Dorling D. (1994) Cartograms for visualizing human geography, in D. Unwin and H. Hearnshaw (eds), Visualization and GIS, London: Belhaven Press. 85-102.

11 Cartograms for visualizing human geography

D. Dorling

...Visualization in human geography

This chapter presents the argument that without the extended use of cartograms, future visualization in human geography will merely repeat a fundamental distortion of much past thematic cartography in (literally) drawing our attention to the patterns in places where the fewest people live. It is now possible to produce cartograms relatively effortlessly and the author's work on this is summarised. The important decisions to make today are, first, what form of cartogram to adopt in a particular situation, and, second, how to best visualize human geography upon it. First I shall describe what I mean by the terms 'visualization' and 'cartogram'. Next I explain in more detail why we must extend the use of cartograms, and briefly explain how they can be made. Finally I give examples of how they can be used in the visualization of human geography.

This book has introduced several definitions of visualization, but each author will have a slightly different view of so large a subject. To me, visualization means making visible what was obscure, what could not easily be imagined or seen. Scientific visualization (ViSC) uses our inherent ability to appreciate a picture. By transforming large amounts of data into pictures, we can begin to understand the underlying structure. This approach is based upon the unique nature of the link between eye and mind. We depend on vision, we think visually, we talk in visual idioms and we dream in pictures. Unfortunately we cannot easily transmit a picture directly from one mind to another, we have to describe or draw it. Throughout history we have developed (and sometimes forgotten) ingenious methods of turning numbers and ideas into diagrams and pictures – turning information into understanding. This process has been most prolific at those times when the flow of new information was greatest, for example, at the end of the eighteenth and twentieth centuries.

The first cartograms were created as another way to show just how uneven was the geographical distribution of population, but later came to be used as a basis for illustrating the human geography of those populations (Raisz, 1934; 1936). I define cartograms as maps in which a particular exaggeration is deliberately chosen. For example, area cartograms are drawn so that areas on the paper represent places in proportion to a specific chosen aspect of those places. Thus an ordinary planimetric map is an equal land area cartogram on which,

projection permitting, areas are drawn in proportion to the amount of land in each place. They are appropriate as a base if you are interested in the spatial distribution of something across the land such as crops. Conversely, in an equal population area cartogram, or population cartogram, areas are proportional to the number of people in each place. A population cartogram is an appropriate basis for seeing how something is distributed spatially across groups of people. Such a cartogram is *not* a distortion of the world, but a representation of some particular aspect of it. Any two-dimensional projection of the surface of the earth must select some aspects to represent and reject others. Almost all ancient maps would today be seen as cartograms, as their exaggerations are seen to be so great, and yet they depicted the reality of their times with uncharted lands compressed and religious capitals in the centre of their worlds (Angel and Hyman 1972). Later on, depicting reality came to mean straightening compass directions to enable trade and conquest over the seas:

> The map is not some inferior but more convenient substitute for a globe. Map projections are not simply choices of lesser evils among distorting possibilities. On the contrary, the map allows the geographer to twist space into the condition he wishes, For purposes of finding lines of constant compass direction, the Mercator projection is far superior to the actual surface of the earth. The earth itself lacks the spatial property of having such lines being straight lines. (Bunge, 1966, p. 238)

Today, depicting reality is still a means to an end, not just to know how to sail around the seas of Europe, but to ask how many people live on each part of the land and in what social conditions. To see the latter more clearly we must begin by using maps in which all groups of people are given equal prominence. The mechanics of this process will now be discussed. Population cartograms giving equal representation to all the people in the picture far outnumber all other kinds produced this century. However, sometimes a selected group from the population would be more relevant (children, households or electors for example). The spatial units used to construct a cartogram are usually politically defined geographical areas but they need not be. The only restriction is that each unit has a known value. However, the units in the cartograms considered here also have known locations and known topological relationships with other units. These are referred to as areal units in the rest of the chapter.

In the 1970s machines were developed to construct population cartograms mechanically, as their manual creation has always been difficult and tedious (Skoda and Robertson 1972). These early methods were not particularly successful in practice and their products were not widely used for other work. By the 1980s work was well underway to create computer algorithms capable of producing useful population cartograms (Tobler 1963, 1976, 1986; Dougenik et al., 1985). Because of the poor visual and cartographic quality of these early attempts most cartograms used today are still generated manually (Eastman et al., 1981), and many from the past have been repeatedly re-used (Hollingsworth, 1964; 1966). This writer has worked on an algorithm to produce cartograms by computer which are acceptable as the basis for future cartographic work. Equal area cartograms of many thousands of areal units can now be generated with ease. The most important current issue is to inform people that usable cartograms exist, and persuade them of their advantages. We need to convince people that using cartograms will broaden their understanding, and that many traditional maps give a false impression of the spatial

patterns in human geography. This is not a new debate: '[Cartograms] from many points of view are more realistic than the conventional maps used in geography.' (Tobler, 1961, p. 163) The strongest argument for using a population cartogram rather than a topographic map base is not that the traditional map distorts the pattern across the population, but that most of the pattern is simply not visible! An excellent example is given by Coulson (1977) of a Canadian electoral map in which half the results could not be seen without a magnifying glass. The majority of the population of most countries live in small, densely populated areas which need numerous insets on a national map to give any semblance of justice. This problem becomes more acute as a finer spatial resolution is sought: less than 1 per cent of the (inhabited) 1km grid squares of Britain contained over 30 per cent of the population in 1971 (Craig, 1976). The *People in Britain* 1971 census atlas was an achievement in its time, but the characteristics of the lives of most of the 'people in Britain' were given minimal representation, with those of the sparse rural population dominating the national picture. Data transformations merely served to reduce the arbitrary variations displayed by presenting so many sparsely populated areas so prominently and places with very few people still dominated the map: 'Hence, the maps in "People in Britain" (CRU/OPCS/GRO(S) 1980) are the first reliable maps of unpopulated areas in Britain!' (Rhind, 1983, p. 181)

...THE CHOICES FOR VISUALIZATION

I wanted to draw maps of the populated areas in Britain, to represent facts about the British people equitably, but still to show how each area is related to others spatially. Visualization is about how to see both the detail and the whole picture (Tufte, 1990). As interest grows in high resolution mapping of populations in large areas, so the necessity of employing cartograms will increase. A traditional map of Britain that showed every ward would require an entire atlas of insets, yet a cartogram can show every ward clearly on a single page. These solutions will, however, present us with new problems. An infinite number of 'correct' population cartograms can be constructed for every grouping of any population (Sen, 1975). This is both an asset, as it allows us to choose some other properties we might wish our model to have, and a hindrance, as the superficial appearance of a cartogram of the same population will vary from one author to another. People like familiarity and that is one reason why the deficiencies of traditional map projections have been so widely ignored for so long.

One debate on the nature of cartograms is whether they should be continuous (strictly preserving topology) or not. A continuous area cartogram creates no gaps between the places represented, with all places initially neighbours remaining so. The author originally worked on this type of cartogram and considered further constraints which could be added (Dorling, 1990). For example, as shown in Plate 7, the outer boundary of the area (the perimeter) can be preserved, or the lengths of interior boundaries can be minimised. It is possible to achieve both of these aims simultaneously. As the Plate shows, maintenance of the original perimeter dramatically restricts simplification of the internal boundaries, but gives the map a familiar feel. If the shape of the perimeter is not preserved, a continuous area cartogram can then be produced which can be

claimed to minimise local 'distortion'. The early work of Tobler (1961) had just such an aim and defined the term far more rigorously than it is defined here. Such a representation is very useful for some particular applications, such as the mapping of discrete incidents (for example incidents of a possibly contagious disease, see Levison and Haddon, 1965).

