

ColorBrewer.org: An Online Tool for Selecting Colour Schemes for Maps

Mark Harrower¹ and Cynthia A. Brewer²

¹(Corresponding author) Department of Geography, University of Wisconsin–Madison, 550 North Park Street, Madison, WI 53706, USA. Tel.: 608 262 2138. Email: maharrower@wisc.edu

²Department of Geography, Pennsylvania State University, University Park, PA 16802, USA. Tel.: 814 865 5072. Email: cbrewer@psu.edu

Choosing effective colour schemes for thematic maps is surprisingly difficult. ColorBrewer is an online tool designed to take some of the guesswork out of this process by helping users select appropriate colour schemes for their specific mapping needs by considering: the number of data classes; the nature of their data (matched with sequential, diverging and qualitative schemes); and the end-use environment for the map (e.g., CRT, LCD, printed, projected, photocopied). ColorBrewer contains 'learn more' tutorials to help guide users, prompts them to test-drive colour schemes as both map and legend, and provides output in five colour specification systems.

INTRODUCTION

Colour plays a central role in thematic cartography. Despite this, using colour effectively on maps is surprisingly difficult and often exceeds the skill and understanding of novice mapmakers. On the one hand, a 'good' colour scheme needs to be attractive. On the other hand, the colour scheme must also support the message of the map and be appropriately matched to the nature of the data. Moreover, colour schemes that work for one map (e.g. a choropleth map of income) will not necessarily work for another (e.g. a map of dominant commercial sector by county). Relying on the same colour scheme for all thematic mapping needs is a mistake. Unfortunately, many novice map makers have become conditioned to use the default colour schemes built into commercial mapping and GIS packages and sometimes are even unaware that they can change those default colours. If colour schemes are not carefully constructed and applied to the data, the reader may become frustrated, confused, or worse, misled by the map.

An understanding of how to manipulate the three perceptual dimensions of colour (hue, saturation and lightness) is required to create attractive and logical colour sequences for thematic maps. These dimensions are three of the visual variables or basic 'building blocks' of graphics (Bertin, 1983). Nearly a century of colour theory development combined with perceptual testing has allowed us to better understand how individuals perceive and understand colour. From a semiotic perspective, colour works as a 'sign vehicle' when the map reader is able to understand that a specific

colour on the map represents or *stands for* something in the real world and that multiple occurrences of that colour stand for the same kind of thing (MacEachren, 1995).

THE PROBLEM

Federal agencies such as the US Census Bureau, National Center for Health Statistics and National Cancer Institute produce numerous maps for both internal and external use (for example: Brewer and Suchan, 2001, Pickle *et al.*, 1996, Devesa *et al.*, 1999). As collectors and distributors of geospatial data, these agencies make extensive use of thematic maps — especially choropleth maps — to communicate facts to the public and to facilitate exploratory data analysis by their own researchers. The individuals who produce these maps rarely have the time to worry about carefully crafting individual colour schemes every time they make a map. Although most GIS software incorporates default colour schemes for thematic maps, it provides no guidance on how to best use these default colour schemes, and many of these schemes are simply unattractive. More importantly, these default schemes are not appropriate for all mapping tasks.

Given the importance of maps in the activities of these agencies, and the central role colour plays on maps, poor use of colour is a concern. Agencies, and more generally novice map makers, would benefit from tools that could quickly guide them through the colour selection process and let them 'test drive' a colour scheme and see it on a

map before committing to it. Such tools would let them work more *quickly* and *confidently* by reducing the chance of misapplied colour schemes on thematic maps.

THE SOLUTION: WWW.COLORBREWER.ORG

This paper outlines the development of ColorBrewer (Figure 1), an online tool that helps users identify appropriate colour schemes for maps. The reader is encouraged to try ColorBrewer online at www.ColorBrewer.org. The impetus for this work came from watching individuals that produce thematic maps at federal agencies struggle with selecting good colour schemes for maps. ColorBrewer is designed to take some of the guesswork out of this process. The system suggests possible colour schemes by prompting the user to identify how many data classes they have and what kind of colour scheme best suits their data and map message (i.e., sequential, diverging or qualitative; explained below).

ColorBrewer also provides guidance for varied display environments — CRT, laptop, colour laser print, photocopy and LCD projector — and warns where and when a

colour scheme might fail. It is important to remind users that the success of a colour scheme is, in large part, a product of the display medium. For example, colours that are easily differentiated on a cathode-ray tube monitor (CRT) may look indistinguishable on a laptop LCD display. As anyone who has made colour prints knows, startling shifts in the appearance of colours can occur when moving from electronic displays to printed displays. Compounding this, many of the maps produced by federal agencies must work across multiple media (e.g. both as an electronic display and as a paper report) and finding truly robust colour schemes that work well in multiple environments is difficult.

