

Cartogram Mapping and its Application to Cancer Data Visualisation

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Abstract

1 Introduction

Cancer statistics directly represent and relate to the people living within geographical areas. Geospatial statistics have been presented on maps to communicate information to the general public for centuries as they utilise familiar geographic shapes. The mapping of diseases summarises spatial variations and can be considered a descriptive statistic of the relationship between a disease and the underlying geography (Elliott et al. 2001). The distribution of the statistic must be visible, it is not enough for areas on maps to be recognisable. It is reasonable to explore views that enhance the communication of the cancer statistics, especially as it is the people that are of interest, not

the land they live on. This has spurred innovations over the previous centuries to enhance maps to effectively communicate cancer outcomes, and health outcomes more broadly.

The visualisation methods used to present cancer statistics will depend on the intended message and users of the map. Presenting statistics as visualisations requires transforming individual observations into aggregations of communities as geographical units. Visualising diseases on maps is often the first step in exploratory spatial data analysis and effectively helps in the formulation of hypotheses (Jahan et al. 2018). Disease maps help to present geographic patterns that may have been overlooked in a table, obscuring the geospatially related statistics (Moore and Carpenter 1999). By providing a visual representation of cancer outcomes, geographic patterns of disease are able to be identified and effectively addressed. Exeter (2017) recognises one of the key challenges with mapping spatial patterns of disease is the design of visualisations. This paper addresses the visualisation techniques and their applications to cancer statistics. Highlighting the differences and historic use of these displays.

2 Map displays for disease data

A choropleth map is used to display the characteristics of a spatial relationship of measurements. They are true maps of the topology, constructed for visual inspection of spatial patterns on a familiar geographic form. Classed choropleth maps break a continuous variable into a small set of categories, often quintiles, and use a gradual colour scheme to shade all areas that fall in the same category (Bell et al. 2006). 1 1 shows a choropleth map where each state of the United States of America is coloured by the average annual rate of new cases of lung and bronchus cancer from years 2012 to 2016. Identifying and explaining spatial structures, patterns, and processes involves considering the individuals in communities and organising communities into representable units (Moore and Carpenter 1999). A choropleth is constructed by drawing the geographic or political boundaries, and filling the shapes with colours to represent values of a measured variable (Tufte 1990). Early versions of choropleth maps used symbols or patterns instead of colour. As an alternative storage device to a table, it preserves locations for geographically ordered data, with usage dating back to the 1800s (Berry, Morrill, and Tobler, n.d.). Bell et al. (2006) discuss the use of choropleths to visualise cancer data, and Walter (2001) gives an overview of the development of these maps for displaying disease data.

Utilising the familiar state boundaries can make a map intuitive to read (Brewster and Subramanian 2010), and allow viewers to visually infer the spatial relationships in the data, i.e. how cancer rate differs across the states. The familiarity of the geography is a worthy consideration when presenting results of spatial analysis. Just as geographers are no longer the only creators of maps, Bell et al. (2006) suggests the audiences of spatial health data analysis have extended beyond researchers to the public, policymakers and the media. While the areas are recognisable shapes, they are often politically driven boundaries with individual areas being of non-uniform size, containing different population densities and subject to change over time. The different population and geographical sizes of administrative areas can attract attention to the shades of the unpopulated but large areas (Tufte 1990). Choropleths can inhibit visual inference when presenting human related statistics as the display may draw attention from the ‘potentially more important results in the more populous communities’ (Exeter 2017).

Choropleth maps can be useful devices for communicating information to public on a familiar map base. A cancer atlas is a choropleth map, or collection of maps, representing cancer incidence and