For mapping the general characteristics of a population, however, there is much merit in adopting the noncontinuous form of cartogram (Olson, 1976). Most areal units have relatively simple shapes in physical space which can become very complex on a continuous area cartogram. If a noncontinuous area cartogram is constructed, areal units can be represented by any desirable shapes such as circles. There are immediate benefits to be gained from this approach. For example, the area of each unit and hence its population is easier to gauge by eye. A greater benefit of this approach is realised later, as these simple shapes can be extensively manipulated to produce sophisticated pictures of population characteristics. The main disadvantage of this approach is that locally the geographical topology can be disrupted; although the algorithm to produce the cartogram can be devised to attempt to minimise the frequency and severity of this.

The algorithm the author designed (Dorling, 1991) began by positioning the areal units correctly on a land map and then applied an iterative procedure which slowly evolved a cartogram with the desired characteristics. The method used was to repel independently all areal units from each other in proportion to their population sizes (in order to give places with larger populations more room), while simultaneously applying forces of attraction in the directions of their original neighbours in proportion to their relative border lengths (in order to preserve the original topology when possible). Figure 11.1 illustrates the process of creating a noncontinuous cartogram of the counties of Britain. Places bordering the sea had a degree of inertia because part of their perimeter, being coastline, did not make up a common border. This helps to maintain prominent peninsulas and other landmarks. Thus, although the exact shape of the coastline was sacrificed, many of its well-known features could actually be retained. The algorithm has been successfully applied to create population cartograms based on as few as seventeen areal units and as many as 100 000. Figures 11.2 and 11.3 show a population cartogram and conventional map of the districts of Britain. The altered geography has been indicated on Figure 11.2 by the pattern of the lines shown connecting neighbouring areal units. To create cartograms of a few dozen units using this algorithm implemented on a home microcomputer required a few seconds, a few hundred units required a few minutes, a few thousand required a few hours, and many thousands required several days! Cartograms have been constructed of the counties, districts, constituencies, wards, census enumeration districts and several other geographical subdivisions of Britain. The algorithm can be applied to any place of any size, from the countries of the world to the buildings in a town. Its implementation is theoretically parallel in operation and in practice not necessarily limited to two dimensions.