In addition to simply suggesting colour schemes, ColorBrewer allows the user to 'test drive' each of the colour schemes to see how well they perform as both an ordered legend and as a choropleth map in order to give the user a better sense of how an individual scheme will function when it is applied to a real map. Differentiating colours within a complex distribution — especially when additional map information such as place names and linework is overlaid — is a harder perceptual task than seeing differences in simple and logically ordered data legends. Put another

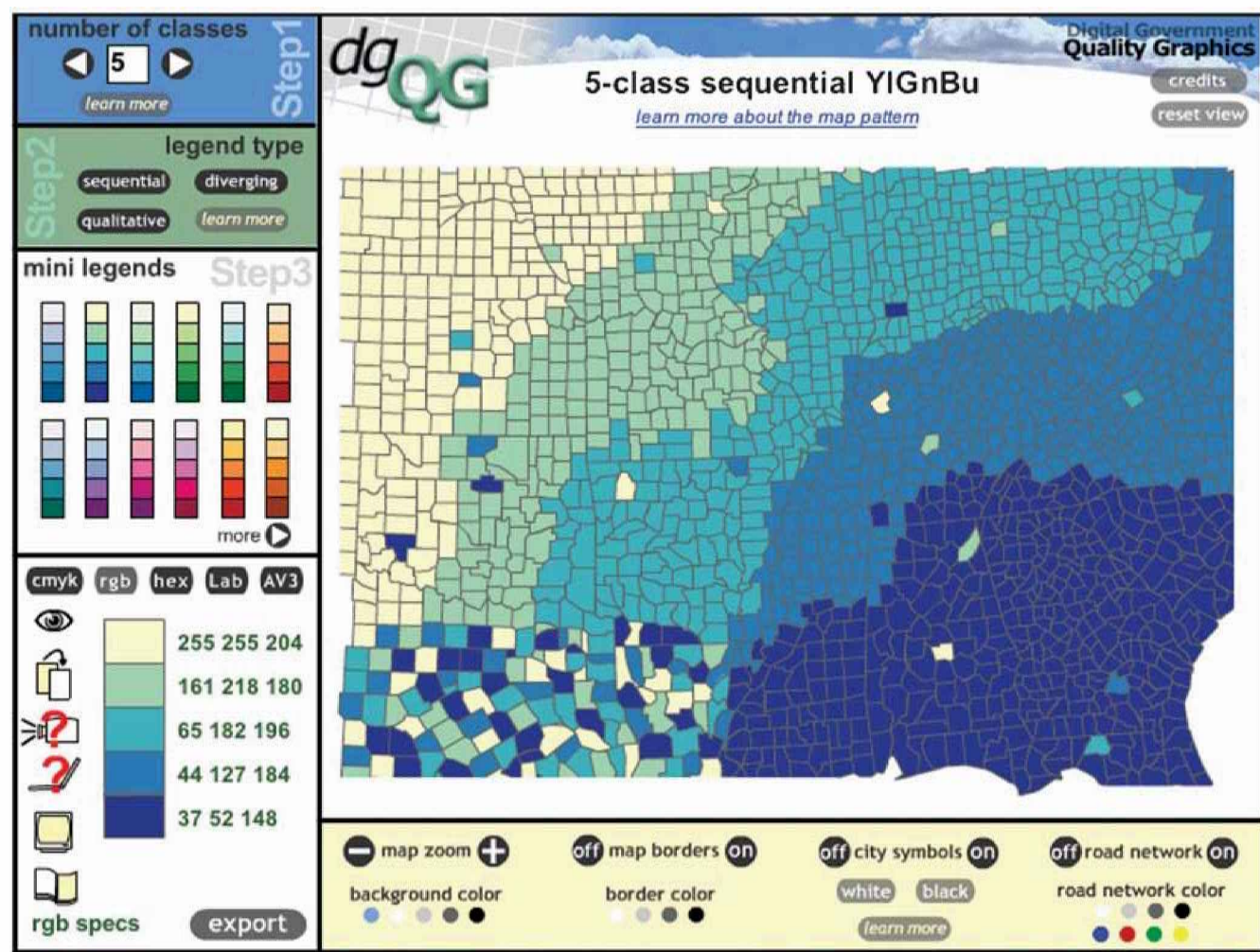


Figure 1. ColorBrewer walks users through the process of identifying an appropriate colour scheme and allows them to 'test drive' the colour scheme formatted as a thematic map and not simply as a colour legend. The Web-based tool was built in Flash 5

way, just because a map reader can see subtle differences between the individual colour patches in a legend does not mean they will be able to recognize those same differences on the map (Brewer, 1997).

The appearance of colours can change with the presence or absence of enumeration unit borders, and the colour of those borders. To accommodate this, ColorBrewer allows users to turn enumeration borders on and off, as well as change their colour. Our goal was not to suggest what border colours to use, but to remind the user that this is yet another component to map design. Since thematic maps often contain additional base information, similar functionality has been built in with an overlay of roads and cities to demonstrate the effects of additional linework and point symbols on the appearance of the colours. The colour of these overlays can also be changed. Though the examples we have chosen are highways and cities, they should give users a good idea of how other linework, points, and text will function on their map. Some colour schemes make it easier to read base information than others, and this legibility may be more important for some map purposes than others.

Not all maps are displayed with a white background. Black backgrounds, for example, have become common in on-screen geovisualization environments. Since the appearance of a specific colour is influenced by the colours that surround it, ColorBrewer allows users to adjust the colour of the background display to determine how well different colours function against different backgrounds.

In short, the ColorBrewer system:

- asks the user to specify the number of classes and type of colour scheme;
- displays a selection of colour schemes for the user to choose among;
- presents the selected colour scheme on a map and in a legend display;
- displays guidance for each scheme on the potential for good results in different media;
- suggests whether a selected scheme will accommodate colour-blind people;
- allows the user to change colours of enumeration unit borders (or remove them);
- displays an overlay of sample line, point, and text base information;
- displays a variety of map background colours.

Beyond our description of system basics, a more in-depth discussion of the rationale behind and implementation of ColorBrewer follows in the next section.

