

## The visualization of local urban change across Britain<sup>†</sup>

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**Abstract.** The author argues for the increased use of population cartograms to visualize changing geographies and uses British localities as an example. Population cartograms are increasingly being recognized by researchers as a major solution to many spatial visualization problems. The gross misrepresentation of many groups of people on conventional topographic maps has long been seen as a major problem of thematic cartography, highlighting difficulties such as the modifiable areal unit problem in preventing the development of visual palliatives. Population cartograms made up of many thousands of areal units are simple to construct with an appropriate algorithm. The author has designed a particular solution for use in the visualization of high-resolution spatial social structure. The problem now is not of writing more computer programs, but of convincing other researchers of the necessity of using cartograms in place of conventional choropleth maps for showing many population-related distributions. The author shows how our pictures of space can be changed and argues why they should be.

### Introduction

In this paper I present 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. My own 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 best to 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. Last, I give examples of how they can be used in the visualization of human geography.

### Visualization in human geography

Visualization means making visible what was obscure, what could not easily be imagined or seen. Scientific visualization uses our inherent ability to appreciate a picture. By transforming large amounts of statistical information into pictures, we can begin to understand the spatial 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

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those times when the flow of new information was greatest—at the end of the 18th and 20th centuries (Beniger, 1976).

### **The first cartograms**

The first cartograms were created as another way to show how uneven the geographical distribution of population was. Cartograms later came to be used as a basis for illustrating the human geography of those populations (Raisz, 1934; 1936). I would define cartograms as 'maps in which a particular exaggeration is deliberately chosen'. 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 map is an equal land area cartogram—areas are drawn in proportion to the amount of land in each place. It is appropriate as a base if you are interested in the spatial distribution of something across land—crops for instance. Conversely, on an equal population area cartogram ('population cartogram' for short) 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 be selecting some aspects to represent, while rejecting others. Almost all ancient maps would today be seen as cartograms, as their *exaggerations* are seen as 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, 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, page 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 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 paper.

### **The creation of cartograms**

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, 1973; 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 reused (Hollingsworth, 1964; 1966). I have 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 to 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, page 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 them any semblance of justice. This problem becomes more acute as a finer spatial resolution is sought: less than 1% of the (inhabited) 1 km grid squares of Britain contained over 30% of the population in 1971 (Craig, 1976)! The *People in Britain* census atlas (CRU, 1980) was an achievement of 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 transformation by 'Chi-squared mapping' merely reduces the arbitrary variations displayed by presenting so many sparsely populated areas so prominently. Places with very few people still dominated the map:

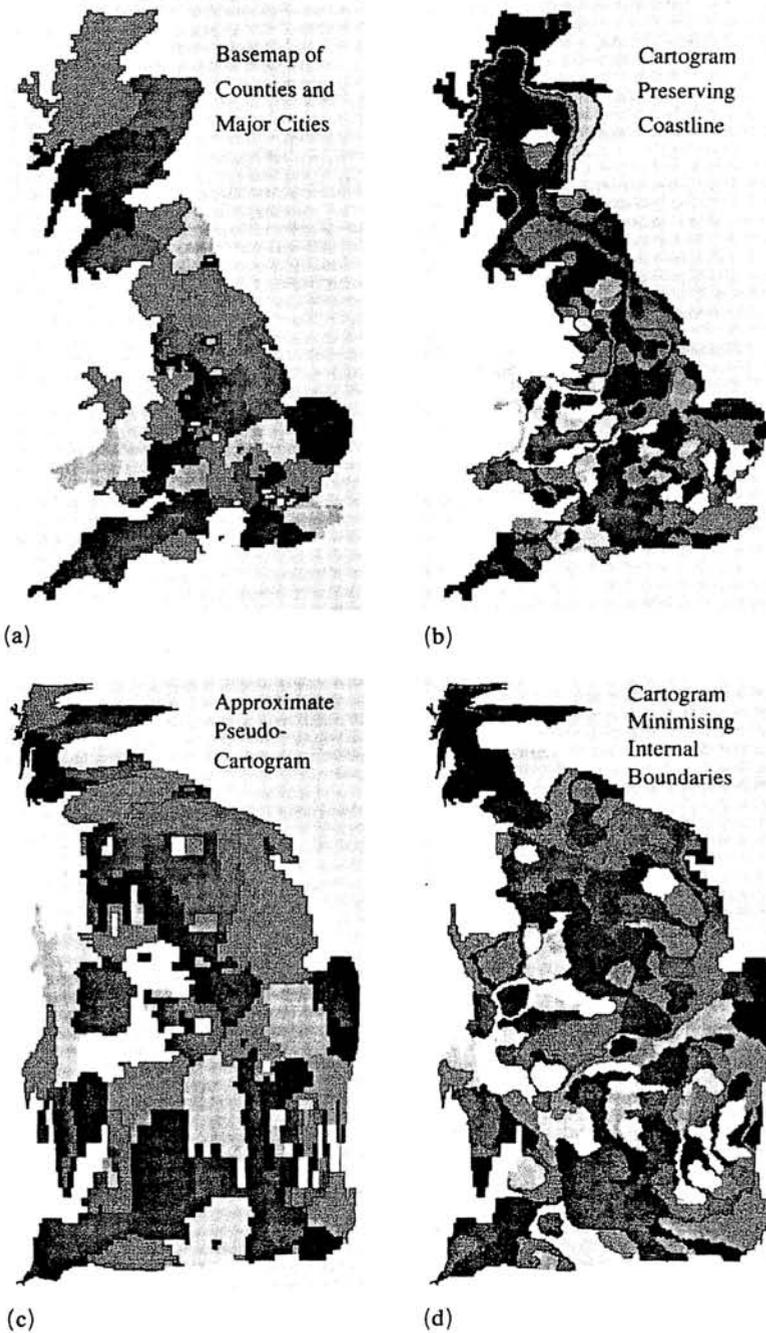
"Hence, the maps in 'People in Britain' (CRU/OPCS/GRO(S) 1980) are the first reliable maps of unpopulated areas in Britain!" (Rhind, 1983, page 181).