Painting in population space

The layout of the cartogram produced is of interest even before we begin to

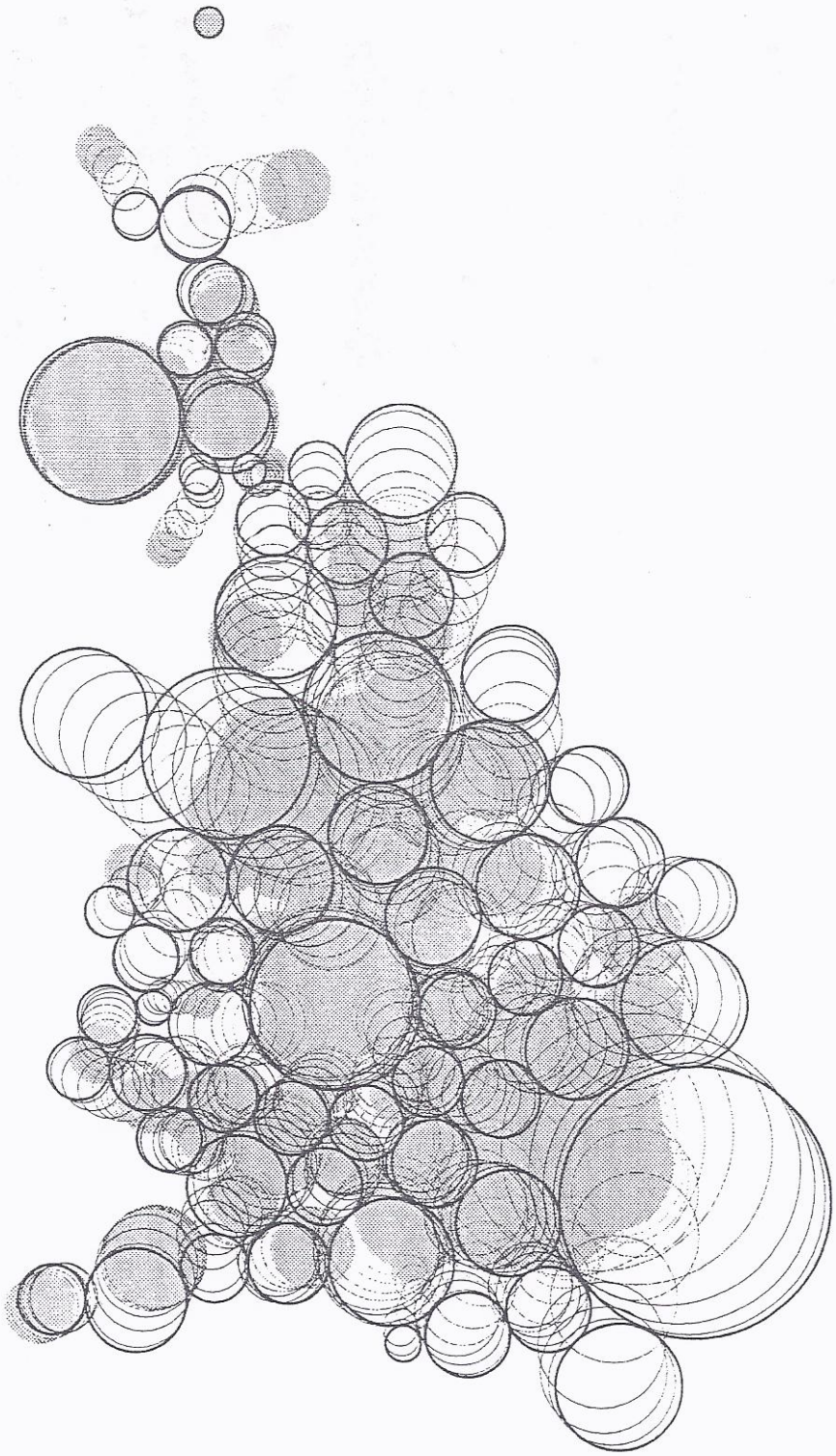


Figure 11.1 Illustration of a cartogram of British county populations evolving

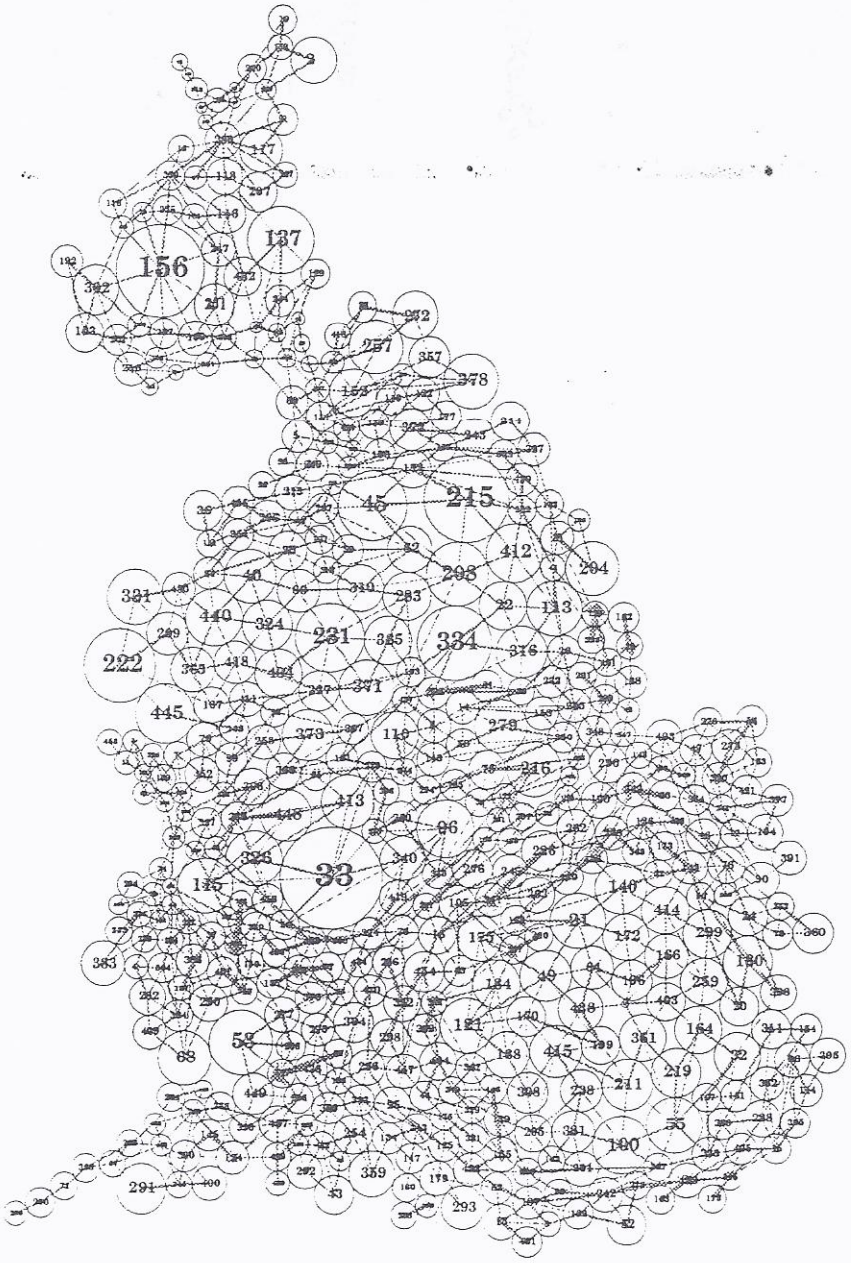


Figure 11.2 Contiguity on the local authority districts population cartogram

Figure 11.3 Conventional local authority districts base map and key

use it to depict other information. A population cartogram tells us a lot about the human geography of places, how they are related to each other in a new and intriguingly unfamiliar way. We can see from Figure 11.2 that nearly half the people of Britain come under London's immediate influence and that this structure is repeated recursively since the extended Glasgow area makes up more than half of Scotland and dominates that country. Working with this visualization of the population rapidly alters the way you think about the human geography of Britain and the patterns of people's lives within it. Comparing a traditional map and cartogram of the same areal units side by side graphically illustrates how the majority of the people who live in the towns and cities are dominated by rural dwellers in the maps normally used to study them, maps which would be more appropriate for depicting the geography of sheep than people.

How the characteristics of a population can be depicted on this kind of cartogram depends on the number of areal units used or, more precisely, the final size of each unit. With over 100 000 Census Enumeration Districts, for example, each appears as a tiny dot on the screen or paper. This is large enough for the viewer to see its colour, but not its shape or small variations in its size. Nevertheless, quite sophisticated schemes can be used, from simple grey-shading to bivariate or trivariate colouring to show the distributions of one, two, or even three, population groups simultaneously. Using red, blue and yellow as primaries, mixing into purple, green and orange combinations, can produce dramatic but complex pictures such as that shown on Plate 8. The distribution of British people by their country of birth (predominantly England, Scotland or Wales) is shown by the choice of one of a possible sixty-four colours (mixtures of four levels of red, blue and yellow respectively) in each of 129 211 populated enumeration districts. The dominance of a few shades show how distinct the national divisions within Britain are, but this pattern is broken up most clearly in London where large numbers of Scots and Welsh migrants settle, colouring the western side of the capital green. Areas of white show places where large numbers of people born outside Britain have settled, for example on the east side of London, and in distinct parts of the West Midlands, Manchester, Leicester and Bradford. The equivalent map, Plate 9, swallows these people in the centres of cities and instead highlights the settlement of American airforce families in sparsely populated parts of East Anglia as white areas. The colour mixing of the Border Counties is interesting, as purple and orange are blended, but this picture tells more the story of the land than of the people. Migration to and in Britain is mainly a tale of people in cities, not of the mixing of people in remote farmland on the borders of nations, or the small scale invasion of previously unpopulated airfields.

When only 10 000 areal units are being depicted it is possible to give each a black or white border to allow them to be more distinctive and so reduce the effect that neighbouring colours have upon one another. Variation in size is easily seen and is appropriate when areal units vary a lot in size, but at this scale one cannot usefully vary shape. Figure 11.4 is a cartogram showing the distribution of unemployment in 10 444 wards in Britain at the time of the 1981 census. The important areas of high unemployment are clearly seen in Inner London, South Wales, Birmingham, Liverpool, Tyne and Wear and Glasgow. At the same time, their extent, the number of people affected, is also

