12 Cartography and map production

OVERVIEW

- This chapter reviews the nature of cartography and the ways that users interact with GIS in order to produce digital and hard-copy reference and thematic maps.
- Standard cartographic conventions and graphic symbology are discussed, as is the range of transformations that are used in map design.
- Map production is reviewed in the context of creating maps for specific applications and also map series.

LEARNING OBJECTIVES

After studying this chapter, students will understand:

- **The nature of maps and cartography;**
- **Key map design principles;**
- **The choices that are available to compose maps;**
- **The many types of map symbology;**
- **Concepts of map production flow lines.**

KEY WORDS AND CONCEPTS

Cartography, reference maps, thematic maps, maps vs GIS, map design principles, symbolization, graphic variables, choropleth maps, dot density maps, classification schemes, digital landscape model (DLM)

OUTLINE

CHAPTER SUMMARY

12.1 Introduction

- Maps are a very effective way of summarizing and communicating the results of GIS operations to a wide audience.
- Is useful to distinguish between two types of GIS output:
- Formal maps, created according to well established cartographic conventions, that are used as a reference or communication product
- Transitory maps and map-like visualizations used simply to display, analyze, edit, and query geographic information
- This chapter focuses on maps and the next on visualization.
- Cartography concerns the art, science, and techniques of making maps or charts.
- Paper maps remain in widespread use because of their transportability, their reliability, ease of use, and the straightforward application of printing technology that they entail.
- Today's mapping must be capable of communicating an extensive array of messages and emulating the widest range of 'what if' scenarios

12.2 Maps and cartography

- There are many possible definitions of a map; here the authors use the term to describe digital or analog (soft- or hardcopy) output from a GIS that shows geographic information using well-established cartographic conventions.
- There are two basic types of map: reference maps and thematic maps
- Maps fulfill two very useful functions as both storage and communication mechanisms for geographic information.
- A major function of a map is not simply to marshal and transmit known information about the world, but also to create or reinforce a particular message.

- Maps have several limitations
    - Can have the effect of miscommunication, accidentally or on purpose
    - Are a single realization of a spatial process
    - Use complex rules, symbology and conventions that may be difficult to understand and interpret by the untrained viewer

12.2.1 Maps and media

- Digital cartography and GIS frees map-makers from many of the constraints inherent in traditional (non-GIS) paper mapping.
- Paper maps:
    - are fixed scale, zoom facility of GIS allows viewing at a range of scales
    - are fixed extent, GIS can provide a seamless coverage
    - present a static view of the world, GIS representations can be animated
    - are flat, GIS can provide 3D visualization
    - provide a complete view of the world, GIS allows supplementation of additional data
    - provide a map producer-centric view, GIS allows users to create their own view

12.3 Principles of map design

- Primary goals in map design are to share information, highlight patterns and processes, and illustrate results.
- A secondary objective is to create a pleasing and interesting picture, but this must not be at the expense of the message inherent in the data
- Robinson et al (1995) define seven controls on the map design process: purpose, reality, available data, map scale, audience, conditions of use and technical limits

12.3.1 Map composition

- Map composition is the process of creating a map comprising of several closely interrelated elements: map body, inset/overview map, title, legend, scale, direction indicator, map metadata
- A key requirement for a good map is that all map elements are composed into a layout that has good visual balance.

12.3.2 Map symbolization

- The data to be displayed on a map must be classified and represented using graphic symbols that conform to well-defined and accepted conventions.

- Measurement scales and spatial object types are thus one set of conventions that are used to abstract reality.

12.3.2.1 Attribute representation and transformation

- Attribute mapping entails use of graphic symbols
    - Basic point, line, and area symbols are modified in different ways in order to communicate different types of information.
- The nature of these modifications was first explored by Bertin in 1967, and was extended to the typology illustrated in Figure 12.9 by MacEachren.
- Some of the common ways in which these graphic variables are used to visualize spatial object types and attributes are shown in Table 12.1.
- Automating placement of symbols and labels presents some challenging analytical problems.
- Most GIS packages include generic algorithms for positioning labels and symbols in relation to geographic objects
- As a general rule, the typical user is unable to differentiate between more than seven (plus or minus two) ordinal categories, and this provides an upper limit on the normal extent of an ordinal hierarchy.
- There are a variety of conventions used to visualize interval- and ratio-scale attributes.
    - Ascribing interval or ratio scale attribute data to areal entities that are pre-defined.
- The standard method of depicting areal data is in zones. However, the choropleth map brings the dubious visual implication of within-zone uniformity of attributes
    - Moreover, conventional choropleth mapping also allows any large (but possibly uninteresting) areas to dominate the map visually.
- Dot density map, which uses points as a more aesthetically pleasing means of representing the relative density of zonally averaged data – but not as a means of depicting the precise locations of point events.
- Proportional circles
- There is no natural ordering implied by use of different colors and the common convention is to represent continuous variation on the red-green-blue (RGB) spectrum.
- There are four basic classification schemes to divide interval and ratio data into categories:

