical symbol; and then one must assign the coordinates of the multidimensional data to the parameters that describe the construction of that symbol. Kleiner and Hartigan's method can be decomposed into a way to perform each of these two steps: for the first, they choose trees or castles as the display; for the second, they assign the data coordinates to the tree or castle construction parameters in a way designed to depict an hierarchical organization obtained from clustering the coordinates.

I find their solution to the second problem—the clustering—to be a valuable contribution; but the tree and castle displays are not always a good choice for solving the first problem.

First, the good news: Kleiner and Hartigan's idea of clustering the data coordinates in order to decide how best to assign them to display parameters can be applied to a variety of other graphical displays, many of which have perceptual advantages that trees and castles lack. Such display methods do not normally address the problem of assigning coordinates, and this has been a deficiency of many such methods. Clustering provides a good solution that can be used to improve the methods.[1] Figures 1, 2, and 3 show how one might do this for several multidimensional displays: bar charts, profiles, and a new variant, inward-pointing glyphs, respectively. The figures use Kleiner and Hartigan's clustering of the data from their first example, cut off at an appropriate number of clusters.

Displays such as those in Figures 1, 2, and 3 have important benefits that should not be discarded simply because, as Kleiner and Hartigan mention, their correlation structures may not match that obtained from clustering a given set of data. In fact, the real correlation structures of interest for trees or other displays are largely unknown, since they depend on the process of perception. First, data are transformed by the graphical representation into pictures; but then the pictures are transformed by the observer's perception into some mental impression of the data. It is the combination of the two transforms that determines how the data are perceived. Showing good qualities in the first transform for a particular type of graphical representation, such as the trees, is not sufficient.

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[1] Jacob (1978) presents one effective, but cumbersome, way of assigning data coordinates to the features of Chernoff faces for specific applications. This approach consists of obtaining observers' ratings of faces, performing a multiple regression of face parameters on ratings, and using the resulting regression axes through the face parameter space as the new parameters.

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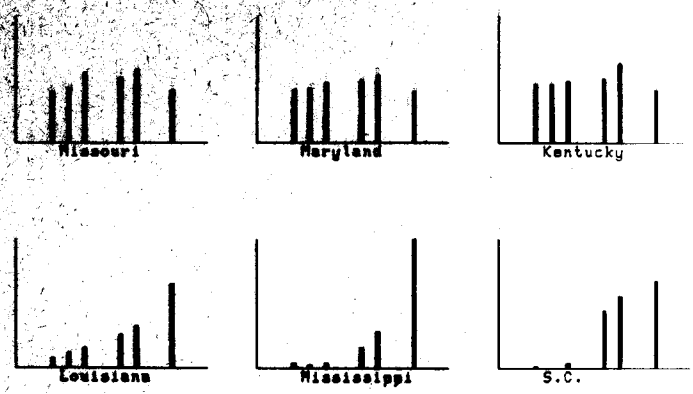

Figure 1. Bar Charts With Clustered Coordinates

A significant disadvantage of the tree and castle displays is, ironically, that they provide more information about the results of the cluster analysis than most other multivariate displays. One must first ask what the purpose of the plot is: to present the results of a clustering procedure or to depict the general distribution of a set of data points in a multidimensional space. The trees and castles are a rather good way to do the former; but Kleiner and Hartigan (properly) suggest that the real goal is the latter, that is, to aid in exploratory data analysis. The object is to help an observer guess at hypotheses about the data, rather than to present conclusions in a convenient or convincing fashion. The clusters should thus be viewed as a tool to aid in constructing a display for the data. Hence one should choose the figures for the displays according to the extent to which they tell about the original *data*, rather than about the *clusters*.