Figure 11.4 Ward population cartogram of unemployment in Britain

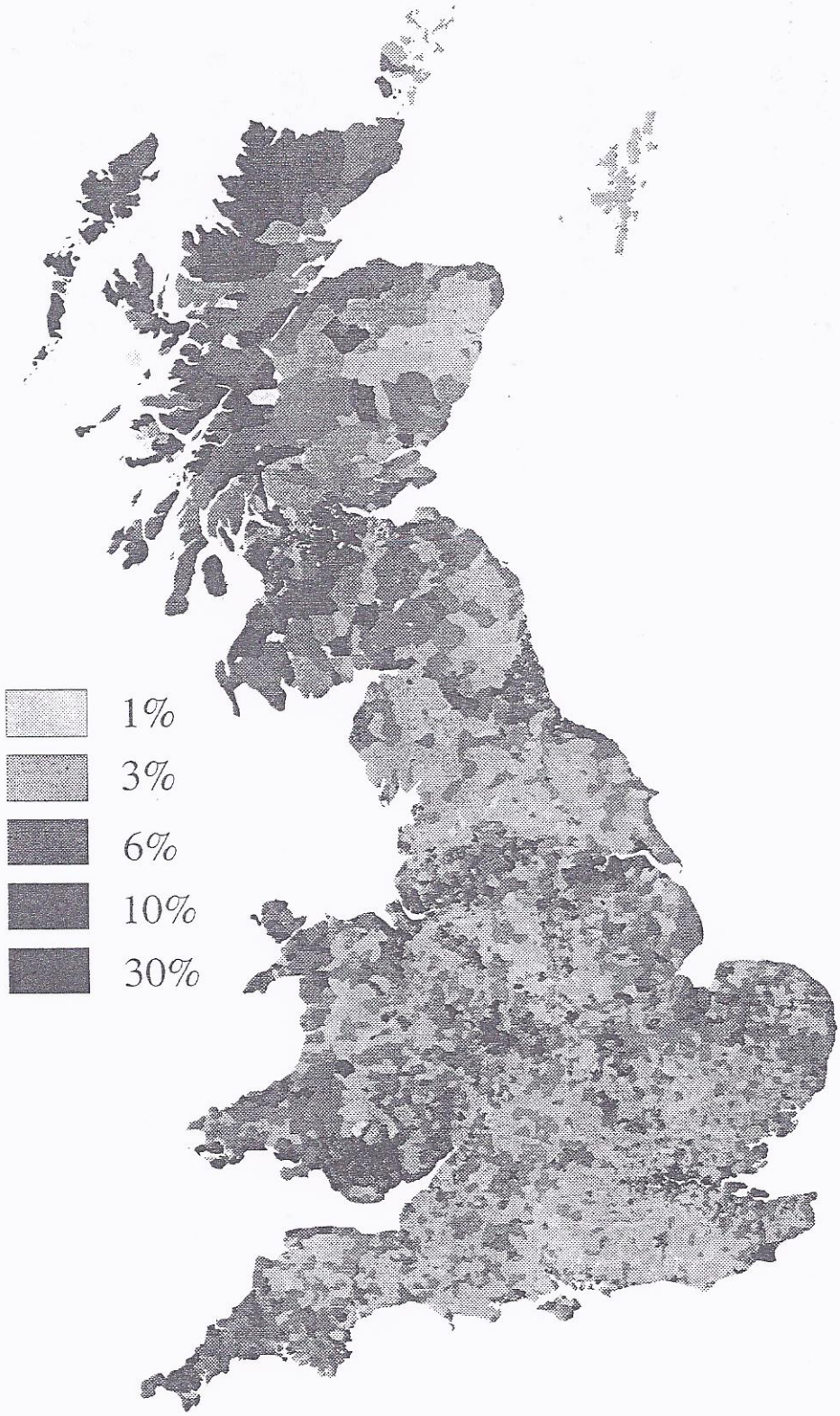


Figure 11.5 Ward map of concentration of unemployment in Britain

plain to see. Conversely, the traditional map of these same data, Figure 11.5 has a larger area than all of these coloured black in the remote northwest of Scotland, the least populous area of Britain. The major areas of unemployment now appear literally as small black spots, and the map gives the impression that most people live with little fear of losing their livelihoods. Traditional maps highlight prosperity because more affluent people tend to live in less densely populated areas.

... ELABORATING THE DESIGN

As the number of areal units is reduced to less than 1000, many more visualization opportunities present themselves. Cartographically, an advantage of using a population cartogram consisting of a mere thousand areal units is that each unit becomes large enough to alter individually, so that non-overlapping symbols called 'glyphs' (Anderson, 1989) can be put in their place. Glyphs are 'sculptured characters'; after fixing their position, colour and size we still have control over the shape and orientation of the objects which represent our cases or places. At the simplest level individual glyphs can be given a length to add an extra variable, or given direction (for example by giving the symbol an arrowhead). Symbols can be divided into two, to show the proportions of, say, men and women, or the situation before and after an election; but divisions into greater numbers often break up the spatial patterns visually. The success of such methods depends on several factors: how 'natural' we find the particular way of representing each facet; how much a group of somewhat similar glyphs creates an overall meaningful impression; and how much inherent pattern there is to the data. A picture that shows no pattern may be showing the truth, but is visually a failure.

At the simplest level the circles can be split into rings, coloured by value for two time periods to show, for example, the change of political party in parliamentary constituencies at elections. Unfortunately this schema visually fails when more rings are introduced, as the temporal pattern appears to dissect the spatial one. Trying to picture patterns that are spread across both time and space is not easy. Recalling the example of political change, suppose we were interested in the swing of the vote rather than simple change of party. The swing has two components, a direction and a magnitude and in a three-party system the direction is itself two dimensional. Upton (1991) has shown how a set of arrows can be drawn to represent the swings of votes between elections on a cartogram base. The result is most effective, even more so when you colour the arrows according to the (red/yellow/blue) mix of the votes in the constituencies to show in which political direction the swing is. Further animation of such pictures is illustrated by Dorling (1992).

Far more complex situations can be visualized. I will illustrate with some examples I have tried. The first method is to show a bar chart or population pyramid in each place. The chart is best filled in a solid colour to form visually a shape which can be quickly scanned when comparing different places or looking for regional patterns. Figure 11.6 shows the distribution of employment by eight types of industry, employee gender and status (full- or part-time) for each constituency. The area of each chart is in proportion to the working

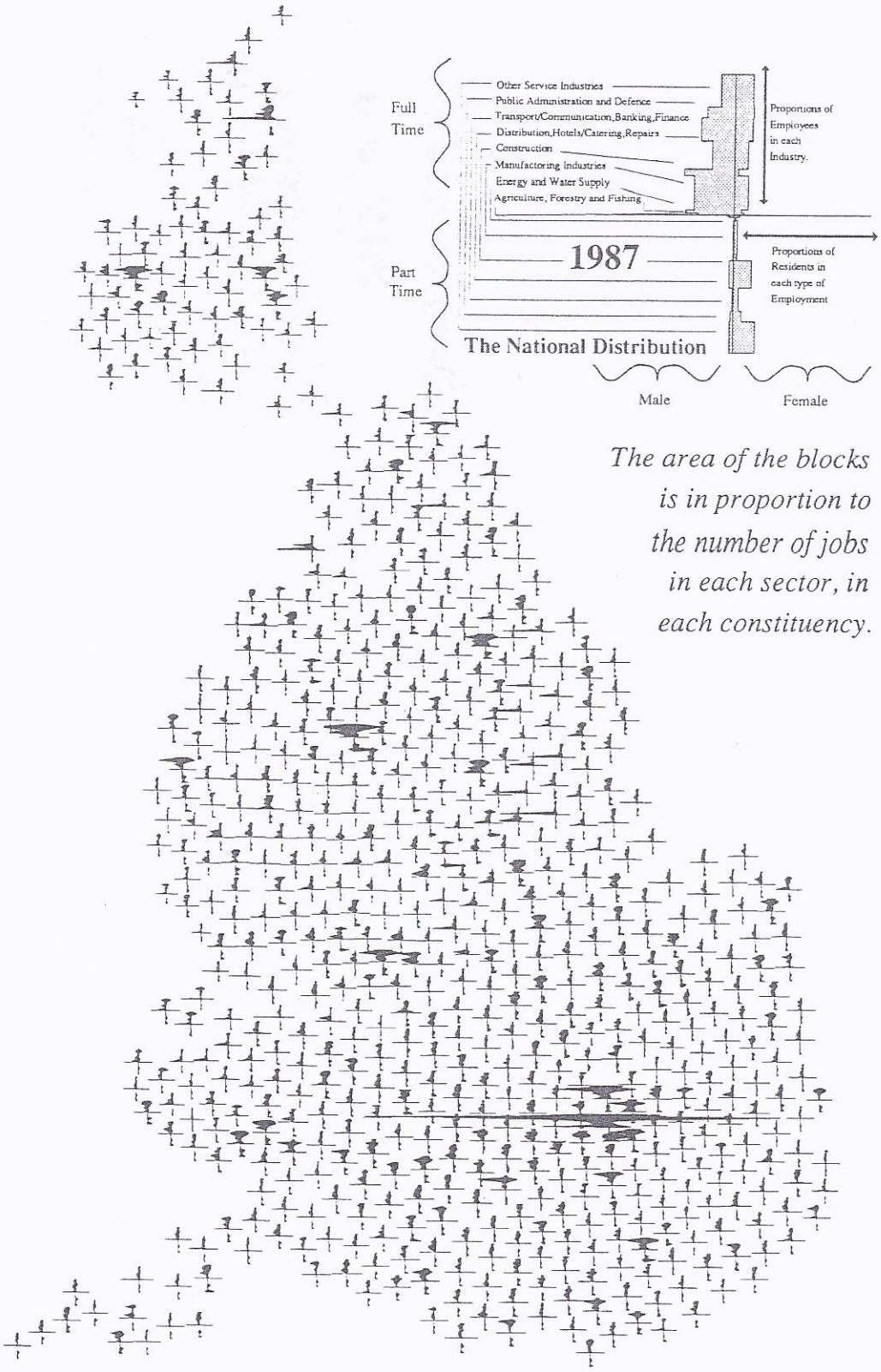


Figure 11.6 The distribution of industry on a cartogram of parliamentary constituencies