    - Natural (Jenks) breaks in which classes are defined according to apparently natural groupings of data values. Best used when the breaks are relevant to a particular application or threshold values
    - Quantile breaks in which each of a predetermined number of classes contains an equal number of observations. Well suited to the spatial display of uniformly distributed data
    - Equal interval breaks. Best applied if the data ranges are familiar to the user, such as temperature ranges
    - Standard deviation classifications
- The choice of classification is very much the outcome of choice, convenience, and the accumulated experience of the cartographer and is aided by the ease with which different classifications can be tested in GIS

12.3.2.2 Multivariate mapping

Multivariate maps show two or more variables for comparative purposes
This sections illustrates how this can be done with a few examples

12.4 Map series

- Map series by definition share a number of common elements (for example, projection, general layout, and symbology) and a number of techniques have been developed to automate the map series production process.
- The heart of map production through GIS is a geographic database covering the area and data layers of interest
- Such a base cartographic data model is often referred to as a Digital Landscape Model (DLM) because its role is to represent the landscape in the GIS as a collection of features that is independent of any map product representation.
- For each DLM, one or more cartographic data models (DCMs) can be created
- Thus it will be possible to create multiple different map products from this DLM database.
- Many similar maps can be created efficiently from a common map template that includes any material common to all maps (for example, inset/overview maps, titles, legends, scales, direction indicators, and map metadata).

12.5 Applications

- The goal of this section is to highlight a few examples that raise some interesting cartographic issues

- In some instances, prevailing conventions will have evolved over long periods of time, while in others the new-found capabilities of GIS entail a distinct break with the past.
- As a general rule, where accuracy and precision of georeferencing are important, the standard conventions of topographic mapping will be applied
- Utility applications often use schematic maps and now hybrid schematic and geographic maps, *geoschematics*
- Transportation applications use linear referencing
- Military uses of maps have special cartographic conventions of multivariate symbols that have operational and tactical significance

12.6 Conclusions

ESSAY TOPICS

1. In what ways does the printing of a map on paper differ from display on a computer screen and how does this impact on the cartographic techniques that might be used?
2. Describe some methods for the display on a single map of multivariate data.
3. Over the entire range of cartography, to what extent is it true to assert that ‘color is a cartographic quagmire’?
4. With reference to specific examples from the history of mapping, is a picture really ‘worth a thousand words’?
5. Outline the major uses and limitations of maps and mapping.
6. Cartography is often described as both an art and a science. In the production of a map, when is it ‘art’ and when ‘science’?
7. An objective of many national mapping agencies is to replace multiple map scales and series with a single geospatial database from which a very wide range of maps can be produced. To what extent does the nature of cartography doom this objective to failure?
8. What are the additional cartographic considerations in the production of a series of maps rather than a single product?
9. To what extent do you agree with Wooldridge and East’s assertion that "In Geography we may take it as an axiom that which cannot be mapped cannot be described." (Spirit and Purpose of Geography, 1951)?
10. You have been asked to generate maps to be served to user’s cell phones, such that they are centered at phone’s location and show the road network in the

surrounding square mile. Describe and justify the cartographic methods you would use.

MULTIPLE CHOICE QUESTIONS (MCQ)

1. For each of the listed properties, say whether it is more characteristic of a computer display or a printed paper map:

Property	**Paper, display or both?**
Uses symbolism	
Has a single purpose	
Is an end product	
Is selective	
Has many purposes	
Is used to find the unknown	
Can be photo realistic	
Is intended for many viewers	
Is a means to an end	
Can show all the data	
Is used many times	
Demonstrates what's known	
Is used by one person	
Is used once	

2. Which of the following cartographic techniques are best suited to showing the shape of a field such as that of the Earth's surface relief? Select just two from the list.
   a. Spot heights
   b. Hachures
   c. Hypsometric tinting
   d. Contours
   e. Hill shading
3. For each of the graphic variables illustrated in Figure 12.9 state the type of attribute (nominal, ordinal, interval, ratio or cyclic, see Box 3.3) it is best suited to display:

4.