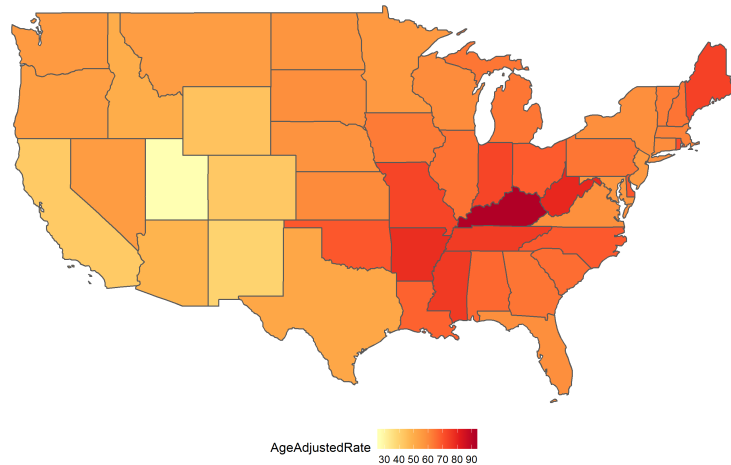


Figure 1: A choropleth map of the United States of America. Each state has been coloured according to the average age-adjusted rate of incidence for lung and bronchus for females and males in the United States 2012-2016. The state of Utah has an unusually low rate of lung and bronchus incidence. The state of Kentucky is high, the surrounding states also have high rates. There is a pattern of average higher rates toward the East Coast and lower rates toward the West Coast.

mortality for a country, or group of countries. In epidemiology, choropleths are often used as a tool to study the spatial distribution of cancer incidence and mortality. The data collection methods of cancer mortality rates across regions, and the administrative control within regions lends itself to choropleth visualisation. d’Onofrio et al. (2016) provides the definition of a cancer atlas, beginning with Haviland’s maps in 1875, they attribute UK cancer atlases to Howe (1963), and early work in US cancer atlases can be attributed to Burbank (1971). The increasing development and use of disease maps can be attributed to the availability of geographic information system software (Exeter 2017). The choropleth maps presented levels via hatchings or dots on a black and white scale. These atlases were key to developing hypotheses regarding areas with unusually high rates, geographic correlations, work related exposures, and high risk diets (d’Onofrio et al. 2016).

Almost 100 years of cancer mapping in the United States and the United Kingdom has seen increased effectiveness in the presentation cancer statistics. Mortality rates are now often presented as relative rates of risk across the population, and age adjusted to correct for the higher prevalence of cancers in older populations. Howe (1989) describes Stock’s development of the standardised mortality ratios through the 1930s. Table 1 presents summarises the measures presented in published cancer atlases, and provides a definition of each measure.

Table 1: Measures used to report cancer statistics

| Measure | Details |
|---------------------------------------|--|
| 1. IR (Incidence Ratio) | $(IR)_i = \frac{(Incidence\ Rate)_i}{Average\ Incidence\ Rate},$ Cancer incidence rate in region i over the average cancer incidence rate for the total region |
| 2. SIR (Standardised Incidence Ratio) | IR standardised by age structure in each region i |

| Measure | Details |
|----------------------------------|--|
| 3. RER (Relative Excess Risk) | $RER = \frac{(Cancer\ related\ mortality)_i}{Average\ cancer\ related\ mortality}$ Represents the estimate of cancer related mortality within five years of diagnosis Also referred to as ‘excess hazard ratio’ |
| 4. Age Adjusted Relative Risk | RR standardised by age structure in each region i |
| 5. Rate per 100,000 | Cancer incidence per 100,000 population |
| 6. Age Adjusted Rate per 100,000 | #5 standardised by age structure or region |
| 7. New cancer cases per 100,000 | Specific methods could not be found |
| 8. Count | Crude cancer counts |
| 9. Below or above Expected | Alternative expression of the SIR |

The atlas of Cancer in Queensland (Cramb, L Mengersen, and Baade 2011) focussed on highlighting the difference in experience for those living in rural and disadvantaged areas. They used Standardised Incidence Ratios modelled via Bayesian methods, and explored the information presented in a range of selected atlases. These atlases provided Incidence, Survival and Mortality rates to the public on Areal or Isopleth map bases.

The presentation of these rates considered not only the map base, but also appropriate choices of colour blind friendly colour schemes, and categories of the values to highlight significantly different areas.

3.1 Supporting statistics in public facing atlases

The primary display of an atlas is often the choropleth map. Cruickshank’s (1947) as cited by Walter (2001), discusses using visuals as ‘formal statistical assessment of the spatial pattern’. Atlases can also utilise bar charts, tables and scatter-plots as useful alternative displays. These displays can present the cancer incidence and mortality rates, as well as the supporting statistics of the atlas. When presenting cancer atlases, d’Onofrio et al. (2016) believes the intuition derived from maps must be ‘validated by rigorous statistical analyses.’ Bell et al. (2006) suggests additional materials such as ‘good tables, graphs, and explanatory text’ support understanding and inference derived from maps, ensuring the message communicated will be consistent across a range of viewers. The interactivity of modern maps enables supplementary information to be incorporated without cluttering the screen, such as in a tool tip feature. The atlases provided additional information to help users understand and interpret the spatial distribution presented. The use of these supports were found in a variety of online map sources. These additional pieces of information can help to validate, explain or explore relationships between cancer incidence and survival rates.