KINDS OF COLOUR SCHEMES

A total of 35 colour scheme ‘sets’ are contained in ColorBrewer and they are divided into three groups: qualitative, sequential and diverging. These sets have been designed to produce attractive colour schemes of similar appearance for maps ranging from 3 to 12 classes. Not all colour schemes can be expanded to 12 classes, and many of the sequential scheme sets, for example, stop at 9 classes because further divisions within the scheme are perceptually unreliable (Figure 2).

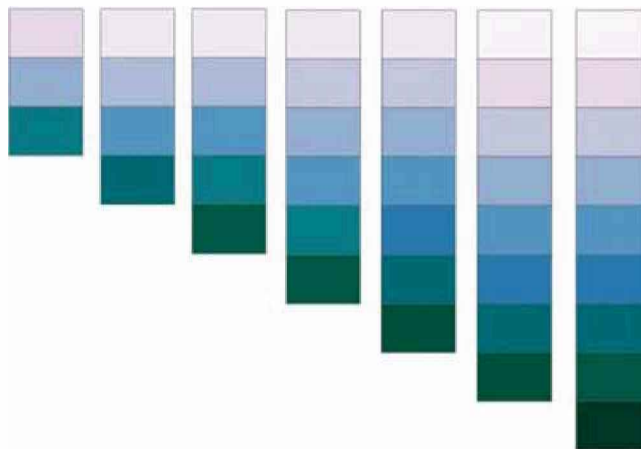


Figure 2. One sequential scheme that ranges from pink to blue-green is shown with 3 to 9 classes. Differences between adjacent colours become smaller as the number of classes increases

Colour can be used to imply categorical differences (e.g. forest, city, marsh) or to imply ordered differences (e.g. population density rates). Figure 3 contains examples of sequential, diverging and qualitative colour schemes (also see Slocum, 1999, Olson, 1987). The kinds of data appropriately matched to these types of schemes are outlined below.

Sequential Colour Schemes

Sequential colour schemes (Figure 3a) imply order and are suited to representing data that ranges from low-to-high values either on an ordinal scale (e.g. cold, warm, hot) or on a numerical scale (e.g. age classes of 0–9, 10–19, 20–29, etc.). Lightness steps dominate the look of these schemes, usually with light colours for low data values and dark colours for high values. ‘Dark equals more’ is a standard cartographic convention. Sequential schemes can be either single hue (e.g. same blue, with different lightness and saturation levels) or multi-hued (e.g. light yellow through dark green). ColorBrewer includes 12 multi-hued sequential schemes and 6 single-hued schemes.

We included more perceptually-graded multi-hue sequential colour schemes in ColorBrewer for two reasons: (1) they provide better colour contrast between classes and (2) they are more difficult to create than single-hue schemes because all three dimensions of colour are changing simultaneously. Moreover, since the default sequential colour schemes in commercial mapping and GIS packages are usually single hue, we felt the inclusion of multi-hued schemes would help novice map makers who wished to use more sophisticated colour schemes.

Diverging Colour Schemes

Diverging colour schemes (Figure 3b) should be used when a critical data class or break point needs to be emphasized. The break or class in the middle of the sequence is emphasized by a hue and lightness change and should represent a critical value in the data such as the mean, median or zero. For example, a choropleth map of poverty rates might be designed to emphasize the national

