INTRODUCTION TO GIS

Note: Most of discussions were directly quoted from Dirk U.P., Timothy P.R., Mark S., Kim B.S., David J.R., and Clements A. (2008) *Spatial Analysis in Epidemiology*, Oxford University Press, New York.

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1. Introduction

- One of the first steps in the spatial analysis is to **visualize the spatial characteristics of a dataset**.
- This allows for an appreciation of any patterns that might be present, identification of obvious errors, and the generation of hypotheses about factors that might influence the observed pattern.
- **Visualization is also important for communicating the findings** to the target audience using, for example, maps of distribution, with or without correction for the influence of known confounders.
- This lecture outlines techniques for visualizing spatial data, and describes methods that might be applied in the **early phase of an analysis** where the objective is to **detect obvious spatial patterns** and to screen a dataset for errors.
- It also considers elements of **good cartography** and other factors that need to be taken into account when **communicating spatial information**.

Source: Directly quoted from Dirk U.P., Timothy P.R., Mark S., Kim B.S., David J.R., and Clements A. (2008) *Spatial Analysis in Epidemiology*, Oxford University Press, New York

2. Point data

- Perhaps the oldest and most frequently used method for visualizing point data is to plot the locations of study subjects using their Cartesian coordinates.
- **John Snow's** account of the **Golden Square cholera epidemic** in 1854 bears testimony to the usefulness of this technique, when high numbers of cases of cholera around a public water pump provided powerful support to the hypothesis that **the disease was transmitted via contaminated drinking water** (Snow 1855, McLeod 2000; Johansen et al. 2003)
- Although point maps are the simplest way to visualize disease event information when the locations of events are known, the present problems where there are either large numbers of events or events at the same location. In such situations **the resulting maps tend to be cluttered**, making it difficult to appreciate the density of events.

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Original map by John Snow showing the **clusters of cholera cases** in the **London epidemic of 1854**, drawn and lithographed by Charles Cheffins.

Source: https://en.wikipedia.org/wiki/John_Snow

Source: https://en.wikipedia.org/wiki/John_Snow

Source: https://en.wikipedia.org/wiki/John_Snow#/media/File:Dr_John_Snow_(24023399742).jpg

2. Point data (cont'd)

- Further difficulties with point maps arise when attribute information needs to be displayed at each location.
- The use of **different symbols to represent attribute values** is one solution, but large numbers of points and a wide range of attribute values results in a display that is difficult to interpret.
- Where there are few locations to be plotted and interest lies simply in showing the location of events rather than the spatial distribution of attribute values, **point maps provide a means of presenting the data in its raw' format**, unmodified by an statistical analysis that might be applied to aid or enhance interpretation.
- This can be **useful for communication**. A display of the raw data allows users of the information to **appreciate the spatial pattern without being burdened by the technical details** of analyses done to facilitate data display.

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3. Aggregated data

- The process of aggregation involves summarizing a group of individual data points into a single value to produce, for example, a total, mean, median, or standard deviation.
- This summary statistic may then be assigned a spatial location, often a discrete area such as a state, county, or some other administrative region.
- In spatial epidemiology, the most common form of data aggregation occurs when counts of disease events within a defined area are summed to yield the total number of cases in each area.
- **Choropleth maps** are the **most commonly used** means **for visualizing data in this format**. The term choropleth is derived from the Greek khoros, meaning place" and plethein, meaning 'to be full, or to become full.
- Thus, as implied by its Greek derivative, a **choropleth map shows information by filling (colouring) each component area** with colour, providing an indication of the magnitude of the variable of interest.

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3. Aggregated data (Cont'd)

- Although **choropleth maps** tend to be the **most widely-used method** for illustrating the spatial distribution of data, they have **three inherent problems**.
- Firstly, component polygons of the study region that are **large tend to dominate the display** and may induce bias in interpretation (Monmonier and De Blij 1996).
- Secondly, patterns that are observed across zones may be as much a function of the **chosen zone boundaries** as of the **underlying spatial distribution** of the attribute of interest, an effect known as **the modifiable areal unit problem** (MAUP) (Openshaw 1984).
- The third problem relates to the distribution of the data values being plotted, as **highly skewed distributions** are **difficult to display** using a **finite number** of **colour shading scales.**
- One approach to the problem of physical dominance of large areas to geometrically **transform each of the areas of interest**, thereby making its area **proportional to the corresponding attribute value** but maintaining the spatial contiguity of each area.