3.1.1 Geographic hierarchies

While atlases are often used to describe differences between areas, statistics may be displayed at different levels of aggregation. The World Health Organisation and UN Regions can also be used to aggregate areas (Ferlay J 2018). World atlases can allow for displays of data aggregated into continents, countries, states, provinces and congressional districts (Group 2019).

3.1.2 Population distribution

It is likely that each population area will have a different amount of people, information regarding the distribution of population levels may be provided in a table or histogram display (“All-Ireland Cancer Atlas 1995-2007” 2011). Atlases have the opportunity to connect the population to the land available to them by communicating population density. Atlases can also connect the population to the land available to them by communicating population density as is shown in the United States map examples.

3.1.3 Statistical uncertainty

Statistical uncertainty is communicated through a Confidence (CI) interval, statistical significance levels, Boxplots, Distribution plots, and reporting the Sample Size and Standard Deviations. The additional statistics often include a measure of the statistical uncertainty of the values of the statistics presented in a choropleth. In the review of atlases in the public domain, atlases were considered to report uncertainty to the non-expert user if they included a measure of statistical uncertainty either within or alongside the map. The maps considered used standard and well known measures including credible intervals and standard deviation, statistical significance, box plots and distributions. The maps employing uncertainty ranged from static pdfs or infographics, to interactive online resources. Close to half of the atlases identified (42%, n=14) included some measure of uncertainty. The most common measure used to represent uncertainty were credible or confidence intervals (CIs).

3.1.4 Demographics

Demographics include information regarding the age and sex distribution of the areas presented. Sex is an important cofactor for cancer atlases. As some cancers are sex specific, and others may be found in both males and females, atlases often specify their use of gender in the displays. Atlases can allow for interaction as users can select between displays for males, females or both depending on the type of cancers explored.

3.1.5 Socio-economic indicators

Socio-economic indicators can explain how the experience of cancer prevalence varies for various members of a society. These indicators include unemployment rates, poverty rates and percentages, remoteness and education levels achieved though only a few atlases also explored the impact of rurality on cancer rates. The Human Development Index can be used to understand the socio-economic experience of a community, as can the Income levels as measured by World bank list of economies (Ferlay J 2018). The areas are usually ranked and allocated to quintiles to be presented as categories describing the ranking.

4 Alternative displays

4.1 Cartograms

A cartogram alters the map base with the intention of improving the presentation of the statistic of interest. For a single variable of interest, each map area is changed to emphasise the distribution by representing the corresponding value, in comparison to the value of the other areas (Dougenik, Chrisman, and Niemeyer 1985). The changes in the map base occur by altering individual areas, by altering the shapes or boundaries.

Australia presents an extreme case of an urban rural divide. The land mass occupied by urban electoral districts is only 10% of Australia, yet 90% of the population live in these urban areas. To present election results on a choropleth map should be ‘unthinkable’, as it means diminishing the visual impact of majority of the electorates. A 1966 cartogram was presented an alternative which uses mostly straight lines, and the result looks very little like the geographical shape of Australia. This issue is felt in any nation which experiences an uneven population distribution. The United States is affect by the different densities of neighbourhoods or states. As this population distribution continues to change the need for cartograms as an alternative to a choropleth map should only increase.

Choropleths may be considered true topological maps, however, if the land mass displayed covers enough of the globe, there must be a transformation or distortion to display the land in 2D. The amount of distortion is related to the distance covered by the landmass displayed Tobler (1963). World map projections reflect the frequent perspectives used to view the earth. Choropleth maps will always be distorted if they cover enough of the globe, just like photographs of the globe from space. Choropleth creation requires choosing a map projection that shows a favourable distortion of the geography for presenting the set of spatial information. Selecting a display can prevent misinterpretation of global statistics, as global maps face the challenge of equitable displays of land mass on maps (Raisz 1963). Maps that do not specify a projection can be considered to have