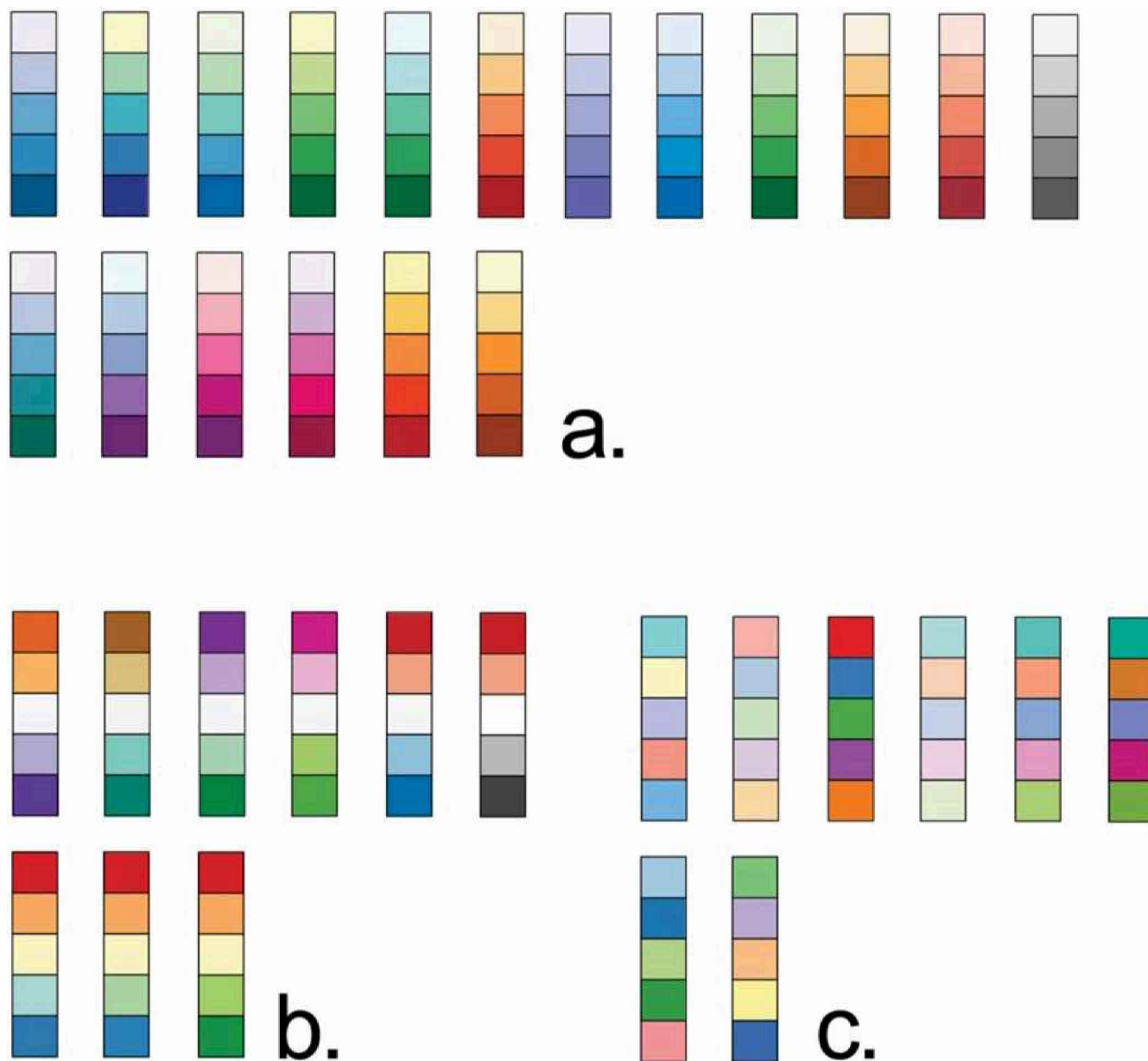


Figure 3. ColorBrewer contains 35 colour scheme sets that can be used to create legends for maps ranging from 3 to 12 classes. The sets are organized into three kinds of colour schemes: (a) sequential, (b) diverging and (c) qualitative

rate (midway through the range of rates shown on the map) so that places above and below the national rate are shown with different hues and thus have similar visual emphasis. Diverging schemes are always multi-hue sequences and, because of the way in which lightness is varied, do not make good black and white photocopies or prints (which only capture differences in lightness).

Although we have designed the diverging schemes to be symmetrical (e.g. equal number of colours on either side of the middle break point), designers may need to customize schemes by moving the critical break/class closer to one end of the sequence. For example, a map of population change might have two classes of population loss and five classes of growth, requiring a scheme with only two colours on one side of a zero-change break and five on the other (Figure 4b). To construct an asymmetrical

scheme, the user should choose a ColorBrewer scheme with more colours than they need and omit colours (as needed) from one side of the scheme.

For this project both the sequential and diverging schemes were constructed from conceptual arcs across the outer shell of colour space. Colours were chosen that are well saturated and organized in orderly lightness sequences. The scheme was not designed using perceptual colour specifications, but knowledge of the relationships between CMYK colour mixture (cyan, magenta, yellow and black) and perceptually ordered colour spaces were used, such as Munsell (Brewer, 1989), to design the schemes. The diverging schemes generally arc over the top of perceptual colour space (with white or light colours in the middle of the arc). The multi-hue sequential schemes include more hue change through the middle of the ranges and