### The choices of visualization

I wish 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 the 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. 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 two cartograms 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.

### Continuous area cartograms

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 initially neighbouring places remaining so. I originally worked on this type of cartogram and considered further constraints which could be added (Dorling, 1993a). For instance, the outer boundary of the



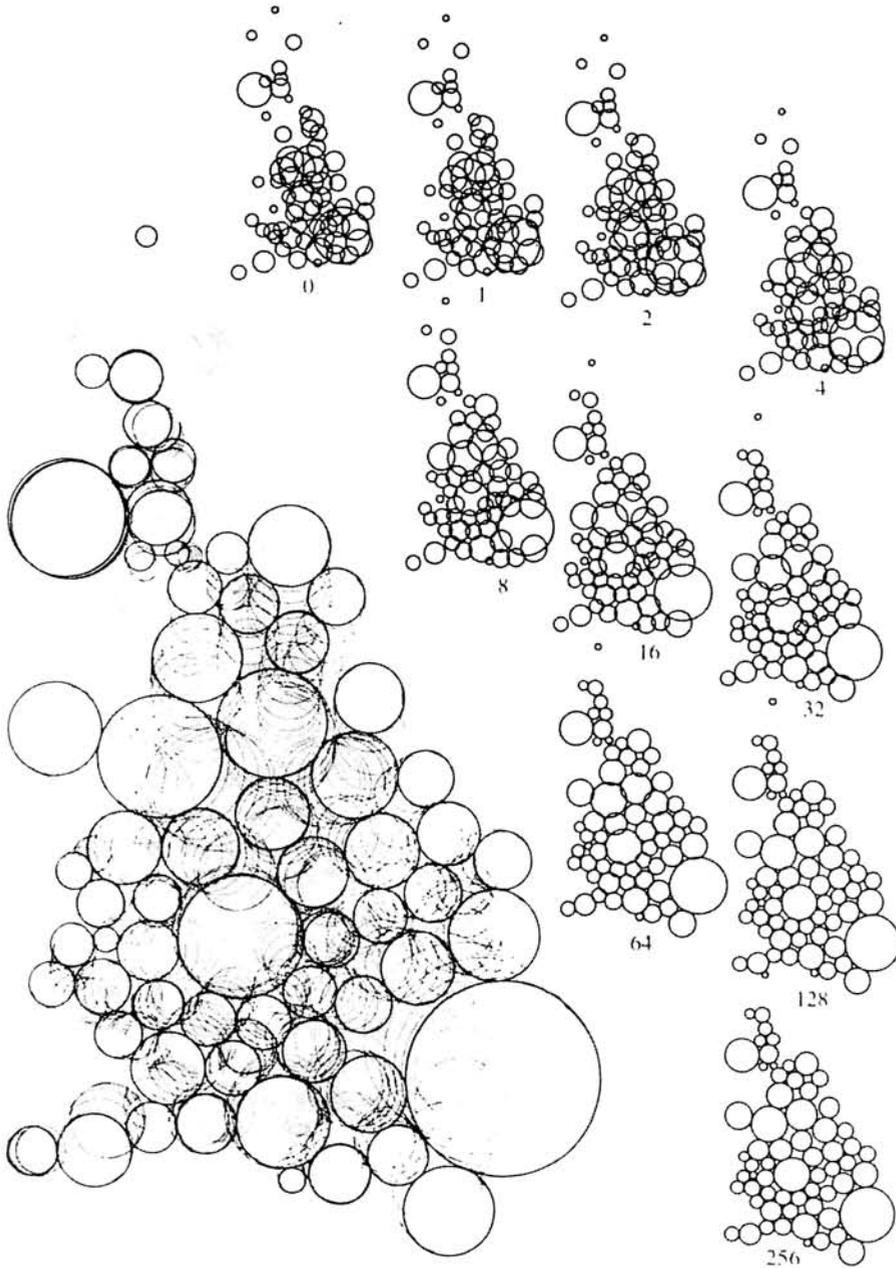
**Figure 1.** Continuous area cartograms of the British population. The same 250 counties and major cities are shown, identically shaded on each of the four images. (a) is the base map; (b) is a continuous area population cartogram preserving the physical coastline; (c) is the result of following a suggestion by Tobler (1986) where the marginal distributions are made uniform; in (d) the boundary of image (c) is used, but each area is in proportion to its population, with the lengths of internal boundaries being kept to a minimum. Although an interesting exercise in using cellular automata, such continuous area cartograms are difficult to embellish further successfully.

area can be preserved, or the lengths of interior boundaries can be minimized (see figure 1). It is possible to achieve both of these aims simultaneously. 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 (although far more rigorously defined than 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; Selvin et al, 1988)].