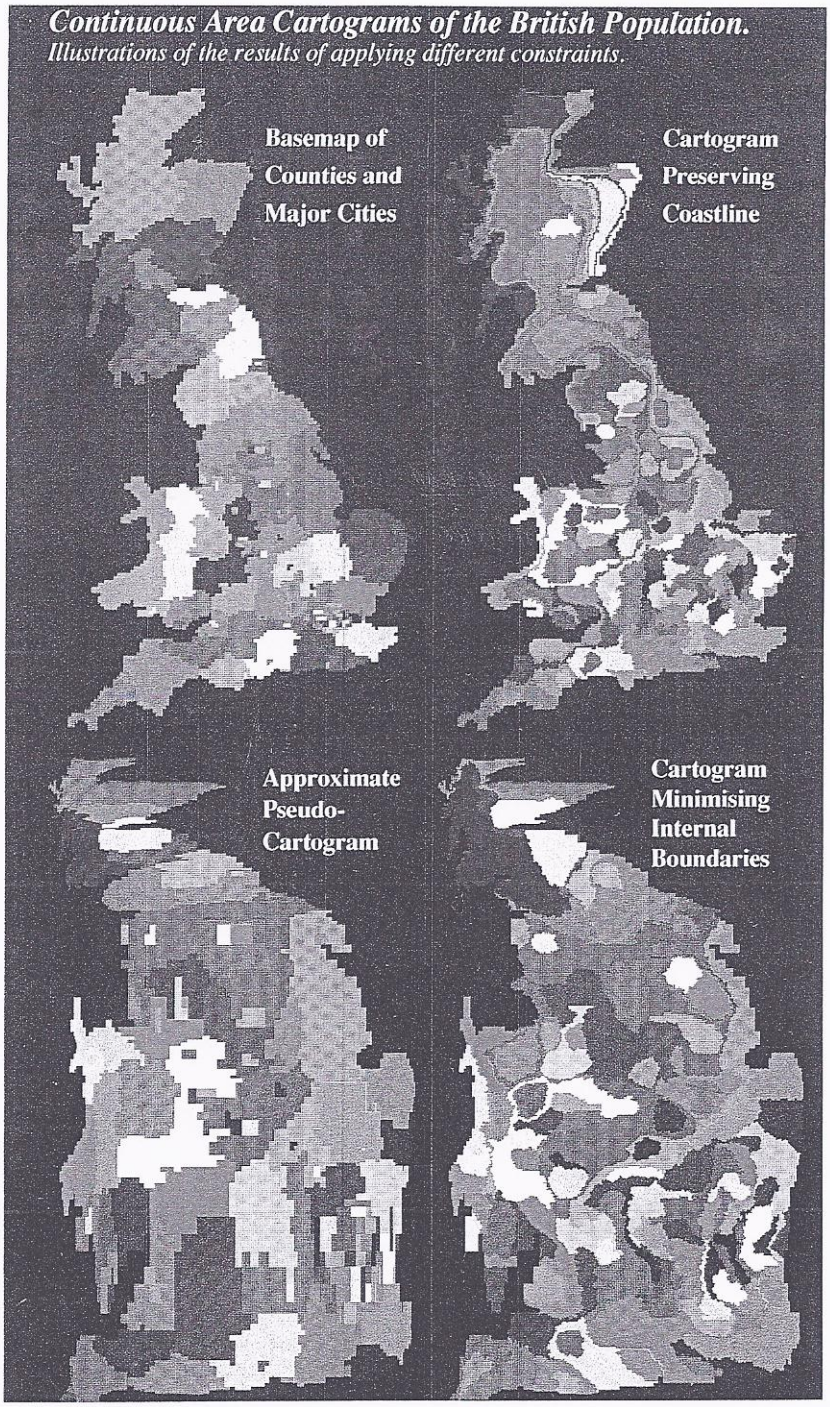


Plate 7 Continuous area cartograms of the British population. The same 250 counties and major cities are shown, identically coloured on each of the four images. Top left is the basemap, next to that is a continuous area population cartogram preserving the physical coastline. The second cartogram follows a suggestion by Tobler (1986) where the marginal distributions are made uniform. The final image uses the boundary of the latter, but each area is in proportion to its population, with the lengths of internal boundaries being kept to a minimum. While an interesting exercise in using cellular automata, such continuous area cartograms are difficult cartographically to embellish further

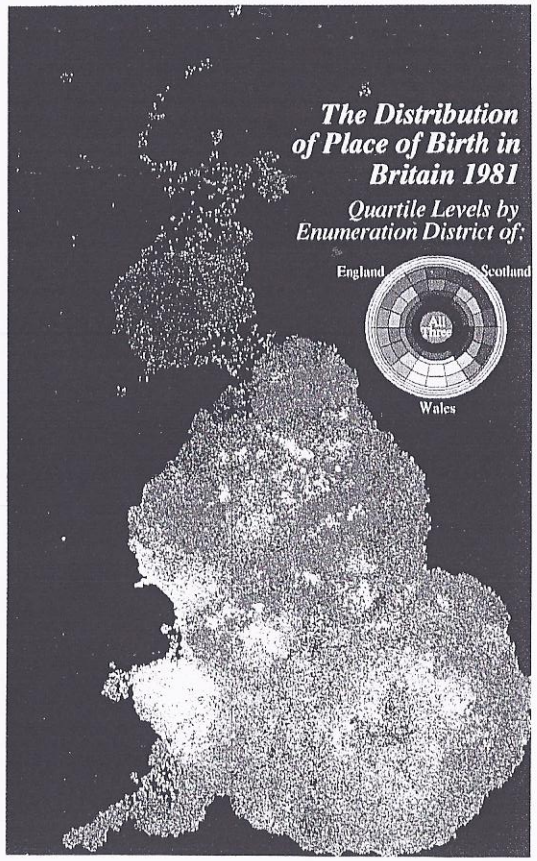
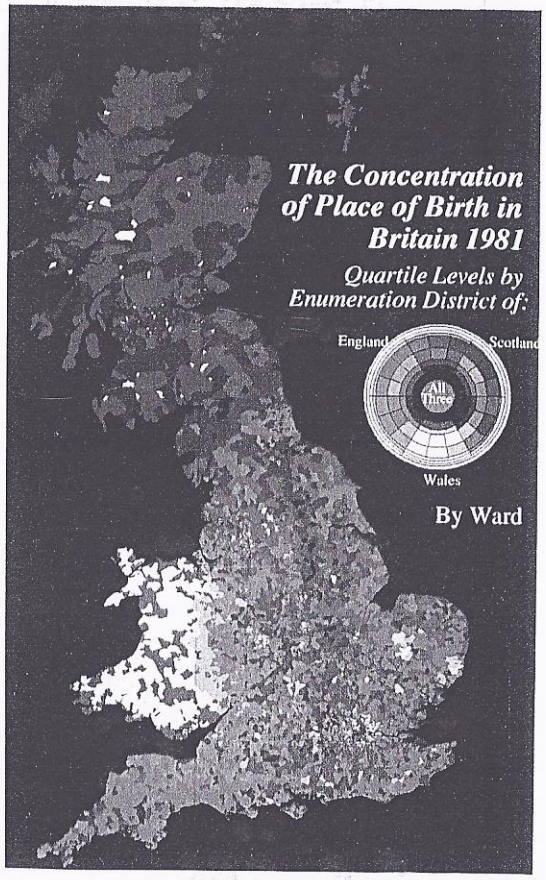


Plate 8 Enumeration District population cartogram showing place of birth in Britain. Each one of 129 211 populated census enumeration districts is shown coloured according to the mix of people living in it, in population space. The more English people the more coloured red whilst Scots are coloured blue and Welsh yellow. These colours mix to show the South West peninsula as generally orange, Scottish borders as purple and the western side of London green. Distinct localities can also be made out. Corby, for example, shows as a greeny blue patch of high Scots (and some Welsh) migration. West of it is Leicester (speckled white), where high numbers of people born outside of Britain have settled