Graphic Variable	Type of attribute
Size	
Value	
Hue	
Saturation	
Orientation	
Shape	
Arrangement	
Texture	
Focus	

5. Match each of the variable frequency distributions listed to what is likely to be the best choropleth map classing scheme:

Frequency Distribution	Answer (a)-(e)	Scheme
J curve		Standard deviation intervals
Normal distribution		Equal intervals
Multimodal distribution		Geometric series intervals
Uniform distribution		Natural breaks

6. For each of the technical properties listed, state whether it is a characteristic of a paper printed map or a computer display:

Capability	Paper, display or both?
Limited to two dimensions	
Cannot easily show change	
Must use a projection	
Can be animated	
Have limited choice of drafting tools	
Can provide depth cues	
Wide range of drafting technologies	
Can wrap round the globe	

7. Which of the following is generally held to be the maximum number of ordinal categories, such as classes in a choropleth that human beings can readily differentiate?
    a. 3
    b. 5
    c. 7
    d. 11

8. Which of the following are not essential elements in a balanced map design?
    a. Title
    b. Legend
    c. Insets
    d. Scale
    e. Direction indicator
    f. Metadata
    g. Map body

9. Of the written word and mapping, which is the oldest form of human communication?

10. Arrange the following processes into a logical cartographic workflow by labeling them (1) TO (5):
    a. Data collection
    b. Analysis
    c. Output
    d. Editing and maintenance
    e. Management

11. Give a suggested example of a map showing each of the following combinations of spatial object and attribute types:

Spatial Object Type & Attribute Type	**Suggested Example Map**
Point/Nominal	
Area/Nominal	
Surface/Ordinal	
Line/Ordinal	
Surface/Ratio	

ACTIVITIES

1. In addition to the body of the map itself, Section 12.3.1 lists a further six map requirements (title, legend, scale, north arrow, metadata and possible insets) that should be balanced into a good map design. Although these can be added to the main body of any map using a full GIS, for publication and for presentations, use is often made of generic software such as Adobe Illustrator™, Microsoft Paint™ or PowerPoint™. Incorporate a section of a scanned map into one of these programs using the JPEG format, and then use the tools provided to create a balanced design. The ability to incorporate and annotate maps into presentations using this approach is a very useful skill. A useful restriction to this exercise is to create a single page showing where your home is, together with photographic and text inserts specifying how to find it.

2. Visit the collection of images of maps at www.esri.com/mapmuseum/index.html and select a volume and applications area of interest to you. For at least five maps rate the quality of each of the seven elements of map composition discussed in Section 12.3.1 (use a simple scale such as “bad” through “good”). Do these vary according to the stated purpose of the map?

3. Find examples of either paper or web maps that illustrate each of the following ways of representing ‘fields’ cartographically: ‘spot heights’, contours, hypsometric tints, relief shading, and hachuring. In each case comment on the effectiveness of the method and its combination with other approaches. A good, but dated, source of examples is the old Tourist Editions of the OSGB’s 1 inch mapping.

4. Experiments with choropleth color. Read the paper by Cynthia A. Brewer (1994) Colour use and guidelines for mapping and visualization. In: MacEachren, A.M. and D.R.F. Taylor (eds) *Visualization in Modern Cartography*, Pergamon: Oxford, pages 123-147 and then run 'ColorBrewer' at http://colorbrewer2.org/ . Try as many of the available choropleth color schemes as you can and comment on their suitability.

5. Make a list of the possibly different design criteria necessary for publishing maps over the web rather than on sheets of paper. The website at kartoweb.itc.nl/webcartography/webbook/index1.htm has useful explanatory materials.

6. Classing a choropleth map. If you have not already done so, read the classic paper on choropleth class intervals by I.S. Evans (1976) The selection of class intervals, *Transactions of the Institute of British Geographers*, New Series, 2: 98-124

7. Below are the frequencies distributions of three variables recorded in 1991 over the 403 Districts of England and Wales. Each variable has been standardised in some way, as a % 'rate' or as an areal density, but each has a very different frequency distribution. For each:

    a) Outline the difficulties that the distribution has for choropleth mapping.
    b) Suggest and justify a choropleth classification scheme involving five classes.
    c) Suggest and justify an appropriate symbolism (i.e. set of shade patterns) for the map to be produced. Should you think it necessary, you are allowed the luxury of colour reproduction with an available gamut of either 256 shades of the same colour or 256 different colours.

Software to assist the classification process has also been developed, see Xiao, N., Armstrong, M.P. and D.A. Bennett, Choroware: a software tool for choropleth map classification, at : www.csiss.org/events/meetings/ spatial-tools/papers/xiao.pdf

a) Population Change (% of 1981 value) to 1991

Class Mid-point	-2	-1.5	-1.0	-0.5	0	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
No:	1	0	10	60	127	100	71	29	2	2	0	0	0	1

b) Unemployment in January 1991 as % of total 1989 population

Mid	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
No:	1	17	60	73	58	55	45	30	36	7	7	4	5	2	2	1

c) Population density (number/km^2 of District area, 1991)

Mid	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000	11000
No:	208	82	44	29	21	4	4	1	4	2	2	2