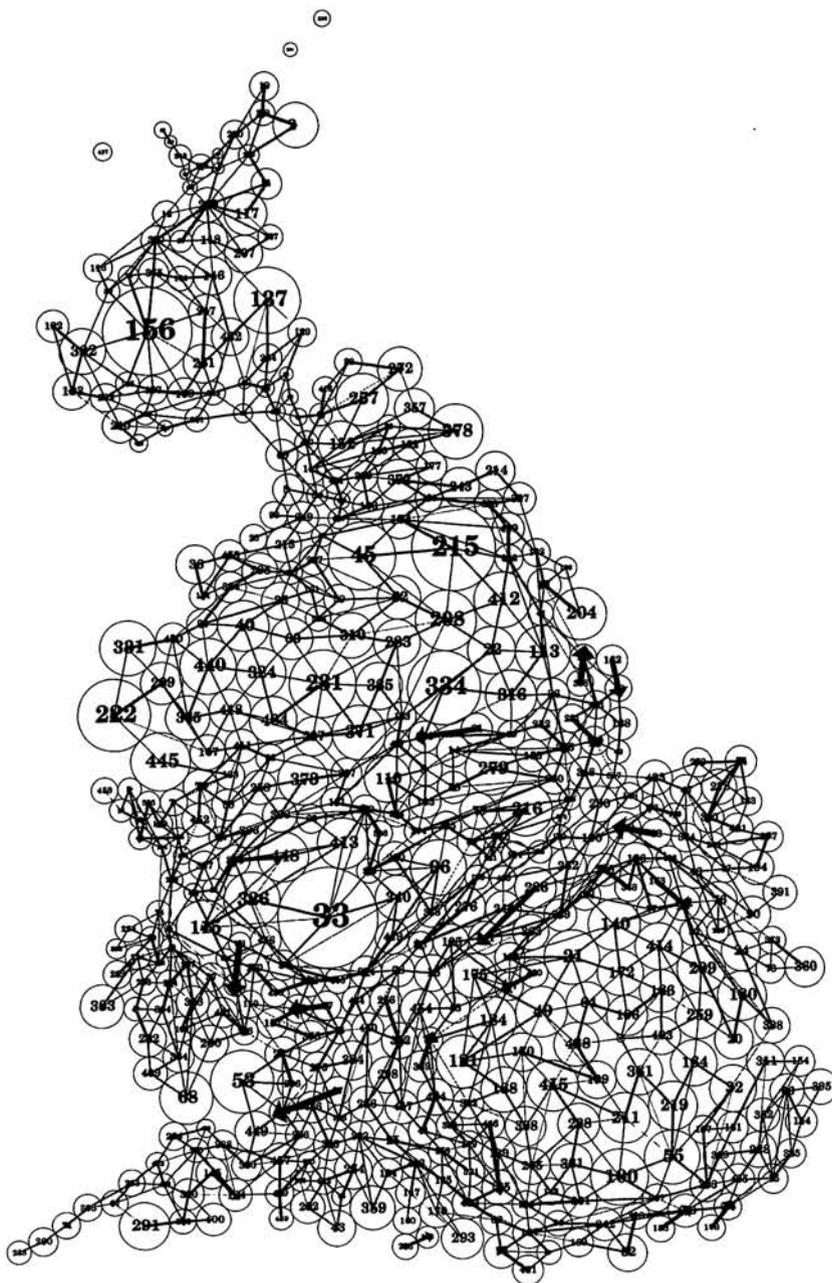
#### **Noncontinuous area cartograms**

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—circles for instance. 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 minimize the frequency and severity of this problem.

The algorithm I have designed (Dorling, 1991) began by positioning areal units correctly on a land map and then applying an iterative procedure which slowly evolved a cartogram with the desired characteristics. The method used is 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 2 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 helped 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 implementation of the algorithm was successfully applied to create population cartograms based on as few as 17 areal units to over 100 000. Figures 3 and 4 show a population cartogram and conventional map of the districts of Britain. The way the geography has been altered is indicated by the pattern of the arrows shown connecting neighbouring areal units. To create cartograms of a few dozen units 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! By this method cartograms have been made of the counties, districts, constituencies, wards, census enumeration districts, and several other geographical subdivisions of Britain. The algorithm could 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 not necessarily limited to two-dimensional work in practice. A computer program which implements the algorithm is listed in a companion journal to this (Dorling, 1995a) in a paper which illustrates how cartograms can be used to visualize 1991 Census statistics.



**Figure 2.** Illustration of a cartogram of British counties' populations evolving. Ten stages in the development of the cartogram based on the 64 counties of Britain are shown. In the composite figure the grey circles show the initial positions of the counties, the outline circles show their positions after successive iterations of the algorithm (shown below the individual frames); circles in bold show their final resting states (after 256 iterations). The large West Midlands circle in the centre can be seen to have hardly moved at all, whereas Kent has been catapulted south by Greater London; although the small island areas to the north of Scotland have not had their initial position affected at all (the average of the centroids of the various islands). The performance of the algorithm is more successful, the smaller and more equal the populations of the areal units are.



**Figure 3.** Contiguity on the local authority district population cartogram. The 459 districts have been indexed for identification against the map of the same areas shown in figure 4. Arrows link the centre of circles connecting districts which are contiguous. The width of the lines is proportional to the *strength* of the contiguity—the proportion of common border between the two areas. This factor was used as a matrix of parameters by the algorithm implemented to create the cartogram (given with this example in Dorling, 1993a). Notice that the vast majority of naturally contiguous districts are still touching each other. Topology is usually broken only where it would be impossible to maintain. The existence of major bridges and tunnels has also been added to the connectivity matrix used to influence the generation of the cartogram.



**Figure 4.** Conventional local authority district basemap and key. The 459 districts are again shown, indexed as in figure 3. The size of the labelling has been made proportional to the physical area of the districts to illustrate the great range of topographical sizes. The labels of the districts containing the majority of the population are thus too small to read (just as the labels of the districts with the largest physical areas but lowest populations are too small to read on the cartogram). This map is familiar to British geographers but as a visual base what purpose does it serve? Which areas does it emphasise over others? There can be no neutral representation of the human geography of a country (Harley, 1990). Do we choose to use what is inappropriate but accepted, or try to change the way we visualize the human world to tell us more about the people who are in it?

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**Painting in population space**

The layout of the cartogram produced is of interest even before we begin to use it to depict other information. The 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. Nearly half the people of Britain come under the immediate influence of London. This structure is repeated recursively—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 towns and cities are dwarfed in the maps normally used to study them—maps which would be more appropriate for depicting the geography of sheep rather than people.

