New maps of the world, its people, and their lives

Danny Dorling

This short paper is based on a presentation given to the Society of Cartographers annual conference in Cambridge in September 2005. The talk was entitled "one small step for two men, one giant leap for mapping" and discussed the academic breakthrough of 2004 in the creation of a new density-equalizing map projection by Michael Gastner and Mark Newman of the University of Michigan, USA. Although this may sound like the most obscure of topics, in the talk an attempt was made to make the claim that what these two had achieved is potentially the most significant breakthrough in cartography since Gerardus Mercator's wall maps of 1569. The talk was illustrated by numerous images. A few are reproduced here and that claim is reiterated. Gastner and Newman have made their projection widely available and new versions of the software are being prepared as I write – it remains to be seen whether it will be as widely used as I predict. Here the new mapping is introduced, first with national examples and then for the world as a whole.

Cartograms

A cartogram is a map-like graphic. Often times two dimensional cartograms show areas of land drawn in proportion to population. In 1975, A.K. Sen published "A theorem related to cartograms" (in American Mathematics Monthly, 82, 382-385) that proved that the 'perfect cartogram' exists – but it took almost thirty years for the computer code to be written that could most closely approximate that solution. Many solutions were suggested in the interim. Readers can consult the Further Surfing Section below for more on those attempts (see in particular Waldo Tobler's 2004 review). However, the efforts of cartographers and geographers did not quite achieve in practice what Sen had shown was possible in theory.

The idea for the solution that Mark Newman and his PhD student Michael Gastner devised came from a fusion of the old cartogram design problem with the rapidly expanding field of diffusion modelling used in, among other things, the design of semiconductors. Although the diffusion algorithms describe the motion of atoms away from concentration gradients in semiconductors, similar algorithms are used in the design of "wiring" on chips. The surface of a silicon chip contains thousands upon thousands of tiny routes. Each route is given a near equal amount of space on that surface. To design the layout of lateral routes computer software was needed: another kind of diffusion modelling. Lateral thinking itself was needed in the development of the new algorithm and it was reported in the scientific press at the time of its publication that the authors of this algorithm were actually working on the problem of how to represent internet traffic congestion when they realised that their solution was well suited to create population cartograms.

There are essentially two types of population cartogram: continuous and non-continuous. In the latter topology is not preserved and an example is shown in Figure One: of the three thousand odd counties of the United States each drawn in proportion to their population around the year 1990. Each county is represented by a circle, drawn with its area in proportion to its population and placed so as to be drawn as near to its original neighbouring counties as possible and as far from areas which it does not neighbour on the original map. For some cartographic purposes non-contiguous, not topologically correct cartograms such as this have been preferred by map makers. The shape of each area is represented by as simple a symbol as possible, and areas can be relatively easily labelled. The cartogram can even be drawn in a spreadsheet as a "bubble plot"! However, this type of cartogram is a little arbitrary in appearance, and areas contiguous on the cartogram may not be contiguous on the ground (such that false clustering of phenomena may be implied, or too simple a picture presented).

A continuous area population cartogram, as shown in Figure Two, almost always produces what initially appears to be a more convoluted image than the original map it was derived from. Figure Two shows the same US counties,

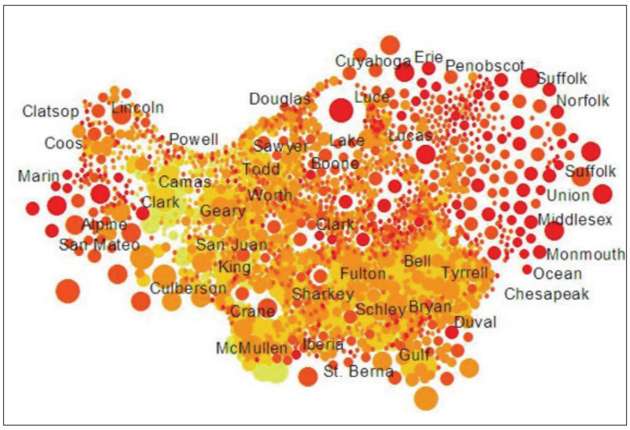

Figure 1 Circle Cartogram of USA Counties

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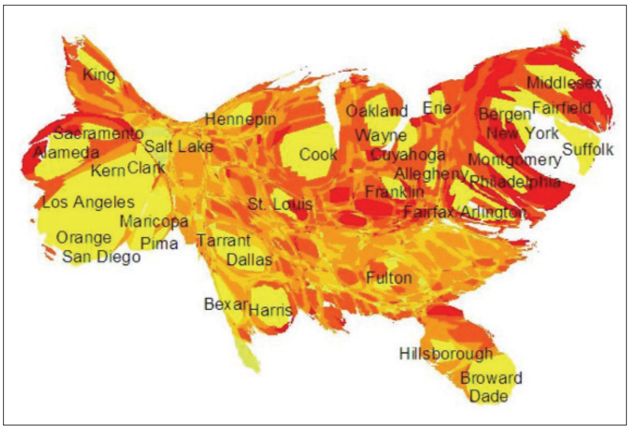