Plate 9 Ward map of the concentration of place of birth in Britain. Enumeration district boundaries were not digitised for the 1981 census, and so the highest resolution conventional choropleth maps that could be drawn at was ward level comprising some 10 444 areal units. The simple regional pattern of Figure 11.2 is again evident but areas of sparse population steal our attention. White polygons in the mountains of Scotland highlight the presence of a few foreign visitors, the same in Wales and on the moors of Devon. The picture is misleading because it creates uniformity over areas where there is little, and apparent variety where few people live. The diversity in London is hidden in an area smaller than the size of a single large ward in the far north of England



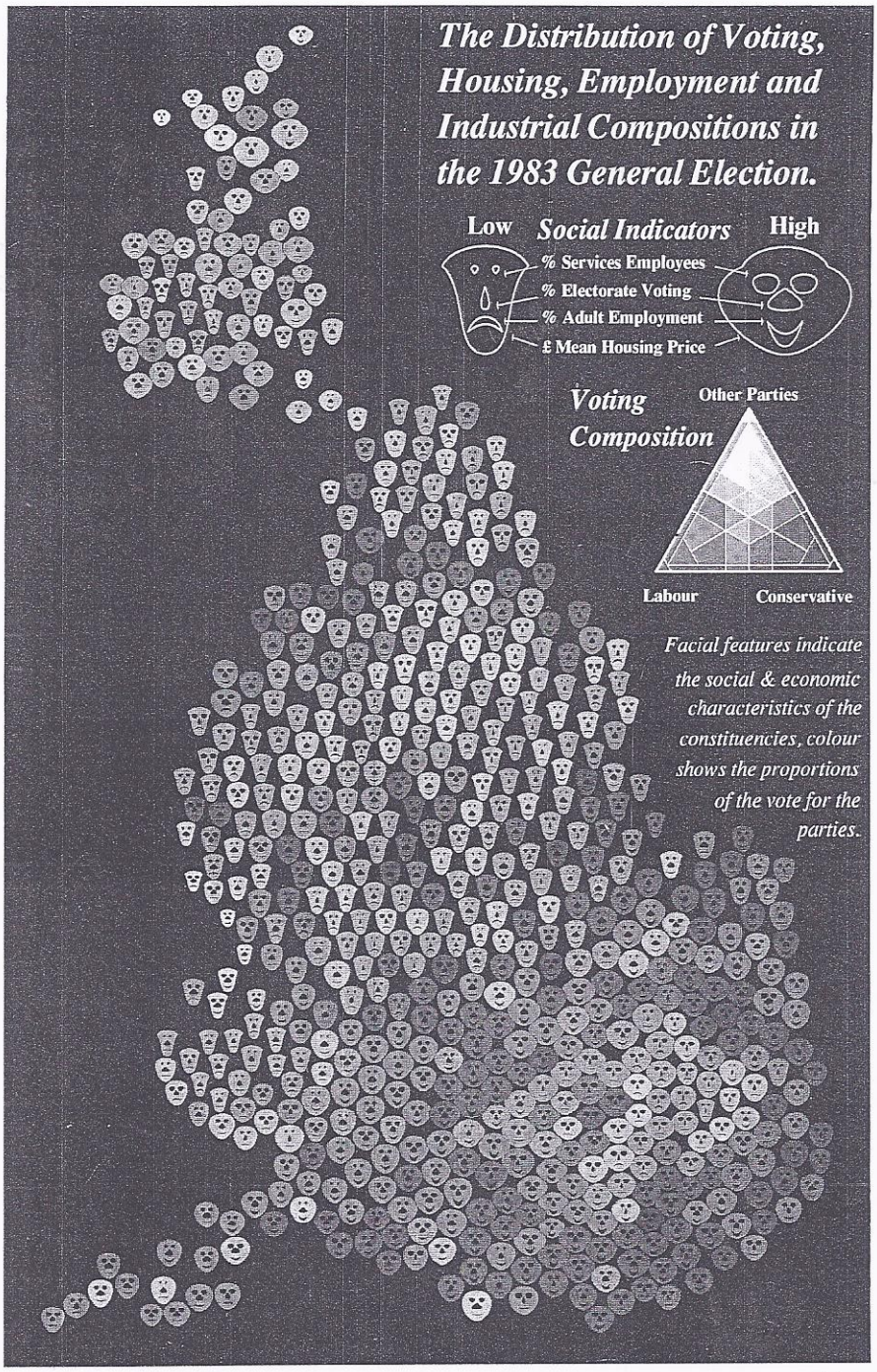


Plate 10 The distributions of voting, housing, employment and industry on a population cartogram. The 633 mainland parliamentary constituencies are each represented by a face whose features express the various variables, and which is coloured by the mix of voting, drawn on an equal electorate cartogram. The patterns in this picture are very interesting and could lead to endless discussion. The 'deaths-heads' inside Glasgow city are solidly red, while the happy-faces around the capital voted strongly for the government of the day. The Welsh may not have had much employment, or expensive housing, but they still turned out to vote in large numbers. This technique is particularly good for identifying exceptions, faces which do not fit in with the crowd

population. Because of regional patterns, the industrial structure can be assimilated visually from several hundred pyramids, spaced out on the cartogram (although interactive zooming was useful to inspect such detailed charts).

Second, the distribution of house prices has been depicted by using a glyph shaped like a tree. The tree branches into different types of housing divided by features such as number of bedrooms, bathrooms, heating and detachment. The width of each branch shows the number of sales of that type of house, the length is in proportion to the average price. It follows that the total depicted branch area gives financial turnover for housing in that spatial area. The result, shown as Figure 11.7, looks like a wood with trees of different species, sometimes occurring in identifiable clumps of particular sizes and shapes. Again, because there is pattern to the distribution, a meaningful picture is created.

An especially fascinating glyph is one based on human faces, first drawn by Chernoff (1973; 1978). Facial expressions, it is argued, are one of the visual images we are best equipped to decipher. We naturally combine their features to interpret moods such as happy or sad, sly or simple. What is more, we can easily compare faces and pick out similarities and exceptions in a crowd. Faces maintain a basic structure within which even slight variation often holds meaning. The original Chernoff faces were designed to portray up to eighteen variables and statisticians have subsequently extended this to thirty-six (Flury and Riedwyl, 1981), but psychological research suggests that the permutation of so many different variables to features resulted in staggering differences in interpretation (Chernoff and Rizvi, 1975). This is hardly surprising as many combinations of variables in the original can visually cancel each other out. It is difficult to see the slant of an eye when its size was reduced to a point! Here, I have been somewhat less ambitious and employed only five features and variables to look at some of the factors behind voting swings across Britain. Figure 11.8 shows the construction lines of the Bezier curves used to create the graphics.

Parliamentary constituencies were drawn as heads, with variation in area to show the total number of voters, width to show house price (fat cheeks when expensive!) mouth style to show employment rate (a smile when high), nose size for electoral turnout, and eyes to show industrial structure (large and low when dominated by younger industries). The colour of the face represented the actual voting patterns. The study was initially meant as a 'tongue-in-cheek' exercise but the result, shown in Plate 10, was revealing. The inner–outer city and north–south divides are in many aspects clear, but the difficulty of drawing precise lines between the regions and around the cities is also apparent. Specific individual faces can be identified which did not 'fit in' (as when plotting swings some arrows did not 'go with the flow'). Strong local trends and relatively sharp divisions are the clearest messages of this visualization. The faces were also used to show change over time, coloured and shaped by the swings in the votes, change in house prices, unemployment increase and so on. Thus the facial expressions become populations' 'reactions' to a changing situation, their colours perhaps indicating a political response by the electorate to economic change. Further psychological work would be valuable to determine how much the apparent increase in insight gained through using these particular glyphs might be outweighed by the possible ambiguities introduced through such an emotive visualization.