**Patterns of points**

How the characteristics of a population can be depicted on this kind of cartogram depends critically on how many areal units are being used or, more precisely, on the final size of each unit. With over one hundred thousand areal units, representing census enumeration districts, for instance, each appears as a tiny dot on the screen or paper; large enough 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 and how they interact at this very high level of resolution. The use of red, blue, and yellow as primaries, mixing into purple, green, and orange combinations, can produce dramatic but complex pictures (see Dorling, 1993b). Unfortunately here we do not have access to colour illustrations and so a simple univariate distribution is shown using only two shades of grey. At this spatial resolution, however, a scheme as simple as that can produce a very complex result.

The distribution of people living in Britain and born in England is shown over each of 129211 populated enumeration districts in the cartogram of figure 5. Enumeration districts with over the median level of English-born residents are shaded darker, those with under the median are shaded light. Scotland and Wales clearly stand out, but the Greater London area forms an even larger mass of people who live in neighbourhoods with lower numbers of English-born residents than the average. The trivariate coloured version of this illustration shows that West London is populated by unusually high numbers of people born in Scotland and Wales. The other areas of light grey show places where large numbers of people born outside Britain have settled—the East End of London and distinct parts of the West Midlands, Manchester, Leicester, and Bradford, for instance.

The map of the same enumeration districts which uses the same shading on a conventional projection, in contrast (figure 6) is very difficult to interpret because it is visually devoted to showing the distribution of the population over the land area of Britain. Thus far more of the paper is white (showing where nobody lives) rather than dark or light grey. The patterns can just be made out, but it could be argued that, from this picture alone, the viewer is unlikely to see just how spatially separate these two 'halves' of Britain are. On an equal land area projection we have very much less space in which to show the characteristics of the population so each enumeration district has to be drawn much smaller. The patterns we are looking for are, in effect, hidden in between the mountains, moorland, and farmland of Britain.



**Figure 5.** Enumeration district population cartogram showing proportion of English born. Each one of 129211 populated census enumeration districts is shown coloured either black or grey depending on a characteristics of the people living within it—in population space. Enumeration districts with more than the median proportion of people born in England living in them in 1981 are shaded darker. Thus half the area of the cartogram is dark and the other half light—showing two halves of Britain, one where English-born people dominate the communities, and another where they are less concentrated (although still often in the vast majority—see below). Apart from the obvious absence of a dominance of English-born people in Wales and Scotland, distinct localities can be made out within England where the English are *underrepresented*. Greater London is most obvious, but also the West Midlands, Manchester, Leicester, Corby (containing unusually high numbers of Scottish-born people), and so on. To the west of London towards parts of the affluent home counties a speckled effect can be seen showing that distinct clusters do not have to form as they do elsewhere. In this area the ‘immigrants’ are mainly Scots and Welsh born residents.



**Figure 6.** Enumeration district equal land area map showing proportion English born. Again every one of the 129211 populated 1981 census enumeration districts is shown coloured either black or grey with the same shading as in figure 5—areas with over the average numbers of English born being darker. Some of the basic patterns can be made out: the low levels of English born in most of London, for instance. However, it is very difficult to form an overall impression of where the major concentrations lie, because it is so difficult to see the shading of the dots and, simultaneously, to appreciate how many people live in each area. This is because most of the paper is shaded white to show those parts of the country where nobody lives. As this is the vast majority of the land area, at this spatial scale, it is not surprising that there is little space left within which to show the patterns over the population that are supposed to be the subject of graphics such as these.

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### People in areas

When only ten thousand areal units are being depicted, it is possible to give each a white border to allow them to be more distinctive and reduce the effect that neighbouring colours have upon one another (when that is desirable). Variation in size is easily seen (much more appropriate when units do vary a lot in size), but you cannot usefully vary shape at this scale. Figure 7 is a cartogram showing again the distribution of the English-born population of Britain at the time of the 1981 Census, but now in 10444 wards with five shades of grey to show varying concentrations. Here Wales and Scotland are differentiated from London (where between 50% and 70% of the population of most wards were born in England). A gradual darkening of the wards can be seen as we move further north although in places, for instance in West Yorkshire, sharp divides are apparent. The majority of people live in wards where between 75% and 90% of people were born in England.