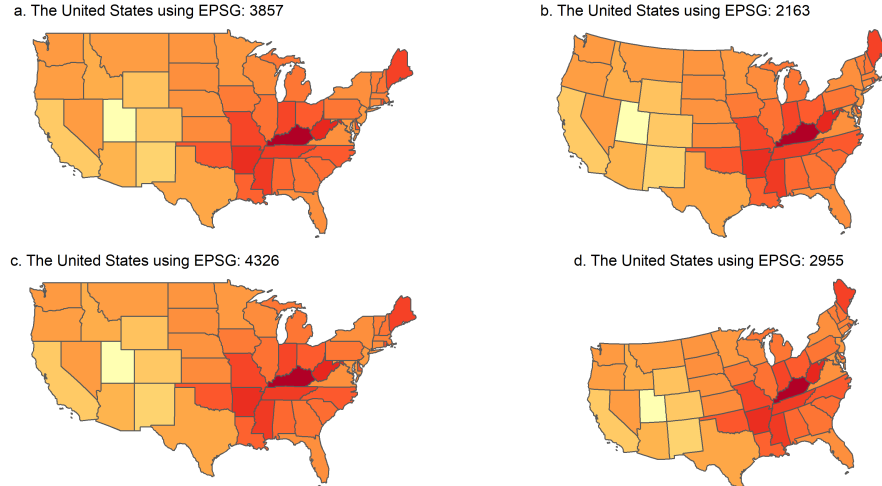


Figure 2: Four choropleth maps of the United States of America using various coordinate reference systems. Each state has been coloured according to the average age-adjusted rate of incidence for lung and bronchus for females and males in the United States 2012-2016. The map projections alter the shapes and angles of the boundaries of each state. Maps a and b are similar in their straight edges, unlike maps c and d which curve on the northern United States border.

some unknown projection. If the statistic presented on the map base relies on physical distance and is influenced by the topology there is no transformation needed, beyond choosing a reasonable projection.

The purposeful distortion of the map space, transformed according to population density, is beneficial when a uniform density of the map base is desired. Population then becomes a uniformly distributed background for the statistic presented (Berry, Morrill, and Tobler, n.d.). Dorling (2011) suggests ‘population distribution is often extremely uneven in former British colonies’, this makes the distortion necessary (Griffin 1980). When implementing a distortion of the geographical shape according to population, the resulting display is an area cartogram (Olson 1976), population-by-area cartogram (Levison and Haddon Jr 1965), or iso-demographic map.

Cartograms provide an alternative visualisation method for statistical and geographical information. The key difference between a choropleth and a cartogram is the desirable augmentation of the size, shape or distance of geographical areas (Dorling 2011). Cartograms may be seen as an extension of map transformations and projections. The favourable distortion is proportional to a value other than actual earth size area (Olson 1976). A disadvantage of the conventional map is that sparsely populated rural areas may be emphasized, whereas the areas representing cities are very small, making interpretation of spatial patterns very difficult. The distortion of a cartogram accounts for the population density, preventing it from obscuring the spatial patterns (Levison and Haddon Jr 1965). The spatial transformation of map regions relative to the data emphasises the data distribution instead of land size (Kocmoud and House 1998). When visualising population statistics Dorling (2011) considers this equitable representation design ‘more socially just’, or honest (Dent 1972), giving due attention to all members of the population and reducing the visual impact of large areas with small populations (Walter 2001). Howe (1989) suggests that ‘cancer occurs in people, not in geographical areas’ and Griffin (1980) believe that spatial socio-economic data, like cancer rates, are best presented on a cartogram for urban areas as the population map base avoids allocating

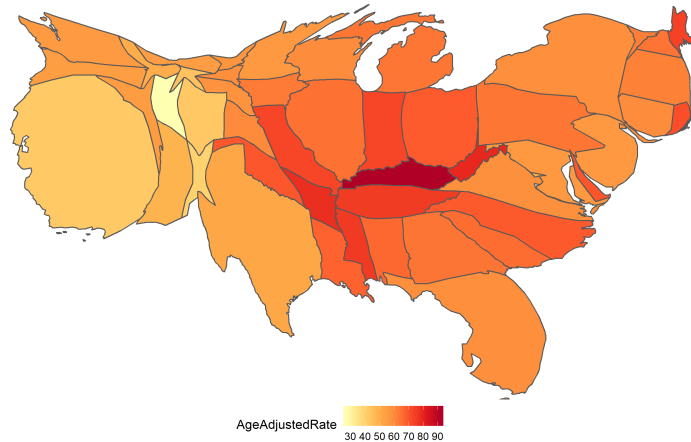


Figure 3: A contiguous cartogram map of the United States of America. Each state has been coloured according to the average age-adjusted rate of incidence for lung and bronchus for females and males in the United States 2012-2016. Each state shape has been distorted according to the population of the state in 2015. The state of California has become much larger due to its large population density. This draws attention to the densely populated North East region, and detracts from the Mid West.