Figure 2 Continuous Cartogram of USA Counties

shaded the same as in Figure One and drawn with area in proportion to the same population, but now with all counties still touching their correct neighbours and no false topology being introduced. This cartogram was created using the new diffusion algorithm. The cartogram appears a little convoluted because the borders of US counties were originally drawn to commonly be quite simple shapes on a traditional map. On this cartogram, were you to trace a route by road on the Federal highways of the United States, and follow it, you would reach your destination just as surely as if you were using a tradition route map. Quite why that matters and why you might wish to do so are explained below. What matters for here is that this is now cartographically possible; it was not practically possible – even if it was theoretically possible – until now.

The new algorithm has one further feature that makes it and the cartograms it creates unique. It is conformal. For British based readers this is best illustrated by Figure 3: an equal population cartogram of the 641 parliamentary constituencies of Britain as they existed in 2001. The cartogram may initially appear odd but look closely within London at the river Thames and see what shape it appears to be. It may be a little clearer on Figure 4. Essentially the Thames in London is almost the shape it should be. Zoom into any part of the Thames and it appears even more the shape it should be. In fact zoom into any part of the cartogram and, as the area under view becomes smaller, shapes appear more familiar. At the limit angles are perfectly preserved and a circle on the ground is a circle on the cartogram. The diffusion algorithm preserves direction just as Mercator's projection did more than four centuries earlier – it just preserves it locally rather than globally. Why should this matter?

Look again at Figure 3. Suppose that you were interested in whether the incidence of a particular disease amongst the population were clustered, or you wanted to know how evenly universities were spread across the country, or to what extent the names that appear in the directory "Who's Who" are geographically biased. On an equal population cartogram all these points should appear evenly distributed if they are evenly distributed amongst the population, but only on a conformal equal population