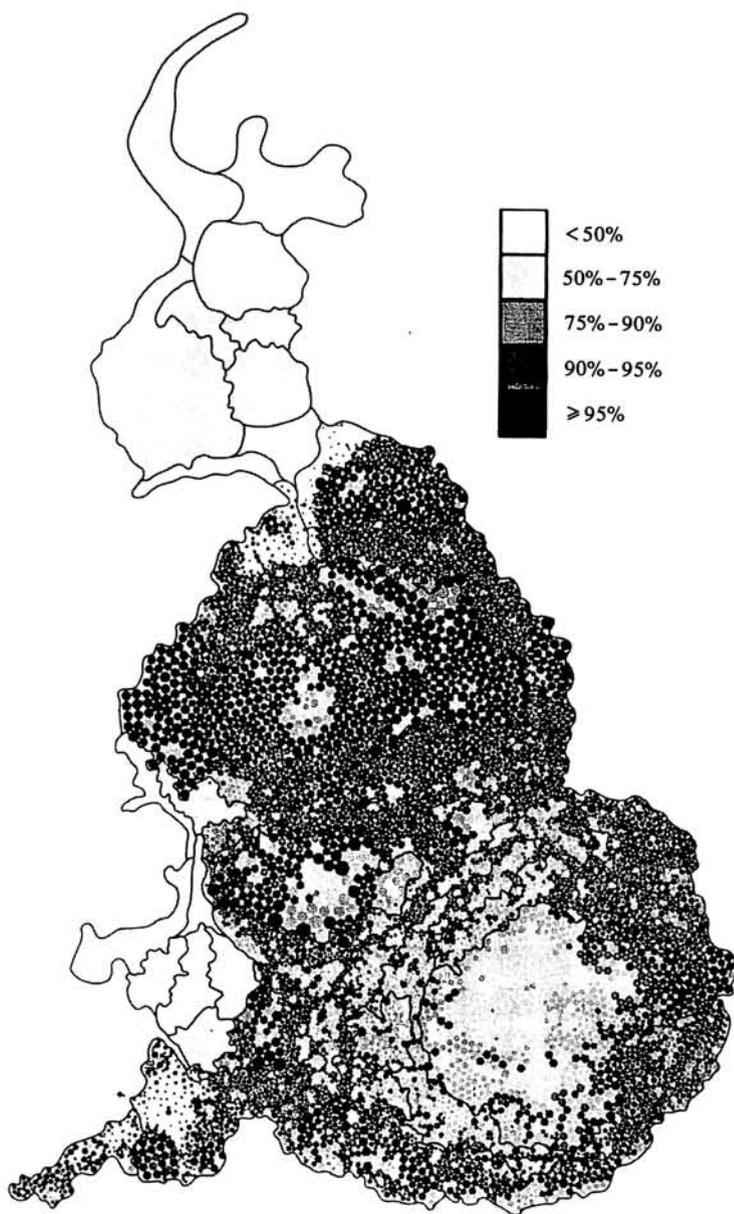
Conversely the traditional map of these same statistics (figure 8) suggests that, outside Scotland and Wales, most people live in areas where more than 90% of the population was born in England. The gradual mixing of English and Scottish or Welsh people as the respective borders of those countries are approached is shown clearly, but these are largely unpopulated areas. The heterogeneity of many English towns and cities is hidden in the traditional map in which the immigration around US airforce bases in East Anglia has a larger visual impact than the whole of Inner London. This picture tells more the story of the land than the people. Migration to (and in) Britain is mainly a tale of people in cities, not of the mixing of people in remote hamlets on the borders of nations, or the small-scale invasion of previously unpopulated airfields.

### Elaborating the design

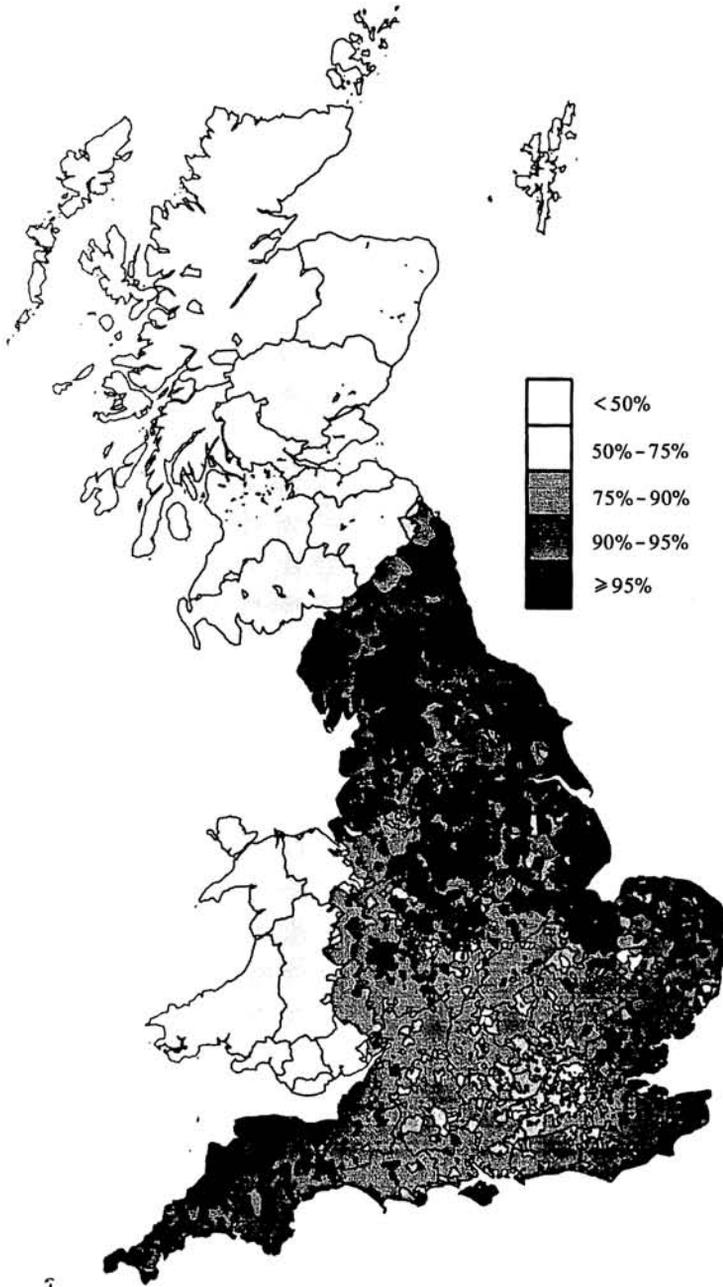
As the number of areal units is reduced to fewer than one thousand, many more opportunities present themselves. Cartographically one advantage of using a population cartogram consisting of a mere thousand areal units is that each unit becomes large enough to alter individually, so that nonoverlapping symbols [called glyphs (Anderson, 1989)] can be put in their place. Glyphs are 'sculptured characters'; after fixing 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 length (for example, height or breadth) to add one 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, for instance; 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.