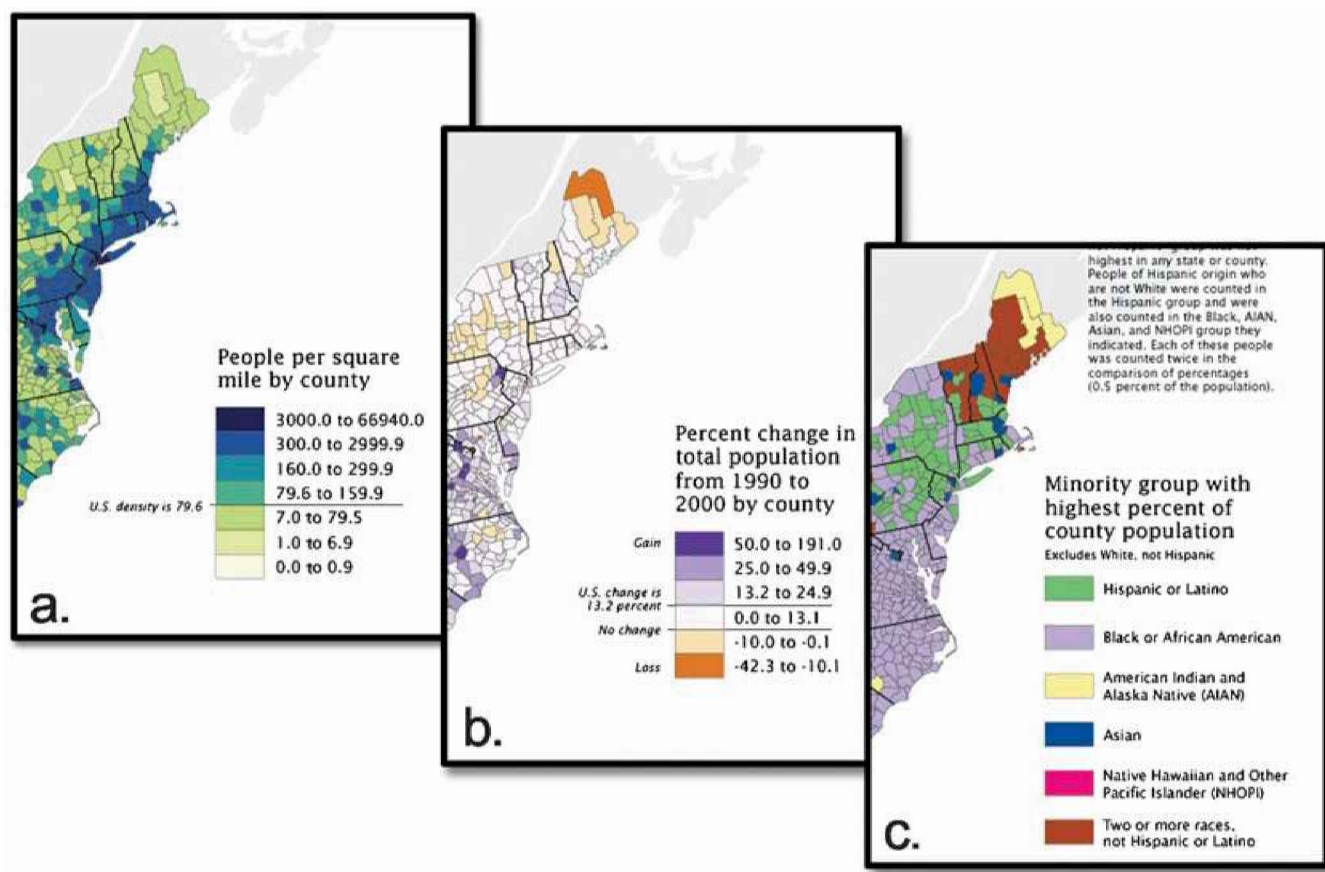


Figure 4. These examples from the *Mapping Census 2000* atlas (Brewer and Suchan, 2001) illustrate appropriate uses of the three main types of colour schemes: (4a) sequential scheme for population density ordered from high to low; (4b) diverging scheme for population change with two hues representing loss and gain and the lightest colour representing the critical mid-range class of no change; and (4c) a qualitative scheme for prevalent minority groups. These example maps are subsets of full maps (pages 11, 10, and 21 in Brewer and Suchan); they are also available online in PDF and Adobe Illustrator formats at www.census.gov/population/www/cen2000/atlas.html

more lightness change at the ends of the schemes. ColorBrewer qualitative schemes generally maintain useful hue contrast with similar lightness and saturation for most colours (the exceptions are obviously the Paired and Accents schemes which intentionally include lightness and saturation differences).

Qualitative Colour Schemes

Qualitative colour schemes (Figure 3c) rely primarily on differences in hue to create a colour scheme that does not imply order, merely difference in kind. Since there is no conceptual ranking in nominal data it is inappropriate to imply order when depicting these data with colour (for example, by using a light-to-dark single-hue sequence). Qualitative schemes work best when hue is varied and saturation and lightness are kept or nearly constant. We do not recommend arbitrarily using strong 'neon' colours (i.e. high saturation) and pastel colours (i.e. light and low saturation) in the same qualitative colour scheme because these variations in saturation might imply order.

In addition to standard qualitative schemes, we offer two sub-categories that do not maintain consistent lightness: Paired and Accents (Figure 5). Accent schemes allow the designer to customize qualitative maps by accenting small areas or important classes with visually stronger colours.

A small number of colours that are more saturated, darker or lighter than others in the scheme are offered as part of the Accent schemes. These accent colours should be used for classes that need emphasis for a particular map topic. Designers must beware of unintentionally emphasizing classes when using these qualitative schemes.

Paired schemes present a series of lightness pairs for each hue (such as light green and dark green). Often a qualitative map will include classes that should be visually related, though they are not explicitly ordered. For example, 'coniferous' and 'broadleaf' woodland would be suitably represented with dark and light green land-cover classes. Although designers will probably not find use for an entire Paired scheme, these pairs can be combined with other qualitative schemes to build a custom scheme for a particular map. Qualitative schemes are, thus, more flexible than either diverging or sequential for which an implied order in the colour sequence is maintained.

NUMBER OF DATA CLASSES

Choosing the number of data classes is an important part of thematic map design. Although increasing the number of data classes on a thematic map will result in a more 'information rich' map by decreasing the amount of

Qualitative Color Schemes

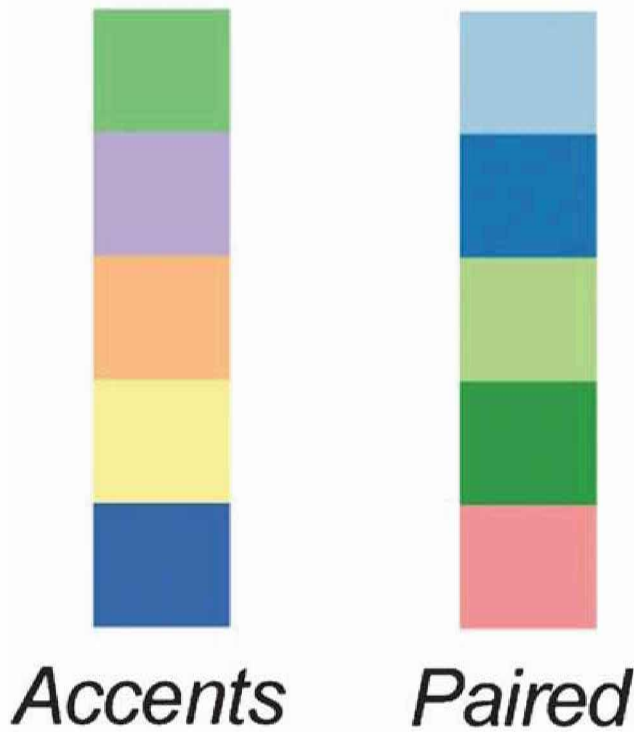


Figure 5. Paired and Accents colour schemes are designed for specific qualitative data mapping situations in which the designer wishes to either emphasize some data classes or pair data classes together