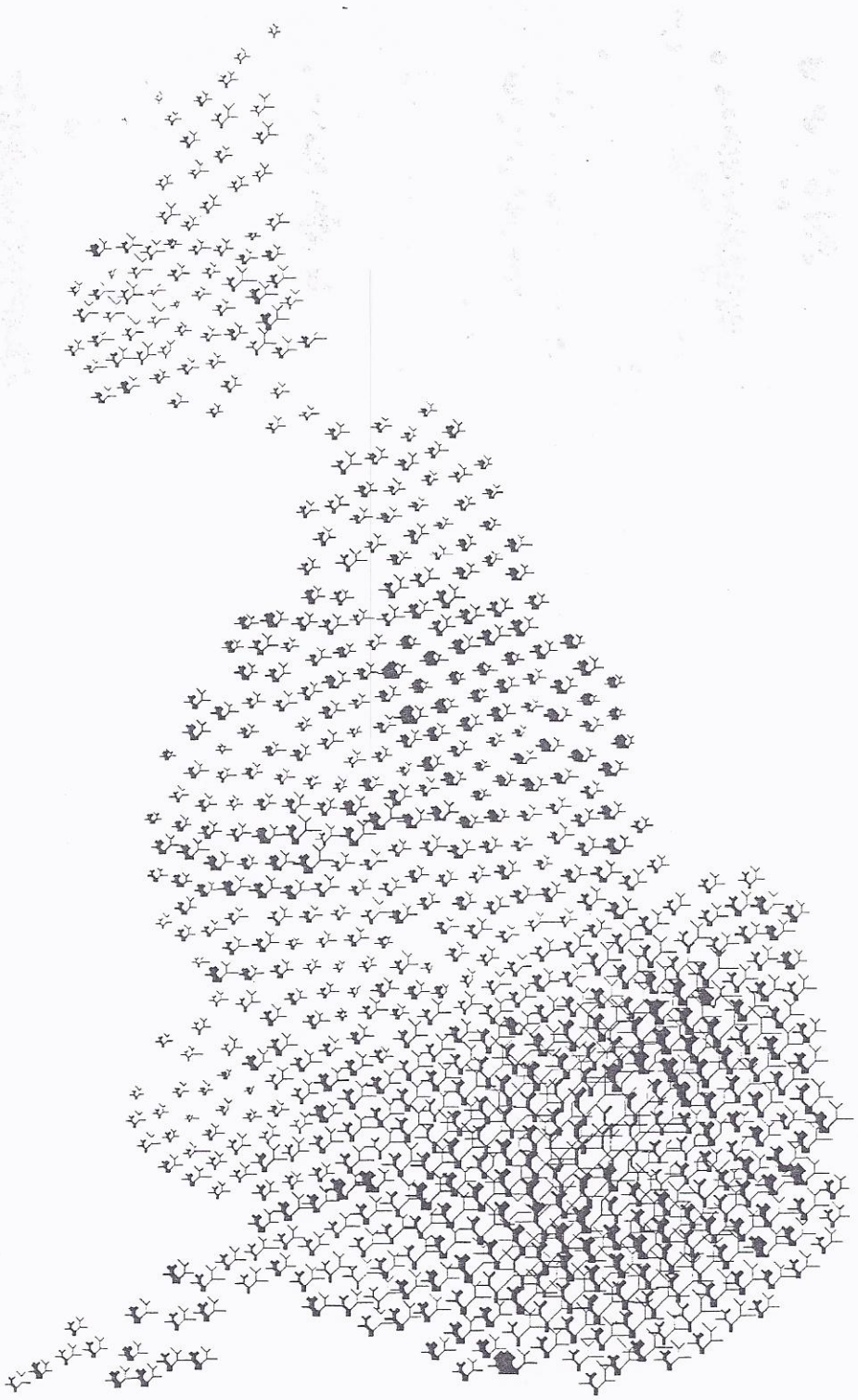


Figure 11.7 The distribution of owner occupied housing on a population cartogram

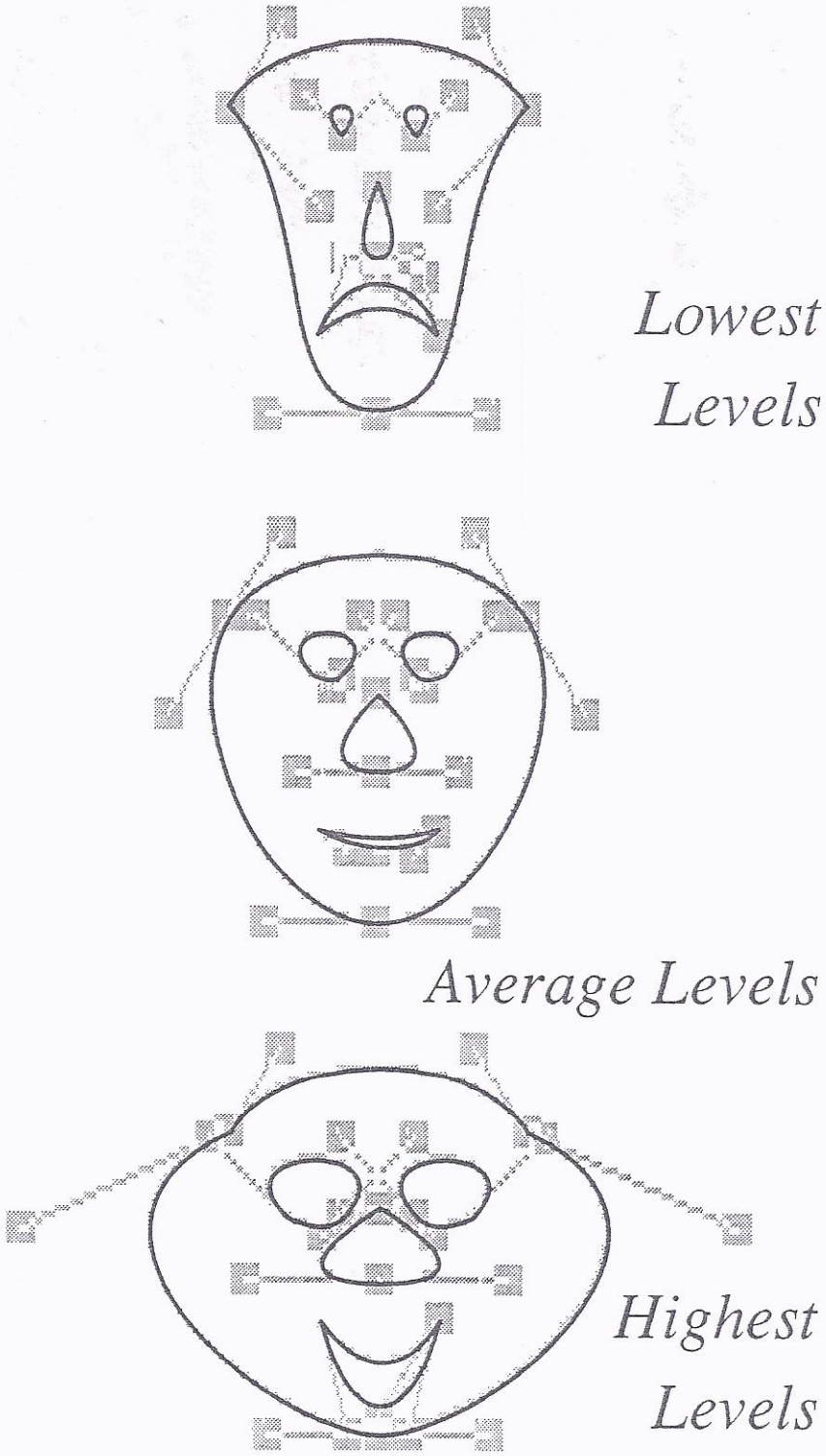


Figure 11.8 The mechanics of constructing glyphs of faces

... CONCLUSION

The argument for the use of cartograms in visualizing human geography has been developed from outlining the geographic disadvantages of not doing so, to the cartographic advantages of using an uncluttered map on which the people actually fit. The arguments against using cartograms have not been put, but it should not be difficult for the reader to begin to list them, so strongly is our present geographical understanding based on the topographic base. Recall that this was originally designed to help sailors over oceans, not to find people in cities. You know where things are on an ordinary map. However, there is nothing fundamentally new in using area cartograms. You already use road maps where the roads are enormous compared to reality and underground maps whose shape is drawn to give a 'clearer picture'. Yet throughout cartographic history people have been developing more appropriate projections for mapping their times and places. These have often met with resistance if they offered a new perspective on the world. Whatever its absolute merits, the so-called Peters projection received considerable criticism for doing just that (Porter and Voxland, 1986); you can expect people not to like the shape of their world being changed!

A number of alternatives to cartograms have been suggested in the literature (and are illustrated elsewhere in this section of the book), but often result in greater disadvantages. A population density surface can be constructed upon an equal land area map (in effect an equal volume population cartogram) to expose those hidden in cities as 'mountains' on this surface, but our ability to gauge volume is poor, and should be avoided when possible. There are also the well-known problems in visualizing surfaces related to orientation, shadow, perspective, hidden sections and so on. There is a most complex relationship between what is actually seen on the paper and what the picture is intending to show. If we are to resort to 3D then drawing a surface upon a cartogram base allows for far more sophisticated and straightforward analyses, for example, a landscape of house prices coloured by unemployment over population space where height is price.

A second substitution sometimes mentioned is to use the interactive animation outlined in Chapters 13 and 14 to focus on the small highly populated areas. Again the usual complaints with insets can be made: we want to be able to see the detail and the whole simultaneously. In contrast, zooming in on a highly detailed area cartogram can allow you to see that patterns perceived at the large (human) scale are often repeated at the small scale (for instance rich and poor areas can be found at each scale). Investigate the distribution within the population, not the distribution of the population.

Cartograms can be seen today as a kind of artificial reality which we deliberately construct to obtain knowledge. They allow us to optimize the visualization of a chosen body of information, and with population cartograms we wish to give every person equal prominence in our picture. If we are to understand the spatial structure of society we must find effective ways of envisioning it. We have to open up our maps to show us all the people, not hide the majority in tiny dots on an agricultural map. Then we can employ a whole battery of techniques – shade, colour, shape, symbols, statistical analysis, even surfaces and animation if necessary – to depict and examine the information we have

about the people who live in these tiny places. Cartograms should not be seen as just another option in a cartographic toolbox, but as a fundamental necessity in the *just* mapping of spatial social structure.

... Acknowledgements

Thanks are due to Zhilin Li, Chris Brunsdon and David Dorling who commented on an earlier draft of this chapter. Many of the participants of the visualization workshop from which this book evolved also helped shape the final version of this text.