In this vein, I am concerned about display methods that "digest" their data extensively, as do trees and castles. When the data must be digested, that process should, ideally, be sufficiently simple that the observer can bear it in mind at all times when he or she is looking at the display. That is, it should be describable by a few words or a simple concept. Otherwise, the observer may lose sight of the structure of the original data. Kleiner and Hartigan suggest that the problem with using a complex algorithm to construct a display is that it is difficult to read the data values back from the display. I think that

Figure 2. Profiles With Clustered Coordinates

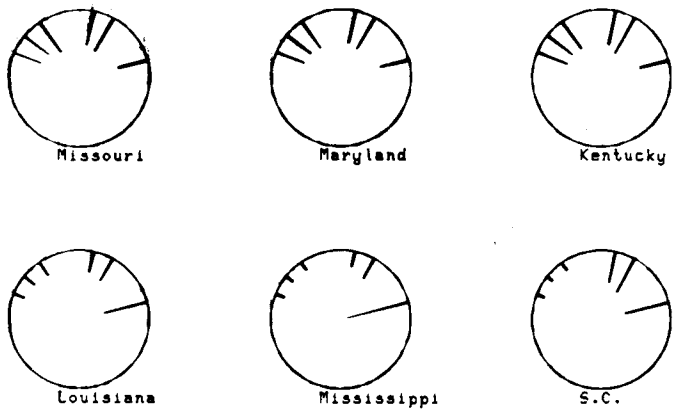

Figure 3. Inward-Pointing Glyphs With Clustered Coordinates

is not an important goal for a display used in initial, exploratory analysis. Later, when individual values are of more interest than the overall picture, one should change to a table anyway. The real problem with a complex display is just the inverse: that the overall appearance of the display is not easy to relate to (or predict from) the data, so that one must keep in mind a very elaborate transformation while attempting to study the data by means of the complex display.

The dimensions of the trees and castles also lack perceptual integrality (Garner 1974). They do not provide their observer a single image or concept or gestalt that he or she can process and remember, binding together the values of all of the coordinates of the point. For example, polygons and faces tend to provide observers with such a concept, while glyphs and bar charts tend to look simply like the accretion of their several elements. Trees and castles appear to fall in the latter category. One minor change that will increase the perceptual integrality of the trees somewhat is to fill them in (see Fig. 4). This makes the tree look a little more like a single figure, and it becomes easier to remember and compare each tree as a whole.

Further, the horizontal lines on the castles seem to add unnecessary clutter. Instead, an approximate indication of the clustering of the variables is obtainable from the relative heights of the bases of the "turrets" of the castle; beyond that, reading precisely which variables were clus-

Figure 4. Filled-in Tree

tered with which is the sort of task better accomplished with a table than a graphic display.

The paper presents only two classes of displays: existing display symbols with coordinates assigned arbitrarily and trees or castles with coordinates assigned by clustering. If one were to notice a difference between these two, it would not be possible to distinguish the effect of introducing the tree display from that of assigning coordinates by clustering. Separating the method into its two constituent parts and applying each to the data in the paper individually would provide two intermediate displays, permitting a more precise comparison: existing display symbols with coordinates assigned by clustering; and trees or castles with coordinates assigned arbitrarily. In this way, each of the two procedures that make up the new method could be compared separately to alternative techniques and evaluated more precisely. For example, it is clear that the trees and castles are very sensitive to the ordering of their coordinates, but one does not notice this since they are always combined with a well-chosen procedure for selecting this ordering.

It would have been satisfying (although most unusual) if Kleiner and Hartigan had examined some of their claims about the tree and castle displays in a controlled experiment. This is generally more difficult to do than it seems, but, if there is a fairly strong effect, it is possible to observe it in a simple experiment. Questions in the area of graphical representations have largely been studied subjectively, by introspection. It would be reassuring to see instead the beginnings of a real empirical basis for work in this field.

Finally, it is indeed possible to say what makes a good picture, if the picture were created for some specific goal. An empirical method is simply to present subjects with alternative pictures of the same information, ask them to achieve that goal, and see which picture best facilitates this. The problem here is that these figures are most helpful in exploratory data analysis, and that is difficult to describe as a specific goal. The real goal is to communicate the data. It is possible to approach that problem indirectly by studying tasks that require a person to perceive a set of data as an intermediate step in performing some other task.

So, Kleiner and Hartigan's method of assigning data coordinates to display parameters is a very good solution to a problem that arises in multivariate displays, but it need not be restricted to trees and castles. By isolating the clustering step from the tree and castle display methods, it can be applied to other displays, which have important properties that trees lack: integrality, familiarity, and simplicity.

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