Figure 3 Conformal Equal Population of the UK

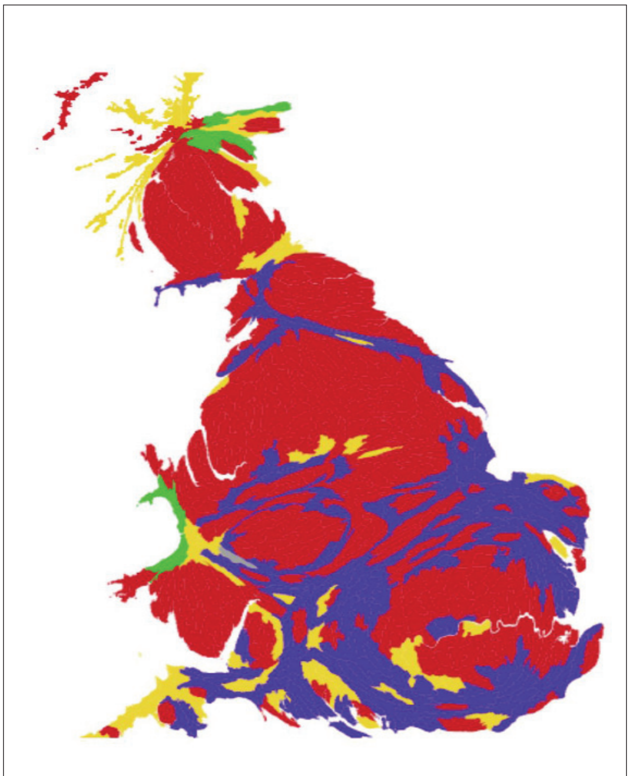


Figure 4 The British General Election of 2001

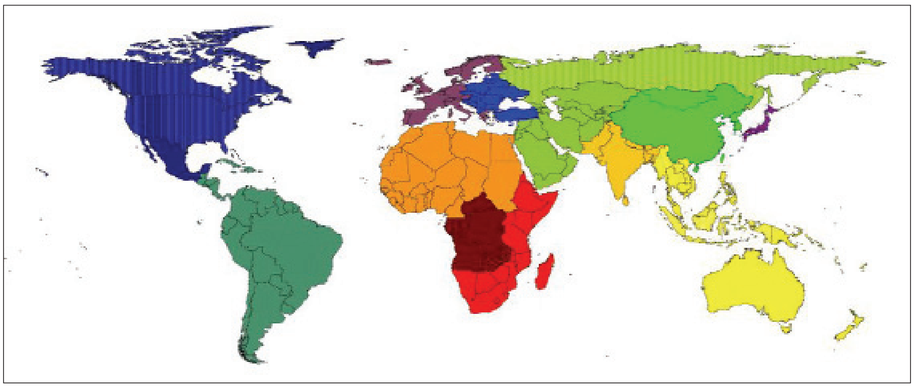
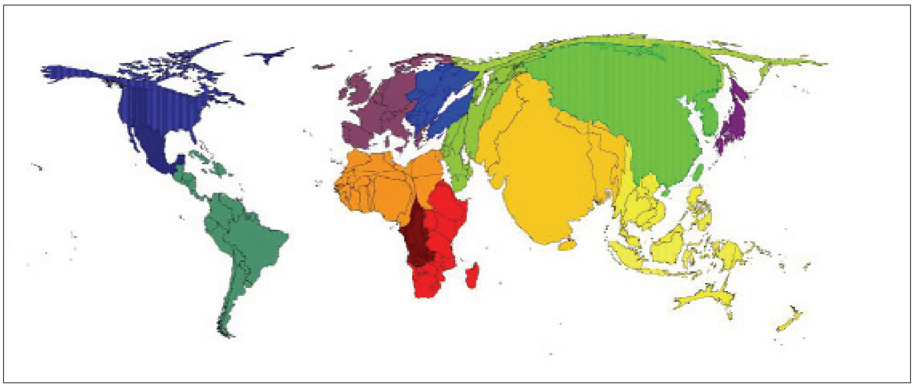


Figure 5 World Equal Land Area Cartogram

Figure 6 World Population Cartogram (2002)



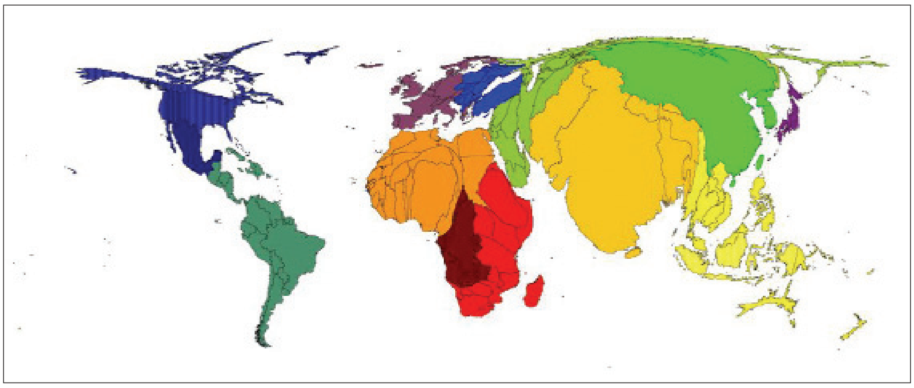
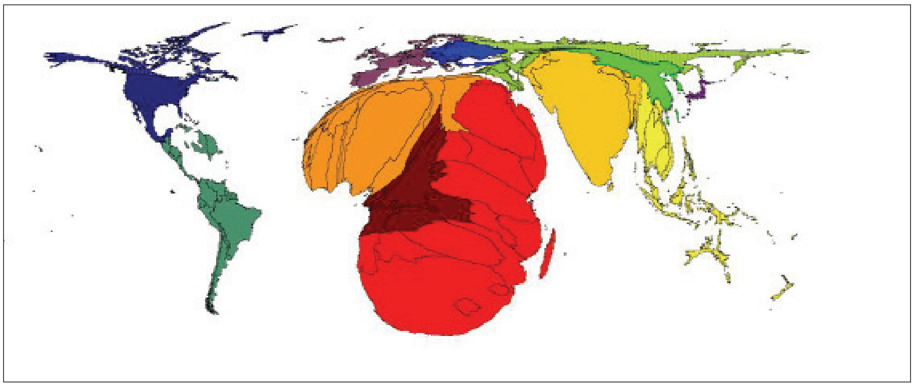


Figure 7 World Cartogram of Births (2002)

Figure 8 World Cartogram of HIV/AIDS (2002)



cartogram can you make claims about the distance between any particular pair of points because on any other population cartogram that distance is arbitrary. On a conformal population cartogram – or rather on the unique conformal population cartogram – that distance is proportional to the square root of the population living between those points. You can then apply statistical measures to the point distribution of diseases to see whether there does appear to be clustering. If two universities abut on the cartogram they abut on the ground. And when the home postcodes of the “Good and the Great” are plotted and are found to be clustered not just in particular counties and particular boroughs of London, but in particular streets in North Oxford and South Kensington – they really are so concentrated. A unique cartogram is of unique value.