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3. Aggregated data (Cont'd)

- The result is known as a **cartogram** (Dorling 1995)
- **Cartograms** distort area and distance, forsaking spatial detail, in an effort to display the spatial characteristics of attribute data more effectively.
- The usual objective is to reveal patterns that might not be readily apparent from a conventional map, or more generally, to improve legibility.

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4. Effective data display

4.1 Media, scale, and area

When using fixed media such as paper, it is not possible to increase or decrease the scale of spatial resolution once a map has been prepared.

- GIS are much **more flexible in this regard as 'zoom' facilities** allow a map's resolution to be readily altered, the area of interest requires more care.
- For example if the spatial distribution of disease around a possible pollution source is to be investigated, **the distance over which the pollution source is expected to exert its influence** needs to be considered.
- If the study area is too small it will be difficult to detect changes in disease density associated with distance from the source.

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4. Effective data display (Cont'd)

4.2 Cartography

- When developing a map, perhaps the **first aspect** that needs to be considered is **the format that it will take**.
- For example, a map developed for display on an internet web page will be quite different from a map used in a printed book or journal article Maps intended for display on a computer screen can make use of colour and detailed symbols to identify features (if it is possible to pan and zoom) whereas printed maps within a book, journal, or thesis are often restricted to black and white and need to **use simple symbology in order to identify features clearly**.
- Almost all maps should include **basic details to provide the reader with key information** about the data being mapped.

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4. Effective data display (Cont'd)

4.2 Cartography (Cont'd)

- These details include a **map title**, **a scale**, **a legend**, the **body of the map** (obviously), **an indicator of north**, and in some circumstances, the name of the cartographer, a neatline, the date of production, details of the map projection, and information about the source of data.
- Some of these elements are found on all maps while the presence of others depends on the context in which the map is place **scalebars, north arrows, legends**, and **source of information** are required for all maps while neatlines, locator maps, and inset maps are elements that tend to be selectively used to further assist effective communication.

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4. Effective data display (Cont'd)

4.2 Cartography (Cont'd)

4.2.1 Distance or scale

- As a rule of thumb, **distance or scale should always be indicated on mapped data** unless the intended audience is so familiar with the map's contents that the concept of distance can be assumed.
- The are **two options** for indicating distance or scale Either a **scale bar** can be used, or distance can be indicated as **part of the labeling** on the **horizontal and vertical axes** of the map

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4. Effective data display (Cont'd)

4.2 Cartography (Cont'd)

4.2.2 Projection

- A projection **transforms** the area being mapped from the **Earth's sphere** to a **flat page or screen.**
- Projections necessarily **distort the Earth** so it is impossible in principle for the scale (i.e. distance on the map compared with distance on the Earth of any flat map to be perfectly uniform, or the pixel size of any raster map to be perfectly constant.
- Projections can however **preserve certain proper ties**, the two most important being:
  - **conformal property**, which ensures that the shapes of small features are preserved on the projection (i.e., the scales of the projection in the x and y directions always equal)
  - **equal area property**, which ensures that **areas measured on the map** are always in the same proportion to the Earth's areas for surface.

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4. Effective data display (Cont’d)

4.2 Cartography (Cont’d)

- Conformal properties are important navigation while equal area properties are important for analyses involving areas Map projections can be divided into **two groups global and regional systems**.
  - **Global projections** (such as the Transverse Mercator projection and the Universal Transverse Mercator projection) are used to define position at all locations across the Earth's surface.
  - **Regional systems** on the other hand are defined for specific areas, often covering countries, states or provinces.
- Typical examples are the **British National Grid** for Great Britain which s based on the Transverse Mercator projection, and the **State Plane Coordinate System** used in the **United States**.
- Projections that preserve area such as **regional systems**, are most suitable for **epidemiological mapping.**

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4. Effective data display (Cont'd)

4.2.3 Direction

- All maps should provide some indication of the **direction of north.**
- Similar to the depiction of distance, north can be **depicted symbolically** or can be inferred through the labeling of the horizontal and vertical axes
- **True north** (the direction to the North Pole **differs from magnetic north**), which changes due to changes in the characteristics of the condition of the Earth's crust and core.
- A map might indicate both true and magnetic north. If not, the **convention is to indicate true north**.