### Changing patterns of voting

At the simplest levels the circles can be split into rings, coloured for instance by values for two time periods—to show, say, 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 time and space is not easy (see Dorling, 1995b). Recalling the example of political change, suppose we were interested in the swing of the vote rather than in simple change of party. The swing has two components:



**Figure 7.** Ward population cartogram showing proportion of English-born residents. For most analysis enumeration districts are considered too small as often the data are not available at that level. In Britain the standard smallest local administrative area is the electoral ward. On the ward cartogram the simple regional pattern of figure 5 is again evident—but here it has been possible to use a slightly more sophisticated key to differentiate between five levels of concentration. In Wales or Scotland below 50% of the population was born in England. As is clear from the cartogram, within England this level is only attained in a very few wards in the centre of London, and in one ward in Leicestershire (County boundaries are shown by dark lines so an imaginative British reader with a little practice can ascertain where places are). For most of London between half and three quarters of the residents were born in England, although there are interesting clusters in the capital where over 95% of the population in 1981 was English born. 10 444 neighbourhoods are shown in this image.



**Figure 8.** Ward equal land area map showing proportion of English-born residents. Enumeration district boundaries were not digitized for the 1981 Census, and so the highest resolution conventional choropleth maps could be drawn at was ward level (and part postcode sector in Scotland) comprising of 10444 areal units. This is a relatively simple picture to paint; but areas of sparse population steal our attention. White polygons in lowly populated rural East Anglia and Oxfordshire highlight the presence of a few foreign (US) visitors and appear as important, in visual terms, as the light area of the entire capital city. 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. The viewer has to be able to integrate this image with their knowledge of the underlying population structure if they are to get a fair impression of the distribution of English-born people. The map might look pretty but it does not truly show us where, in Britain, the largest concentrations of the overrepresentation and underrepresentation of English-born people are.

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direction and magnitude. In a three-party system the direction is 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 those constituencies to show in which direction the swing is (politically). Further animation of such colour pictures is illustrated by Dorling (1992b; 1994a).

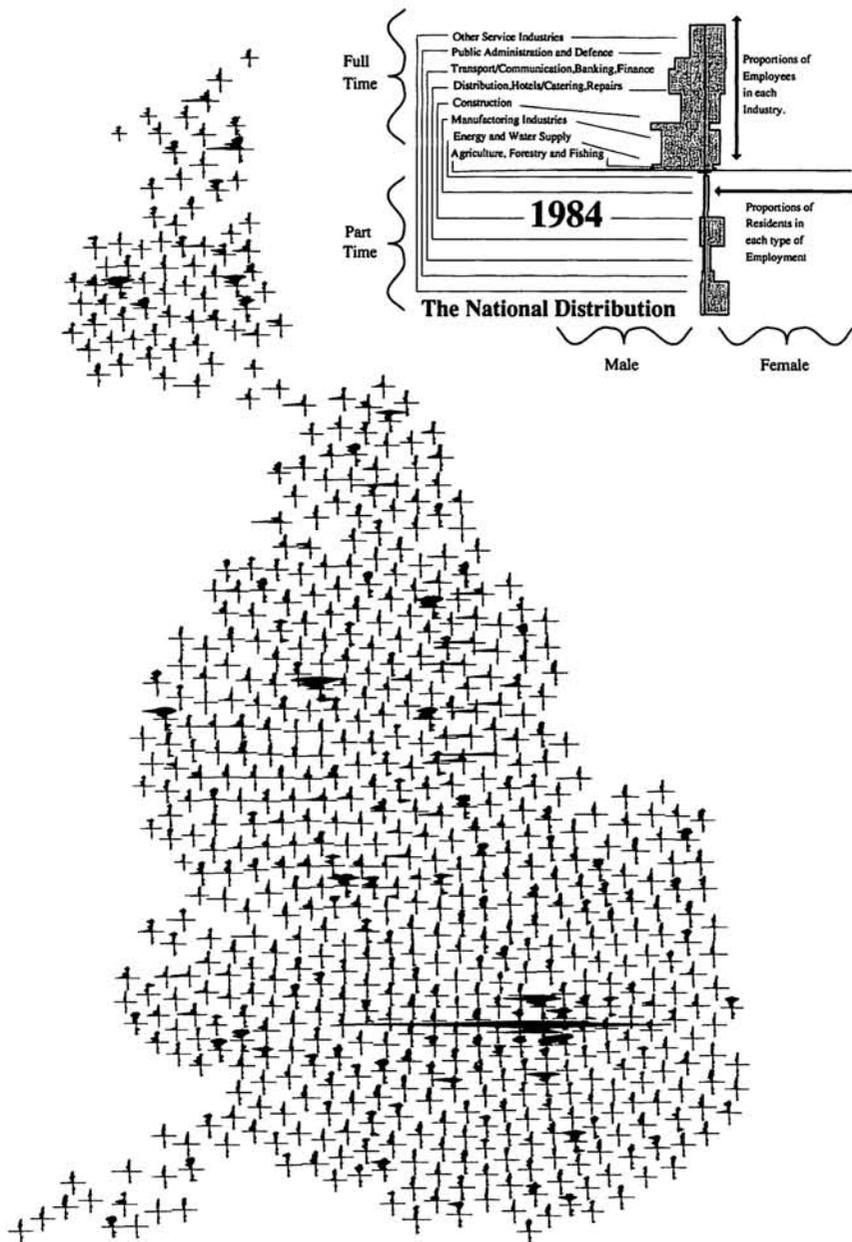
#### **Home and workplace**

Far more complex situations can be visualized. I will just give some examples which I have actually tried. The first 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. The distribution of employment by eight types of industry, employees' gender, and full-time or part-time status was plotted in this way (as a transposed reflected population pyramid), the area of each glyph chart being in proportion to the working population of the area (figure 9). Because of regional patterns, the industrial structure could be assimilated visually from several hundred pyramids, spaced out on the cartogram (although interactive zooming is 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, and thus the total area gives financial turnover for housing in that place. The cartogram of these (figure 10) 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. The largest tree-stump-like glyphs, scattered mainly across northern England are where the building society (from which the data came) sold an exceptional number of mortgages in that one year (Dorling, 1994b).