‘undue prominence’ to rural areas. Jahan et al. (2018) encourage the use of cartograms to highlight small areas and uncover local-level inequalities.

The creation of cartograms was historically in the hands of professional cartographers (Kraak 2017). Early approaches including John Hunter and Jonathan Young (1968) and Durham’s wooden tile method, Skoda and Robertson’s (1972) steel ball bearing approach and Tobler’s (1973) computer programs (Dorling 2011). Geographical information systems allowed map users, and researchers to implement their own cartograms, but these systems are utilised depending on ‘the effectiveness, efficiency, and satisfaction of the map products (Nielsen 1994)’ (Kraak 2017). Howe (1989) discusses the impact of electronic computer-assisted techniques.

There are many alternatives to consider, the intended audience of the map, and its purpose are key points in cartogram use and creation. Dorling (2011) reiterates: ‘There is no “best” cartogram or method of creating cartograms just as there is no “best” map’ (Monmonier and Schnell, 1988). There have been many algorithms presented, Nusrat and Kobourov (2016) provided a framework to investigate implementations and the “statistical accuracy, geographical accuracy, and topological accuracy”.

4.1.1 Contiguous

A contiguous cartogram maintains connectivity of the map regions while areas are resized according to a statistic. This transformation often occurs at the expense of the shape of areas (Kocmoud and House 1998, @NAC, @TAAM). From a computer graphics perspective, Min Ouyang and Revesz (2000) explain the application of ‘map deformation’ to account for the value assigned to each area, they provide three methods for creating value-by-area cartograms. Examples include Tobler’s Pseudo-Cartogram Method, Dorling’s Cellular Automaton Method (2011), Radial Expansion Method

of Selvin et al., Rubber Sheet Method of Dougenik et al., Gusein-Zade and Tikunov's Line Integral Method, Constraint-Based Method (Kocmoud and House) (1998).

An intentional goal when creating the 1966 Census population cartogram for Canada was to maintain contiguity, while attempting to keep the actual shape of places. The end result was a 'very accurate isodemo-graphic map of Canada'. This intentional design goal coincided with the rising interest in urban geography and presentation of social statistics.

To be able to recognise the significant changes, a reader will usually have to know the initial geography to find the differences in the new cartogram layout (Olson 1976). Tobler's Conformal mapping means to preserve angles locally so that the shapes of small areas on a traditional map and a cartogram would be similar. Kocmoud and House (1998) presents this issue as conflicting tasks or aims, to adjust region sizes and retain region shapes. Cano et al. (2015) define the term 'mosaic cartograms' for hexagonal tile displays, where the amount of tiles for each area can be used to communicate the statistic of regions. The complexity of the boundaries can be adjusted in the resulting display, as the size of the tiles used allows a trade-off be made between boundary complexity and simplicity.

4.1.2 Non-Contiguous

Non-Contiguous cartograms succeed in maintaining the shape of the areas presented. Each area stays in a similar position to their location on a choropleth map. The choropleth map base is often also plotted as a comparison point to highlight the change in area. The addition is the gap between areas, created as each individual area shrinks or grows according the associated value of the statistic. Olson (1976) discusses creation of these maps, the significance of the empty areas left between the geographic boundaries and the new shape, and the 'degree of difference from the original map that is the real message' of these displays.

As the trade-off regarding boundaries approaches simplicity, the distortion of region shapes on the contiguous cartogram presents an additional hurdle to visual recognition and this hurdle is not only eliminated on the noncontiguous cartogram but is replaced by the meaningful empty-space property (Olson 1976, @ECGC). The shapes are valuable for recognition and allows users to orient themselves on the display. Map creators can efficiently communicate with this kind of map by keeping the outlines or particular elements of the original in the new shape (Dent 1972). The scale of the areas does not impact on the shape recognition. However it may impact on the visibility of all areas if small areas expand beyond their boundaries.

4.1.3 Alternatives

Daniel Dorling presented an alternative to highlight the spatial distribution and neighbourhood relationships without complex distortions of borders and boundaries. This approach opposes preserving the intricate shape details. This concept is founded in the simple question put forward by Daniel Dorling (2011):

"If, for instance, it is desirable that areas on a map have boundaries which are as simple as possible, why not draw the areas as simple shapes in the first place?"