... References

Anderson G C (1989) Images worth thousands of bits of data. *The Scientist* 3(3): 1, 16–17

Angel S, Hyman G M (1972) Transformations and geographic theory. *Geographical Analysis* 4: 350–367

Beniger J R (1976) Science's 'unwritten' history: the development of quantitative and statistical graphics. *Abstracts of the Annual Meeting of the American Sociological Association*, New York

Bunge W (1966) *Theoretical geography*. Lund Studies in Geography, Series C, 1: 285pp

Census Research Unit (1980) *People in Britain – a census atlas*, HMSO, London

Chernoff H (1973) The use of faces to represent points in k-dimensional space graphically. *Journal of the American Statistical Association* 68(342): 361–368

Chernoff H (1978) Graphical representations as a discipline. In: Wang P C C (ed.) *Graphical Representation of Multivariate Data*, Academic Press, New York

Chernoff H, Rizvi M H (1975) Effect on classification error of random permutations of features in representing multivariate data by faces. *Journal of the American Statistical Association* 70(351): 548–554

Coulson M R (1977) Political truth and the graphic image. *The Canadian Cartographer* 14(20): 101–111

Craig J (1976) 1971 census grid squares. *Population Trends* 6: 14–15

Dorling D (1990) A cartogram for visualization. *North East Regional Research Laboratory Research* Reports 90/4, University of Newcastle upon Tyne, Newcastle upon Tyne UK

Dorling D (1991) *The visualization of spatial social structure,* Unpublished PhD thesis, University of Newcastle upon Tyne, Newcastle upon Tyne UK

Dorling D (1992) Stretching space and splicing time: from cartographic animation to interactive visualization. *Cartography and Geographic Information Systems* 19(4): 215–227

Dougenik J A, Chrisman N R, Niemeyer D R (1985) An algorithm to construct continuous area cartograms. *Professional Geographer* 37(1): 75–81

Eastman J R, Nelson W, Shields G (1981) Production considerations in isodensity mapping. *Cartographica* 18(1), 24–30

Flury B, Riedwyl H (1981) Graphical representation of multivariate data by means of asymmetrical faces. *Journal of the American Statistical Association* 76(376): 757–765

Harley J B (1990) Cartography, ethics and social theory. *Cartographica* 27(2): 1–27

Hollingsworth T H (1964) The political colour of Britain by numbers of voters. *The Times*, 19 October, p. 18

Hollingsworth T H (1966) The political colour of Britain by winning parties. *The Times*, 4 April, p. 8

Levison M E, Haddon W (1965) The area adjusted map: an epidemiological device. *Public Health Reports* 80(1): 55–59

Olson J M (1976) Noncontiguous area cartograms. *Professional Geographer* 28: 371–380

Porter P, Voxland P (1986) Distortion in maps: the Peters projection and other devilments. *Focus* 36: 22–30

Raisz E (1934) The rectangular statistical cartogram. *Geographical Review* 24: 292–296

Raisz E (1936) Rectangular statistical cartogram of the world. *Journal of Geography* 35: 8–10

Rhind D (1983) Mapping census data. In: Rhind D (ed.) *A Census User's Handbook*, Methuen, London

Sen A K (1975) A theorem related to cartograms. *American Mathematics Monthly* 82: 382–385

Skoda L, Robertson J C (1972) Isodemographic map of Canada. *Geographical Papers* 50, Department of the Environment, Ottawa, Canada

Tobler W R (1961) *Map transformations of geographic space*. Unpublished PhD thesis, Department of Geography, University of Washington, Washington USA

Tobler W R (1963) Geographic area and map projections. *Geographical Review* 53: 59–78

Tobler W R (1976) Cartograms and cartosplines. *Proceedings of the Workshop on Automated Cartography and Epidemiology*, National Center for Health Statistics, US Department of Health, pp. 53–58

Tobler W R (1985) Interactive construction of continuous cartograms. *Proceedings of the 7th International Symposium on Computer-Assisted Cartography*, Washington DC, p. 525

Tobler W R (1986) Pseudo-cartograms. *The American Cartographer* 13(1): 43–50.

Tufte E R (1990) *Envisioning Information*, Graphics Press, Cheshire, Connecticut

Upton G J G (1991) Displaying election results, *Political Geography Quarterly* 10(3): 200–220