#### **The combination of factors**

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! Later statisticians extended these to thirty six (Flury and Riedwyl, 1981) but psychological research suggested that the permutation of so many different variables to features resulted in staggering differences in interpretation (Chernoff and Rizvi, 1975). This was hardly surprising as many combinations of variable in the original construction could visually cancel each other out. It was 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 reasons behind the voting swings mentioned above. Figure 11 shows the construction lines of the Bezier curves used to create the graphics. Almost all basic graphics packages now allow shapes to be defined in terms of these curves.

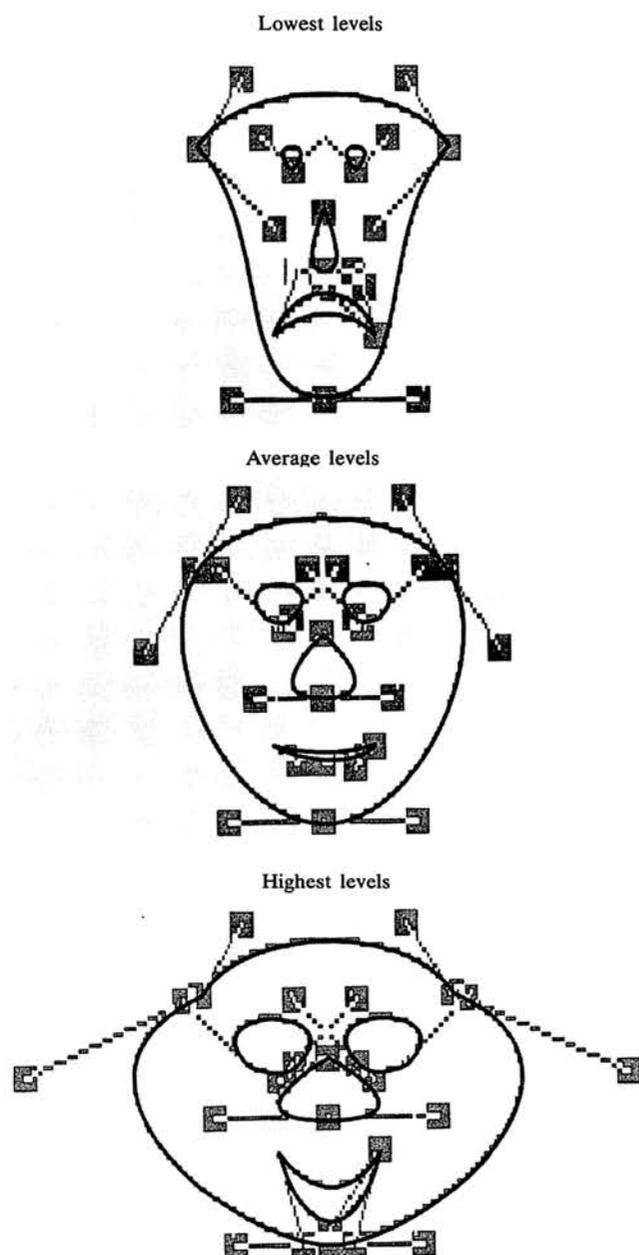
Constituencies were drawn as heads, their area in proportion to the number of voters, width by house price (fat cheeks when expensive!), mouth by employment rate (a smile when high employment), electoral turnout by nose size and industrial structure by eyes (large and low when dominated by younger industries).



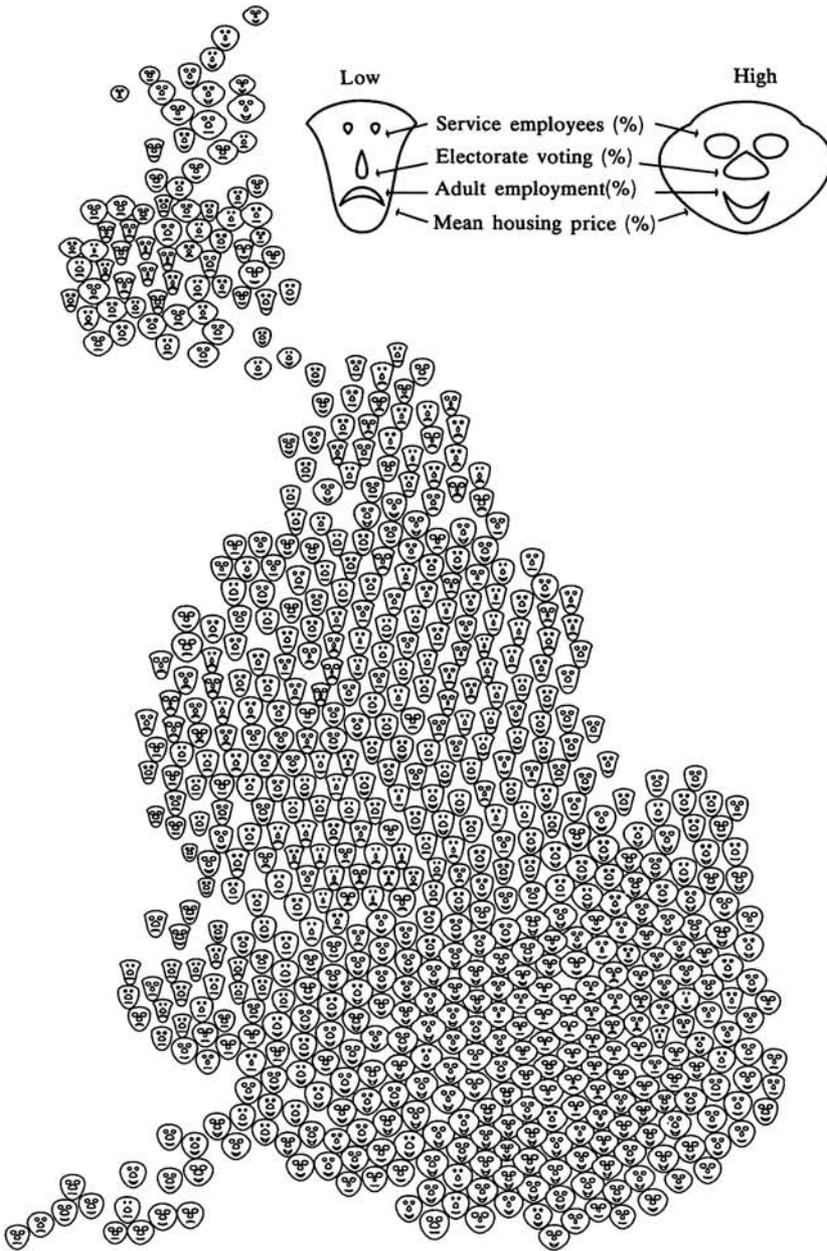
**Figure 9.** The distribution of industry on a cartogram of parliamentary constituencies. Population-like pyramids are drawn in each of the 633 mainland parliamentary constituencies, showing the industrial structure of that area. The construction of the glyph is quite complicated, and such visualizations are usually only intended for people with an established interest in the subject. The number of employees in eight types of industry are shown subdivided by status (part-time or full-time) and gender. The key shows the relative sizes of the national proportions of these groups in Britain in 1984. Regional administrative centres can easily be recognised as *top-heavy mushrooms*—central Glasgow, Edinburgh, Newcastle, Manchester, and so on. The image is dominated by the City of London, in which far more people work than live, creating a glyph which does not fit in a cartogram, such as this, based on nighttime population.