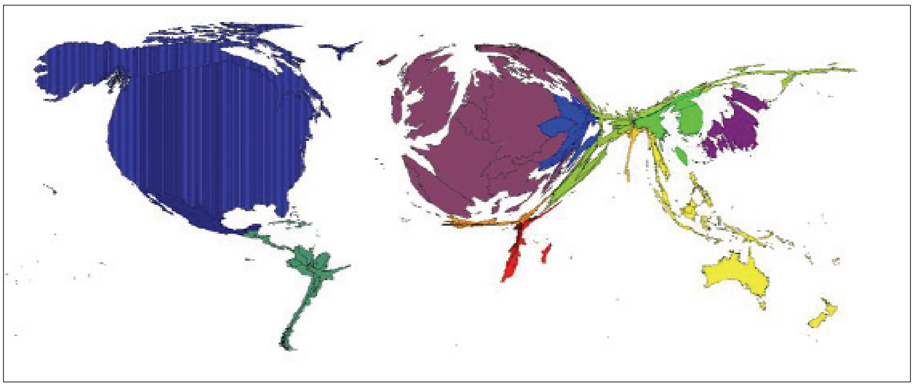
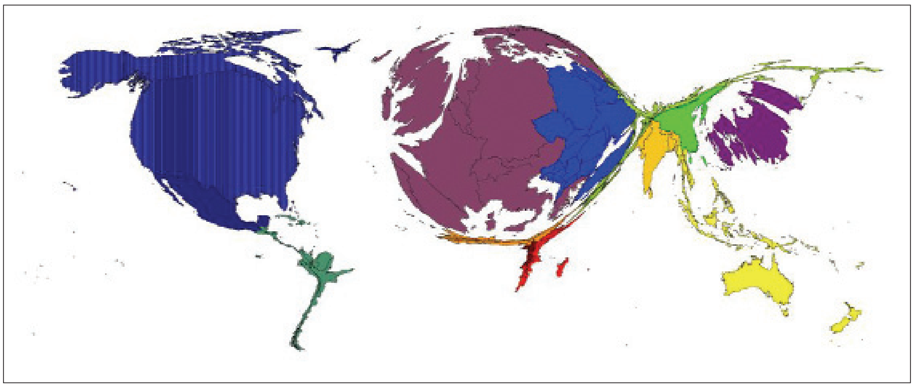


Figure 9 Toys Imported Worldwide ($'s 2002)

Figure 10 Sewerage Connected (people 2002)



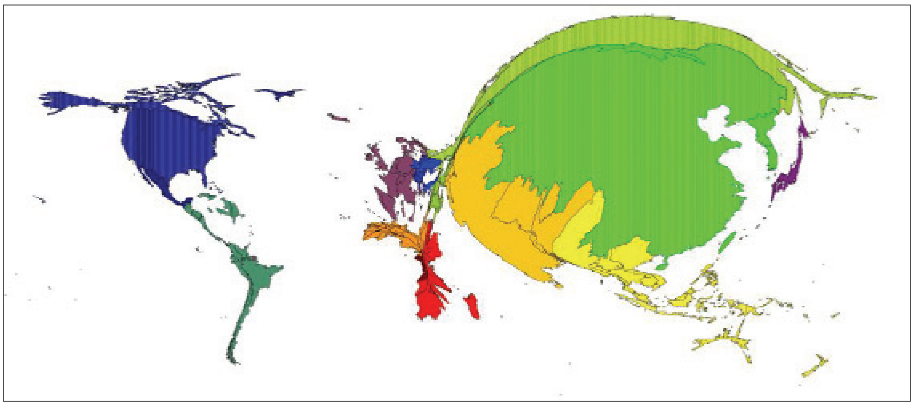
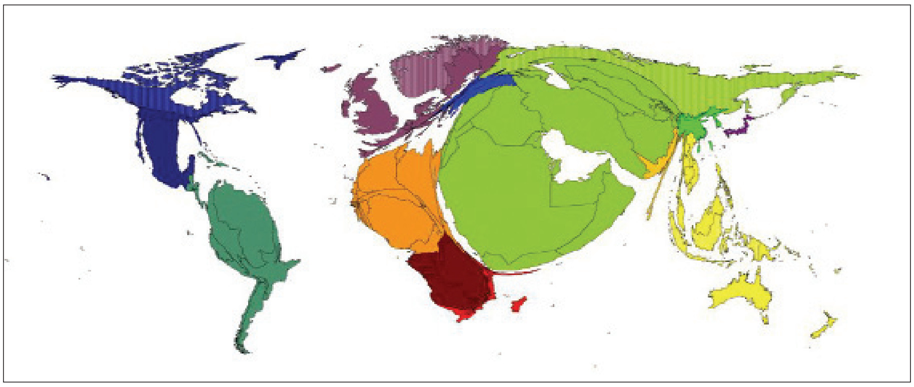