He answers this with his implementation of maps created with 'the simplest of all shapes'. He acknowledged the sophistication of contiguous cartograms but critiqued their 'very complex shapes'.

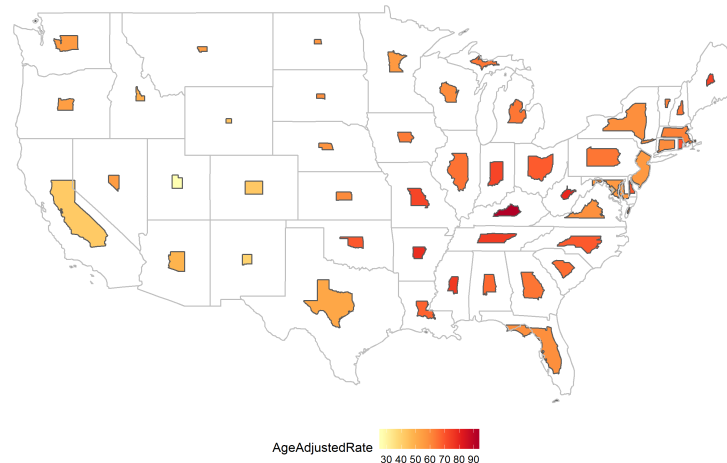


Figure 4: A Non - contiguous cartogram map of the United States of America. Each state has been coloured according to the average age-adjusted rate of incidence for lung and bronchus for females and males in the United States 2012-2016. Each state shape has been maintained, but the size has altered according to the population of the state in 2015. The state of California has remained closer to it's original size than it's surrounding states. The North East states have remained closer to their geographical size, in the case of Massachusetts and Connecticut. This draws attention to the densely populated North East region, and the sparse Mid West.

Circular cartograms use the same simple shapes for every region represented, and size the shapes according to the statistic represented or the population for a base map. This familiar shape may be more effective for understanding the spatial distribution than contiguous cartograms, as the 'nonsense' shapes used have 'no meaning' after distortions are applied Dent (1972). To produce a compelling map, a gravity model is applied to avoid overlaps, and keep spatial relationships with neighbouring areas over many iterations. This implementation can work for up to 'one hundred thousand' areas.

The groundwork for the simplistic approach had been laid in the mid 1930's by Raisz. Tobler (2004) quotes the official definition of Value-Area Cartograms, the simplistic displays which represent each area as a single rectangle, sized according to the value of the statistic. This rectangular display also allows for tiling, where geographic neighbours also share rectangle borders.

5 Comparison of mapping methods

To choose an appropriate map display, the map creator must consider the intended user, and message the map will communicate. To discover whether the display is appropriate, consider the Technology has played an enormous role in increasing the opportunities for map makers. The computation and graphics power have made creation, alteration and interactivity possible. The internet has made communication of scientific data and results increasingly accessible. Creating maps of diseases now involves more decisions as these options have expanded and it is the objectives of the investigator that will drive the choices. Bell et al. (2006) and Moore and Carpenter (1999) have provided suggestions and comments to help map creators best communicate their health data and spatial analyses.

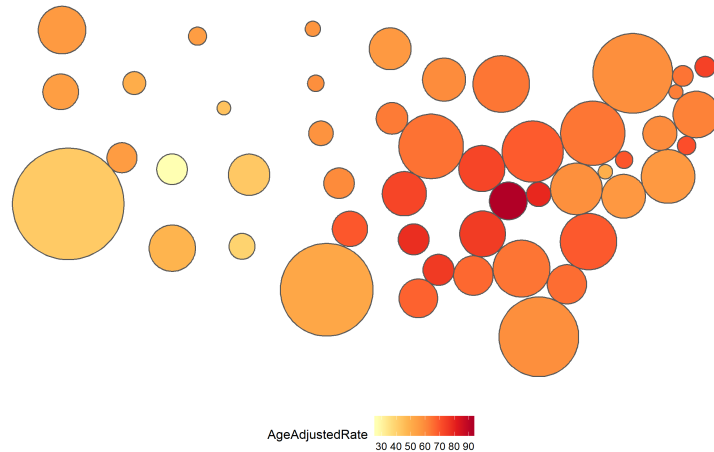


Figure 5: A Dorling cartogram of the United States of America. Each state has been coloured according to the average age-adjusted rate of incidence for lung and bronchus for females and males in the United States 2012-2016. Each state has been represented by a circle, but the size was determined by the population of the state in 2015. The North East states remain closer to their neighbours, and may be displaced from their geographic location. The sparsity of the population in the Mid West is highlighted by the distance between the circles, located at the geographic centroids.