**Figure 10.** The distribution of owner-occupied housing on a population cartogram. The same cartogram base as in figure 9 has been employed here, but a very different style of glyph is being used to show a different kind of pattern. Housing price depends primarily on place, but also on the characteristics of the homes being sold; this detail is highlighted here. The overall size of the *trees* shows the volume of sales for one building society in 1983, and their height shows the price. A ring around London of more expensive properties (taller trees) is clear. Differently shaped trees form distinct *thickets* in different parts of Britain which can be examined and identified as particular types of housing market. The very large glyphs show areas of unusually high sales. One advantage of glyphs is that they highlight outlying observations very well. The use of colour would allow further elaborations (see Dorling, 1991).



**Figure 11.** The mechanics for constructing glyphs of faces using Bezier curves. The original Chernoff faces were drawn by pen plotter using straight lines and quite complicated programs. The faces here are made to look more appealing through the use of curves to describe them. Each face is defined by a single *path* of eleven Bezier curves, each consisting of two control points and an absolute point on which the curve must lie (shown in grey on the diagrams). Three curves are used to describe the shape of the face, and two for each of the eyes, nose, and mouth. The chosen range of possible variation in their positions is shown in the diagrams. In terms of file space these glyphs are very efficient symbols requiring only a few bytes of information to be stored. Good graphics software can also render them on the computer screen as speeds approaching animation rates—so the crowd can be scanned in detail! I hope the result is at least entertaining.



**Figure 12.** The distributions of housing, employment, and industry on a cartogram for 1983/84. The 633 mainland parliamentary constituencies are each represented by a face whose features simultaneously express the levels of five variables, drawn on an equal electorate cartogram. The key shows four of them (which are elaborated on in the text); the fifth is size of population—shown by the size of the face. The patterns in this picture are very interesting and could lead to endless discussion. When the faces are coloured according to the vote at the 1983 election, the *deaths-heads* inside Glasgow city are solidly red, whereas the *happy-faces* around the capital voted strongly for the government of the day and so appear blue. 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.

The colour of the face could be used to represent the actual voting patterns (a trivariate variable in a three-party system such as Britain). The study was initially meant as a tongue-in-cheek exercise, but the results were revealing—as they are shown in figure 12. The inner-city–outer-city and north–south divides in many aspects were clear; but the difficulty of drawing precise lines between the regions and around the cities was also apparent. Specific individual faces could be identified which did not ‘fit in’ (as when plotting swings some arrows did not ‘go with the flow’). Strong local trends—with relatively sharp divisions—were the clearest messages of these images. The faces were also used to show change over time, coloured and shaped by the swings in the votes, change in house prices, increase in unemployment, etc. Thus the facial expressions become populations’ ‘reactions’ to a changing situation, their colours perhaps indicating some political response of the electorate to some of the economic changes. Further psychological work would be valuable to determine how much the apparent increase in insight gained through using these particular glyphs could be outweighed by the possible ambiguities introduced through such an emotive visualization.

### 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 (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 with reality, underground rail maps whose shape is drawn to give a ‘clearer picture’. Throughout cartographic history people have been developing more appropriate projections for mapping their times and places. These have often met with resistance when they have offered a new perspective on the world. The 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 changing!

A number of alternatives to cartograms have been suggested, but these have often resulted in greater disadvantages when visualized. A population 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’. But our ability to gauge volume is poor, and hence should be avoided when possible. Then there are the well-known problems with visualizing surfaces (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 intended to show. If we are to resort to ‘3D’ then drawing a surface upon a cartogram base allows for far more sophisticated and, simultaneously, more 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 interactive animation to focus in 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 those tiny places. Cartograms should not be seen as just another option in the 'toolbox', but as a fundamental necessity in the just mapping of spatial social structure.

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