data generalization, if the cartographer uses too many data classes they may compromise map legibility — more classes require more colours that become increasingly difficult to tell apart. The maximum number of data classes ColorBrewer supports is 12, although only a few of the colour schemes can be divided into this many steps and remain differentiable. As a general rule of thumb, cartographers seldom use more than seven classes on a choropleth map. Isoline maps, or choropleth maps with very regular spatial patterns, can safely use more than seven data classes because similar colours are seen next to each other, making them easier to distinguish. The appearance of a map distribution will also be less varied among different classification algorithms (for example, quantile versus equal intervals) with more classes (Muller, 1976).

ColorBrewer is not a data analysis tool and will not tell cartographers how many data classes they should use for a given mapping project (see MacEachren, 1994 and Slocum, 1999 for summaries of a method for objectively calculating a suitable number of classes). Rather, if a cartographer knows how many data classes they would like to use, ColorBrewer will suggest appropriate colour schemes. Because the main map in ColorBrewer is designed as a diagnostic tool for evaluating the robustness of different schemes in different display contexts, the system is designed to *dissuade* cartographers from attempting to use too many

data classes (i.e. colours). Furthermore, a 10-class scheme that is reliable on a CRT display will most likely fail on a laptop LCD display because of different contrast characteristics. Thus, the number of data classes a designer should use for a specific map is a product of the data characteristics, the intended message of the map, the target audience and (importantly) the display medium. A discussion of how this diagnostic map was constructed and how it works follows.

THE MAP AS A DIAGNOSTIC TOOL

A well-known problem with choropleth maps is *simultaneous contrast* (Brewer, 1997). For example, a single enumeration unit (e.g. county) of medium lightness that is surrounded by dark enumeration units will appear lighter than it actually is. Thus, the map-reader will not be able to accurately match these outlying enumeration units with colours in the legend because they will appear lighter on the map than they do on the legend. A related problem involves the similarity in appearance of all light-coloured outliers surrounded by dark areas. For example, two different light yellows side-by-side would be easily differentiated. When physically separated and surrounded by dark colours, they will likely appear to be the *same* colour. As a general rule, the more complex the spatial patterns of the maps, the harder it will be to distinguish slightly different colours. To illustrate this, the maps in ColorBrewer present colours as both random distributions and well-ordered distributions (sequential banding). All other things being equal, a colour scheme will fail to be fully differentiable in the random portion of the map before it fails in the ordered portion.

Figure 6 is a portion of the ‘diagnostic map’ in ColorBrewer. The base map shows US counties, although the colours do not depict actual data. Colours are easy to differentiate when they appear in a nicely ordered sequence (such as a legend). The task of differentiating colours,

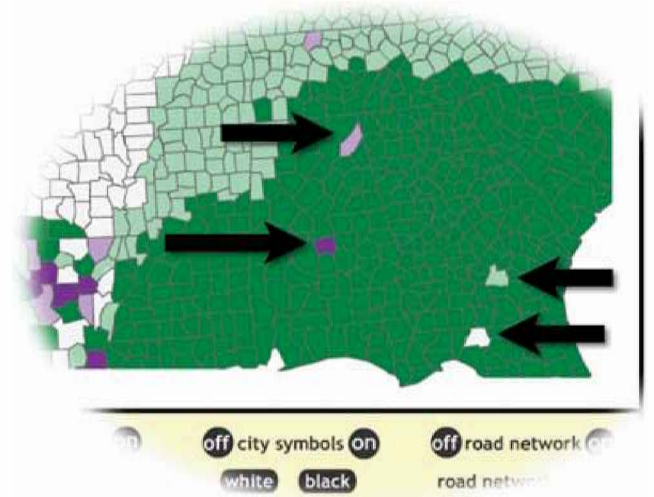


Figure 6. The image shows a portion of a five-class map where the green band has four outliers that can be easily seen. The outliers are the four other colours in the scheme. Users are encouraged to check that each one looks noticeably different than all of the other outliers in the band, and not just different from the band itself

however, becomes much harder when the patterns on the map are complex, such as in the lower left corner of the diagnostic map (Figure 1).

There are two ways the ‘diagnostic map’ in ColorBrewer can be used to evaluate a colour scheme. First, can you clearly see every colour in the random section of the map (Figure 1)? For example, if you have chosen a ten-class colour sequence, make sure that you are able to clearly see ten *unique colours* in this random section. Second, within each large band of colour on the map, we placed one polygon filled with each of the other map colours (the outliers). For example, if you have selected a five-class map, there will be four outliers per band, demonstrating the appearance of all map colours with each as a surrounding colour (Figure 6). Can you see each outlier clearly in Figure 6? Do all pairs of outliers in the band look different? If not, perhaps a different scheme or fewer classes should be chosen.