6. Several authors have attempted to define some form of choropleth 'error' index of which that proposed by Jenks, G.F. and F.C. Caspall (1971) Error on choroplethic maps: definition, measurement, reduction. *Annals, Association of American Geographers*, 61:217-244 is the best known. A simpler, area weighted version, which can be easily computed using a spreadsheet program, has been suggested by Unwin, D. (1982) *Introductory Spatial Analysis*, Methuen: London. This is based on the idea that when a choropleth zone value is allocated to a class, an error equal to the difference between the actual value for the zone and that of the class mid-point is introduced. Squaring and summing over all zones, with or without a weighting for the zone area, gives a simple index. For some choropleth data known to you suggest and calculate this, or a similar, index. On completing this, and the previous exercise, we suspect that you might well have a view on a famous debate on the desirability of classless choropleths between two authorities, see Tobler, W. R. (1973) Choropleth maps without class intervals *Geographical Analysis* 5, 26–28. and Dobson, M. W. (1973) Choropleth maps without class intervals? A comment, *Geographical Analysis* 5, 358–60. On a classless choropleth the error index is precisely zero, but, as Dobson points out, this may not be what we should be trying to achieve!

7. Organize a debate on the motion that ‘This house believes that in the world of mobile and ubiquitous GIS, paper maps have no future’.

8. For your national topographic map series, attempt to classify all the symbolism used into one or other of the ‘cartographic variables’ recognized by Jacques Bertin and extended by Alan MacEachren (Figure 12.9). Summarize your results in a simple table.

9. What is the most beautiful and/or effective map ever created? There is no answer to this, of course, but an amusing and instructive exercise is to ask each member of a class to find one map that they think fits the bill, and then ask them to present their case using just two PowerPoint slides, one of the map itself, the other with bulleted reasons why. The results should be merged into one presentation and stored as a map gallery. Students should vote for the ‘winner’.

10. Two of the world’s leading authorities on the history of cartography are of the opinion that Harry Beck’s justly famous 1933 cartogram of the London Underground network (see Figure 13.9) is ‘the most outstandingly successful practical map of all times’ (C. Delano Smith & R. Kain (1999) *English Maps: a History* (British Museum:London). The website //tube.tfl.gov.uk/content/history/map.asp provides some background on this very influential product, which has been copied in many other cities.

FURTHER READING

Board, C. 1967. Maps as models, in Chorley, R. J. and Haggett, P. (eds) *Models in Geography*, (London: Methuen) pages 671–725.

Dent B.D. 1999 *Cartography: Thematic Map Design* (5th edn). Dubuque, Iowa: WCB/McGraw-Hill.

Downs, R. M. 1998. The geographic eye: seeing through GIS. *Transactions in GIS*, 2(2), 111–121.

Fisher, P.F., Dykes, J., Wood J. (1993) Map design and visualisation. *The Cartographic Journal*, 30: 36–42.

Hearnshaw, H. and D. J. Unwin (eds) 1994. *Visualisation and GIS* (London: Wiley)

Kraak M.-J. and Ormerling F. 1996. *Cartography: Visualization of Spatial Data*. Harlow: Longman.

Robinson A.H., Morrison J.L., Muehrcke P.C., Kimerling A.J. and Guptill S.C. 1995 *Elements of Cartography* (6th ed). New York: Wiley.

Slocum T.A. 1999. *Thematic Cartography and Visualization*. Upper Saddle River, NJ: Prentice-Hall Inc.

Tufte E.R. 2001. *The Visual Display of Quantitative Information*. Cheshire, CT: Graphics Press.

Every GIS library should have this book and others by Tufte.

ONLINE RESOURCES

ESRI Virtual Campus course, *Turning Data into Information* by Paul Longley, Michael Goodchild, David Maguire, and David Rhind (training.esri.com)

Module 1: Basics of Data and Information

Module 2: Cartography, Map Production, and Geovisualization

Section 12.1, Module 2: Cartography, Map Production, and Geovisualization

Unit: GIS-based visualization

Section 12.2, Module 1: Basics of Data and Information

Unit: Creating and visualizing information

Sub-unit: Visualization and interaction

Section 12.2.1, Module 2: Cartography, Map Production, and Geovisualization

Unit: GIS-based visualization

Sub-unit: Properties of GIS-based visualization

Section 12.3, Module 1: Basics of Data and Information

Unit: Creating and visualizing information

Sub-unit: Visualization and interaction

Module 2: Cartography, Map Production, and Geovisualization

Unit: Representing attributes and spatial objects

Section 12.3.2.2, Module 2: Cartography, Map Production, and Geovisualization, Unit: Advanced methods for improving visualizations

Sub-unit: Multivariate mapping

Sub-unit: Multivariate visualization in Australia