Figure 11 Containers Loaded (in 2002)

Figure 12 Crude Petroleum Exported ($'s 2002)



The advantages of this particular projection are numerous. For instance, the shapes on the conformal population cartogram need not be that be that convoluted. They are not on Figure 3 as parliamentary constituencies are more convoluted on the traditional map. On Figure 4 the results of the general election of 2001 are used to colour in the cartogram producing a far simpler – and correct – mapping of the results of that contest than a traditional map ever could show. What is more, for those misguided souls who wish to take the northern coast to coast "Tory constituency walk" – never steeping once into the red, this cartogram shows them how it was still possible back in 2001 to do so. But it does better than that – it shows the walker just how misguided they would be to imagine that they were doing anything other than walking a tightrope of blue constituencies stretching in a narrow band through the north of Yorkshire – an area large on the land area map but somewhat short of people.

This brings us back to the highways of the United States and the question as to why you might ever want to use a cartogram such as that shown in Figure 2 to navigate your way around that nation. For most tourist to the states it is the national parks, the mountains and the coasts (and their theme parks) that are the great attractions. But should you wish to take a driving route, evenly, through the population of the most powerful country on the planet the cartograms shows you the options and lets you plan your route. For instance from the small counties of New York, to Cook (Illinois) in the mid west, across to Orange (California), back through Harris (Texas) and to Dade (Florida). The United States of America is a country of cities and suburbs, not a home where the buffalo roam and the deer and the antelope play! Navigate a nation with the population cartogram as your map and you can navigate through its peoples rather than through its outback. But is there something mischievous in the suggestion that a conformal population cartogram is needed in the United States for navigating through its peoples?

Devilments

What Mercator's wall maps of 1569 achieved most was a change in the way people thought about the world. The world was suddenly arranged with the compass rose supreme, the land masses of the northern hemisphere dominant and the playing field for global trade laid bare. Few serious attempts have been made in the subsequent centuries to alter this view. That is hardly surprising as it was that trade that increasingly defined what the world, as a whole for people, was about. It was from the rest of the world that spice, slaves, sugar, cotton, clothes, electronics, music, food, toys, banks, films, TV, news, eventually almost everything, appeared to come from. The Mercator projection is a projection where what is paramount is direction – to where you have to travel to trade and from where things come. When Arno Peters' promoted a very similar map to Mercator that mainly differed by being equal land area his results were described by some cartographers as a devilment! Play with map projections and you play with people's views of how life itself is organised. Mercator's projection itself was, of course, viewed a devilment as compared to the Christian world images that it replaced (images in which the world map was bordered by the hands and feet of Christ on the Cross, the maps centred on Jerusalem and East was up)!

A Peters' like projection is shown in Figure 5. It is an equal area cartogram of the world but one in which area is made proportional to land area. Note also how 12 regions of the world have been shaded 12 separate shades ranging, on the spectrum, from the richest regions of the globe: Japan, Western Europe and North America, through Eastern Europe (including Turkey), South America, Greater China, Near Eastern Asia, Far Eastern Asia (and Australasia), Greater India, Northern Africa, South-eastern Africa and central Africa. On the maps that follow the colouring of these twelve regions is preserved.

Now consider Figure 6. It looks very like Figure 5. This is part of the beauty of the diffusion algorithm. The cartograms it creates are a beguiling devilment. This is what the first new world maps are likely to look like that drawn on the new projection. Figure 6 is an equal population cartogram but North is still up, the Northern Hemisphere still dominates and Russia and the United States still appear a long way apart despite almost touching on the globe. It takes a little time to realise that Figure 6 is not quite a Mercator projection – that it is, in fact, a conformal equal population cartogram of the world. (devilment is a noun describing something that is mischievous, mischief making and roguish – not necessarily wrong!).