COLOUR SPECIFICATIONS: OUTPUT FROM COLORBREWER

Once the user has identified a colour scheme they wish to use, ColorBrewer can display the numerical specifications of that scheme in five different colour specification formats (Figure 7): CMYK, RGB, hexadecimal, Lab, and AV3 (ArcView 3.x HSV). We provide specifications for each of these colour systems because different mapping and graphics packages require particular specifications or because users prefer to work with one specification. ColorBrewer colours were originally designed in CMYK in Adobe

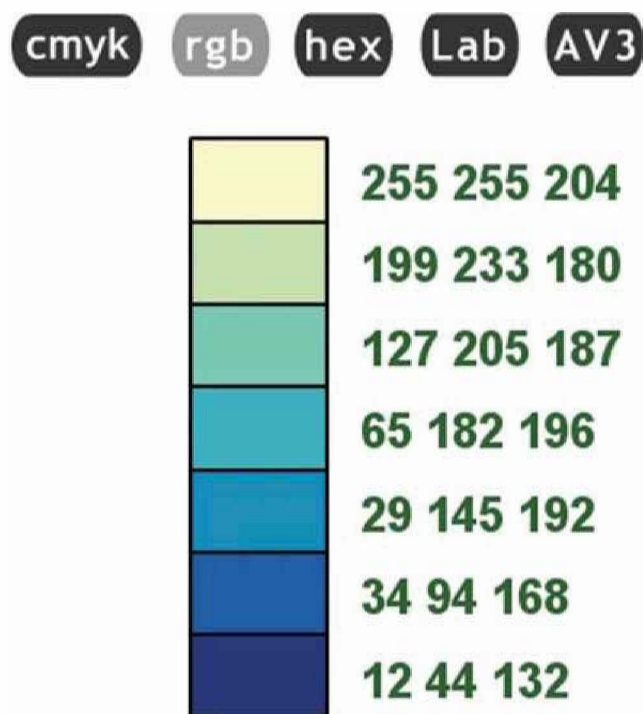


Figure 7. ColorBrewer allows the user to retrieve the exact numbers of any colour scheme in five different color specification systems. Since designers often work with multiple colour systems — and changing between systems can be confusing — we hope this functionality will speed their work

Illustrator 9.0. We looked up RGB conversions for each colour using Illustrator. We used Adobe Photoshop 5.5 to look up the hex and Lab conversions of these RGB colours from Illustrator. We chose these two software packages because a large share of the graphics market uses them, and we were familiar with and trusted the quality of their conversions between colour systems.

Red-green-blue (RGB) is fundamental for specifying onscreen colours (since these additive primaries are used to produce emitted colour). Cyan-magenta-yellow-black (CMYK) percentages are the standard ink specification for printing. Hexadecimal colour specifications are used to define colours on Web pages and in Macromedia Flash. Hexadecimal colour specifications are RGB specifications in base 16. Lab (‘L’ for lightness, ‘a’ for red-green, and ‘b’ for yellow-blue axes) is a perceptually scaled colour system that is available in some graphics and mapping packages, so we have included it in the hope of moving toward perceptual specifications for perceptually ordered colours.

One of the frustrations we encountered as we worked with the five sets of specifications for each colour was that software packages convert colours differently (they use different algorithms to perform these conversions). For example, converting a dark red CMYK of 60C/100M/90Y/0K to RGB in Photoshop produced specifications of 103R/0G/13B. However, this same CMYK to RGB conversion in Illustrator produces 133R/48G/61B, which has a substantially different appearance. Even though the same company produces Photoshop and Illustrator, they apparently use different algorithms to make transformations between colour spaces. We found that Illustrator produced better conversions from CMYK to RGB because when displayed on-screen, these RGB conversions looked more like the original CMYK colours.

We provide an ‘AV3’ version of HSV for ArcView 3.x users (we calculated AV3 specifications from RGB using the algorithm from Hearn and Baker 1986) because ESRI uses an idiosyncratic version of HSV (hue, saturation and value are each rescaled to 0-255) in ArcView 3.x products. The next generation of ESRI mapping tools in ArcGIS 8.x use a more standard version of HSV. To specify custom colours in ArcGIS 8.x, use the RGB specifications from ColorBrewer. Do not use the ColorBrewer CMYK specs in ArcGIS 8.x for maps intended to be viewed onscreen. On the other hand, an ArcGIS map intended for *print* should look right when you use the ColorBrewer CMYK percentages for custom colour specification.

The colour specifications in ColorBrewer should never be treated as ironclad guarantees since colour reproduction (whether onscreen or in print) is an inexact science. As anyone knows who has done production print work before, we cannot guarantee that our CMYK percentages will produce exactly the same colours on the printed page that you see onscreen. It is best to think of these CMYK ink percentages as a good starting point but, because printers vary, some ‘tinkering’ with the exact ratio of inks will be necessary to create a satisfactory final printed product. Colour laser print quality is difficult to control and often produces marked shifts in colour appearance from screen to paper. From our own experiences, cyan pigments seem to be hard to control and light yellows, for example, can become light greens even on expensive

colour laser printers. Worse, colour laser output can change over time (as toner amounts change and imaging drums degrade), and even the kind of paper used will influence the appearance of a colour map. Therefore, it should surprise no one that many trial prints may be required before the colours look right. Even if a designer has no intention of printing his or her maps, the situation is only slightly better with digital displays since computer monitors are calibrated differently, and cross-platform differences (e.g. from Mac to PC) can change the appearance of colours, although these changes are somewhat more predictable.

GUIDANCE FROM USABILITY ICONS

In an effort to help the user navigate the colour reproduction process, we have tested each of the permutations of every colour scheme in ColorBrewer across multiple display types, platforms and printed output. We systematically distilled these qualitative differences into ‘use guidelines’ based on media and display environments. These guidelines are included with ColorBrewer and represent a timesavings function of the tool for novice and expert cartographers alike. In other words, we offer to steer users away from potential problems because we have tried every possible combination of every colour scheme in multiple display environments.