Visualisation properties have been explored across several disease mapping displays. Choropleth displays utilise more traditional cartographic methods, this means they are usually true to the topography. Tobler's work highlights the need for consideration of the transformation of the globe to a 2D space. When there is a relationship between the cancer type being mapped and geographical features, a choropleth map would pair this information visually. These maps are best used when the geography is of importance to the data in the display. Users can identify the areas relevant to them by the familiar boundaries, and can easily contrast the experience of geographic neighbours.

Pairing geography and cancer data was historically the work of epidemiologists, however it did not require them to be the map designer. This was expected as cartographers were the creators of geographic displays, and epidemiologists utilised the maps that had been prepared in advance. This disconnect did not allow the map to be prepared with the data in mind. Cartogram methods began exploring the concept of diagrammatic cartograms, displays that highlighted the importance of data, as well as the geography. This approach began a shift in the focus and responsibility of map creators. Cartogram displays began incorporating the statistics and population into the design of the display. Shifting and sometimes sacrificing familiar boundaries to draw attention to outliers in the data space or population density. The difference between the familiar map display helps highlight the impact of the disease on communities.

By removing the unexpected boundaries and shapes, the spatial distribution is the primary concept communicated by the display. Areas that are geographically close will maintain connectedness in some way, but the population and the statistic will take precedence. These alternatives are especially helpful for data aggregations where administrative boundaries break populations into groups. The experience of each collective may be worth considering as their experiences may be similar in terms of the services and facilities they share. Population affects are highlighted by these displays, as this display allows a more equitable view of each community, and does not minimise those that operate

on a smaller geographic scale.

6 Animation and Interactivity

Traditionally, epidemiologists as disease mappers would have understood the characteristics of a disease lifespan and movements. They would have also considered the interactions between geography, the environment and the people captured by a display. It is important for map creators to develop and then test the message being communicated, epidemiologists are able to do this with their expert knowledge. Static visualisations can help to aid the written results provided by experts, and pairing an explanation with a map or diagram can help to draw attention to a point, group or area of interest. They have the caveat of a need to provide enough information for the static displays to be understandable out of their original context.

Recent developments in technology have created an opportunity to migrate atlases from paper displays in books to interactive web atlases. The medium chosen to communicate health data should always be driven by the message to communicate and the needs of the audience. This can be seen as a continuum, where the message is most important, static or animated graphics allow control over the display and interpretation. Where the needs of the audience is changeable and is the priority, the map creator can allow interactivity for map users to explore.

Bell et al. (2006) provide weather maps as well developed and appropriate examples of spatial displays to communicate to the general public and encourage those creating disease maps to leverage the success of weather displays. The movement of a weather system will follow a forecasted path, the animation will communicate this as all map users can follow the path of the system across the geography over a specified period of time.

The move from static, print media displays toward interactivity allow users to develop maps to ask and answer their own questions. Developments and adoptions of this technology has allowed map users more control of the message displayed. They are able to see the familiar shapes, zoom in to explore densely populated communities, or change the display completely to highlight the population space. Bell et al. (2006) provide three questions that are generally when using a disease map:

- What is the mortality rate in a certain area?
- Are there geographic trends in the data, or regions of unusually high or low rates?
- Is the lung cancer mortality pattern similar to the pattern of smoking prevalence shown in a companion map?

A single map display historically created by epidemiologists, may not effectively answer all three at the same time. Especially when areas are small and hard to identify in a display. However, with the ability to animate, map creators can specify and answer these questions by directing the attention of a map user to the areas of interest. Animations can be used to control the message being communicated by capturing and directing attention of users, it will also ensure all users follow the same interpretive path, as their eyes are drawn across the map to the same comparison points.

This opportunity provides room to move away from the traditional approach of a single map for a single use, into a more explorative territory. Interactivity allows users to drive their own exploration, controlling a display through variable controls, links, tool tips, and data selection tools (Pedersen 2018).

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It was in the development of this online cancer atlas that methods for disease map displays, and visual communication strategies were explored. We are thankful for the opportunity to write about these visualisation displays and the situations in which they are appropriate.

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