By re-projecting the world map in such a way that locally topology is not just preserved but shapes and angles are maintained as well as is possible, the new diffusion algorithm creates projections which are far less alien to our eyes than any world cartograms yet created. Of course if the quantity being mapped differs in land -area ratio between territories even more so than does population, then the images become less and less recognisable – but it is quite a revelation to see just how much the world can be re-shaped and the familiar territories still recognised. Figures 7 to 12 re-project the world showing the roughly 200 territories of the planet drawn respectively in proportion to the number of births that occur in each territory per year (Figure 7); to the number of people infected with HIV/AIDS there (Figure 8); to the value of toys imported there per year (Figure 9), to the number of people connected to a sewerage system in each territory (Figure 10), to the number of times container ships are loaded and unloaded a year on the coasts of each territory (Figure 11), to the value of crude oil exports from each territory (Figure 12).

Both the Mercator, the Peters' and all other traditional map projections of the globe hide any attempts made to show just how unevenly disease and suffering, wealth and luxury, goods and resources are all distributed around the planet. It took four centuries of trade for the world to become this uneven, but the projection that was part of what made such trade possible will not be the projection that most clearly reveals the nature of devilry in the world we now live in. The Peters' projection was announced to the world over thirty years ago and used extensively to paint an ever so slightly alternative image of the world: an image in which each country and each area within each country is drawn roughly in proportion to its land area. There is now a projection available which will create a unique conformal projection in which every territory and every area within every territory can be drawn pretty much exactly in proportion to its population. Is now the time for such a new world map?

Postscript:

Since the publication of the original algorithm Mark Newman has been working on cartogram projections that re-project the surface of the sphere rather than a two dimensional plane. The cartograms show in Figure 7 to 12 were drawn using the first release of the original software and are not perfect in that some countries are not quite drawn in exact proportion to the value being mapped in order to preserve shape (for instance Mongolia should have no area in Figure 11). By the time you read these words it is likely that many more images will be available on the web and new software may be available. In fact it is important to realise that the new world map will not be a wall hanging – as was most appropriate in 1569 – but most likely a re-projection of the surface of a sphere hanging inside the code of a computer – an equal population globe. The world may never look quite the same again!

Acknowledgements:

I am grateful to Tiffany Manting Tao for drawing the two cartograms of the United States used here and to Bethan Thomas for advice over this article. To Mark Newman and Michael Gastner for their help in allowing me access to some of the images used in the talk this short paper is based on – and to Waldo Tobler for his encouragement over many years of my interest in this hopefully soon not to be so obscure a field of enquiry!

Further Surfing

The central repository for information on cartograms is "cartogram central":

http://www.ncgia.ucsb.edu/projects/Cartogram_Central/

The original academic paper giving the new solution is published in the Proceedings of the National Academy of Sciences:

http://www.pnas.org/cgi/reprint/101/20/7499.pdf

The algorithm is given at:

http://www.pnas.org/cgi/data/0400280101/DC1/1

And at the time of writing the software was available at Michael Gastner's homepage:

http://www-personal.umich.edu/~mgastner/

For a series of UK hand and computer drawn cartograms and some world cartograms see:

www.shef.ac.uk/sasi, www.shef.ac.uk/sasi/hguk and www.shef.ac.uk/sasi/thesis

Type "Arno Peters" into google to find his detractors; and for his supporters see:

http://www.petersmap.com/

And for a very useful review see Waldo Tobler, 2004, "Thirty-five Years of Computer Cartograms", Annals, Assoc. Am. Geographers, March – available on the web at:

http://www.geog.ucsb.edu/~tobler/publications/pdf_docs/inprog/Thirtyfiveyears.pdf

which ends:

"The computer construction of cartograms has progressed rapidly in the last several years.

I expect that, with the increased speed and storage capabilities of future computers, the next thirty-five years will lead to further changes in this field. [As an illustration of this an unpublished manuscript by two physicists (Gastner and Newman 2003) came to my attention, as the present paper was undergoing proofing. In this manuscript they use the diffusion equation in the Fourier domain and with variable resolution. This can be considered a mathematical version of Gillihan's (1927) smoothing procedure, to compute a value-by-area cartogram]."

What comes around…..!