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4. Effective data display (Cont’d)

4.2.3 Legends

- **The map legend lists the symbols** used on the map and what they depict.
- Symbols should appear in the legend exactly as they appear in the body of the map.
- **Not all maps require a legend**.
- Sometime particularly with simple maps, the required information can be included in the caption.

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4. Effective data display (Cont'd)

4.2.4 Neatlines (locator or inset map)

- Neatlines (also known as clipping lines) are used to **frame a map** and to indicate exactly where **the area of the map begins and ends**.
- Neatlines are also used to **clip the body of the map** and of locator or inset maps.
- Some maps may portray areas that are **unfamiliar to readers** and therefore, in order to **provide readers with a better sense** of the map context, a locator map is useful for showing **where the mapped data is in relation to an area that is familiar** to them.
- Sometimes mapped data are so densely clustered in small sections of a larger map hat the cartographer must provide the reader with a **close-up view of an area** that is of specific interest.
- These **detailed maps are called inset map**.

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4. Effective data display (Cont'd)

4.2.5 Symbols

Spatial attribute data can be classified as

- **Nominal**: attributes are nominal if they are given names or titles in order to distinguish one entity from another (e.g. place names)
- **Ordinal**: attributes are ordinal if their value take on a natural order (e.g. agricultural land be classed in terms of soil quality with Class 1 rep resenting the best, Class 2 second-best, and so on)
- **Numeric**: examples of numeric data include temperature, elevation, and rainfall. Numeric values may vary on a discrete (e.g. integer) or continuous scale

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4. Effective data display (Cont'd)

4.3 Main Outlines

- Cartographers use **symbols (points, lines, or areas)** and **combinations of shape, hue, orientation, size, and texture** to communicate features of attribute data.
- The choice of graphic to **depict spatial attribute data**, and how best to position them on maps, are important considerations in optimizing map interpretability.
- The representation of **nominal data by graphic symbols** and **icons is apparently trivial**, although in practice automating placement to maximize clarity presents a range of analytical problems.
- Most GIS include generic algorithms for positioning labels and symbols around geographic objects.
- Point labels are positioned to avoid overlap by creating a window around text or symbols, linear features are labeled using splines, and area labels are assigned to central points, usually the centroid.

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4. Effective data display (Cont'd)

4.3 Main Outlines (Cont'd)

- Ordinal attribute data are assigned to points, lines, and area objects in the same manner with the property of the data accommodated through the use of a **hierarchy of graphic variables** (symbol and lettering sizes, types, colours, intensities).
- Most users are **unable to differentiate** between **more than seven ordinal categories** and this provides an **upper limit** on the extent of the hierarchy .
- A number of conventions are used when visualizing interval and ratio scale attribute data.
- **Proportional circles** and **bar charts** are often used to assign interval or ratio scale data to point or area locations.

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4. Effective data display (Cont'd)

4.3 Main Outlines (Cont'd)

- **Variation** in data is usually **represented by colour.**
- Hue refers to the use of colour, principally to **distinguish categories**, for example in land use maps. Hues are usually ranked in order of **lightness to reflect ordering in the data**.
- The simplest approach is to use light to dark colours of a constant hue to represent low to high values.
- Progression through **adjacent hues**, such as **yellow green-blue**, makes it easier to accentuate differences between plotted symbols.
- **Diverging data** may have an obvious structure such as **positive and negative values** as in the case of residuals produced from a regression analysis.

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4. Effective data display (Cont'd)

4.3 Main Outlines (Cont'd)

- **Dark blue** (for negative values through white, to dark red (for positive values) is a **useful colour scheme** for representing this diverging structure.
- It is noted that about **8% of men** and less than **1% of women** have some form of **colour blindness**.
- **Colour blind people** are able to see many hues but there are predictable groupings of hues that are confused with each other, although the extent of this confusion depends on the severity of the person's colour vision deficiency.
- **Hue pairs** that work well for **colour blind readers** are **red-blue, red-purple, orange-blue, yellow-blue, yellow-grey, and blue-grey**. If spectral (rainbow) schemes are used, it is recommended to avoid the greens.

Source: Directly quoted from Dirk U.P., Timothy P.R., Mark S., Kim B.S., David J.R., and Clements A. (2008) *Spatial Analysis in Epidemiology*, Oxford University Press, New York

4. Effective data display (Cont'd)

4.4 Dealing with statistical generalization

- In spatial maps are typically used to **display statistical information**.
- A common procedure is to show **the spatial distribution of data**, summarized by some **level of administrative area**.
- Maps prepared for this task **need to depict**, as accurately and as unambiguously as possible, the **underlying distribution of the data**.
- With **small numbers of categories**, subtle features of the spatial **distribution are obscured**.
- Similarly, **too many categories** make it **difficult for the map-user to identify differences** between adjacent areas.
- As a rule of thumb, it **is difficult for most map readers to distinguish more than <u>about five to seven categories</u>**.

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4. Effective data display (Cont'd)

4.4 Dealing with statistical generalization (Cont'd)

Six basic classification schemes have been developed to divide continuous attribute data into categories.

1. Natural breaks (Jenks method): Classes are defined according to apparently natural groupings of data values. The breaks may be defined by break points that are known to be relevant to a particular application, such as fractions and multiples of mean income levels, or rainfall thresholds known to support different levels of vegetation. Inductive classification of data values may be carried out whereby the GIS 'searches' for large jumps in data values

2. Quintile breaks: Here the data are divided into a **pre-determined number of classes** which contain **an equal number of observations**. For example, **quintile** (five categories) classifications are well suited to displaying **linearly distributed data**.

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4. Effective data display (Cont'd)

4.4 Dealing with statistical generalization (Cont'd)

3.Equal interval breaks: This method takes between the lowest and the highest attribute value and divides this difference into evenly spaced steps. Equal interval breaks are useful for mapping attribute data that follow **a uniform distribution**, or the data ranges are familiar to the user of the map (e.g. herd sizes or temperature bands).

4. Standard deviation classifications: Here, the distance of the observation from the mean is shown. The GIS calculates the mean value and then generates class breaks in standard deviation measures above and below it. A two colour ramp helps to emphasize values above and below the mean. This method is most useful for attribute data that follow **a normal distribution**.

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4. Effective data display (Cont'd)

4.4 Dealing with statistical generalization (Cont'd)

5. Arithmetic progressions: The **widths of category intervals** are **increased in size at an arithmetic (additive) rate**. For example, if the first category is one unit wide and it is decided to increment the width by one unit, the second category would be two units wide, the third three units wide, and so on. This method is particularly useful for **skewed distributions**.

6. Geometric progressions: The widths of the category intervals are increased in size at a geometric (multiplicative) rate. For example, if the first category is two units wide, the second category would be 2 x 2 units wide, the third category would be 2*2*2, and so on. Again, this method is particularly useful for **skewed distributions**.

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5.Conclusion

- Maps are useful for **several purposes** such as **identification of areas** with suspected elevations in risk, formulation of hypotheses, and assessing needs for resource allocation.
- The production of **attractive and informative** maps complements the formal analysis of spatial data, and as a result of **the visual impact** they have, it is likely that maps will **influence the recipient much more than accompanying statistics** (Rezaeian et al. 2004).
- As with any other form of data analysis, **maps** have the **potential both to inform and to mislead**.

Source: Directly quoted from Dirk U.P., Timothy P.R., Mark S., Kim B.S., David J.R., and Clements A. (2008) *Spatial Analysis in Epidemiology*, Oxford University Press, New York

5.Conclusion (Cont'd)

- A key skill in spatial analysis therefore is to **ensure** that apparent **geographical patterns** are **not artifacts** of the mapping process' (Cliff 1995a).
- Investigators should, therefore, produce a variety of maps in order to **illustrate particular aspects of their data** and to validate the **robustness of any inferences** made (Gatrell and Bailey 1996).
- Choice of appropriate study **area boundaries**, **distance** and **scale**, **geographic projection**, **symbology**, **linking maps** with other forms of data display (e.g. dynamic spatial data analysis and conditioned choropleth maps), and dealing with **statistical generalization** are aspects of visualization that should be carefully considered in order to achieve these objectives.

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Overview of Analytical Framework