We examined each of the colour scheme sets using two CRT screens (Mac and PC), two laptop LCD screens (old and new), two LCD projectors (old and new), and prints from a Tektronix colour laser printer and a black-and-white laser printer. We evaluated the schemes by deciding whether we could differentiate all of the colours on the multiple backgrounds offered in the ColorBrewer map display. If we had difficulty with the contrast in a scheme, the icon was marked with a red ‘X.’ If we saw a difference on one display but not another, or if the difference was weak but visible, the usability icon was marked with a red ‘?’ The icons are shown in Figure 8.

The first icon in the usability set, the eye (Figure 8), indicates whether a scheme should be readable by people with red-green colour vision impairments. These approximate evaluations were made using both a theoretical understanding of colour-blind confusions throughout colour space (Olson and Brewer, 1997) as well as an evaluation of the schemes by an individual with red-green colour impairment, although we would like to see more thorough testing of the schemes to confirm that they accommodate a wide range of colour vision impairments. Generally, the hue pairs for diverging schemes were selected to accommodate colour-blind readers, with the exception of red-yellow-green and full spectral schemes. Almost all of the qualitative schemes are difficult for colour-blind readers and all of the sequential schemes are useful to them, because they include visible lightness differences.

SOFTWARE DEVELOPMENT: FLASH 5

The list of functional requirements for ColorBrewer was long: it needed to be (1) Web-based, (2) download quickly, (3) run well on ‘trailing-edge’ computers, (4) work

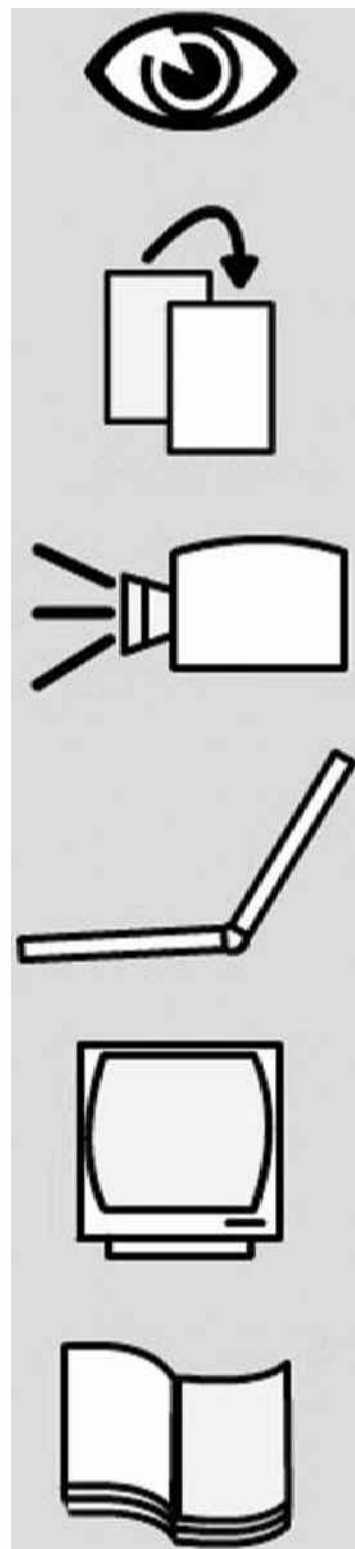


Figure 8. Usability icons to guide map designer's choice of scheme. For each scheme choice, icons are each marked onscreen with an 'X' if we expect it to fail in the display situation or a '?' if we are unsure whether it will function well because of variability in colour differences in our testing. For example, many schemes that work well on a CRT (icon e) will not hold up when photocopied (b) or projected using an LCD digital projector (c). Icon (a) indicates suitability for colorblindness; icon (d) indicates suitability for laptop LCD displays; and icon (f) indicates suitability for colour printing. A description of the meaning of each icon appears when you click on it in ColorBrewer

across different computer platforms (e.g. Mac, Windows, UNIX), (5) allow for a high degree of user-interactivity and (6) require little training time to use. The amount of control that users have in ColorBrewer is less than a full GIS package, but somewhat more than most multimedia Web content. The success of ColorBrewer depended upon providing visitors with enough flexibility and power to quickly find and 'test-drive' many colour schemes, without overwhelming them with a complicated interface.

Few Web technologies could fulfil all of our requirements. Although ColorBrewer could have been built in JAVA, this required a level of programming expertise beyond our abilities and would require that every component be built from the ground up. Instead, Macromedia Flash 5 was selected as it offered the right combination of graphic design capabilities, programming flexibility and rapid development.

Although originally conceived of as a tool for creating simple non-interactive animations for Web pages, Flash has matured into a powerful tool for creating dynamic and interactive Web material. Flash content has become the

de-facto standard for dynamic multimedia online. Because they are vector-based, Flash files are remarkably small and, hence, download quickly. The speed with which online applications download is directly proportional to their success with the public. Flash is attractive because it is compatible with all major Web-browsers (using the Shockwave plug-in) and runs well on lower-end computers. Moreover, current estimates are that over 97 per cent of Web users have the Flash plug-in already installed (Macromedia 2002). Those who need the Flash plug-in can find it for free on the Macromedia website (www.macromedia.com) and the introductory screen for ColorBrewer offers a link to the site. Flash's object-oriented programming language, called Actionscript, allowed us to add functionality such as zooming, panning, pull-down menus and 'pop-up' help windows. A portion of Actionscript code is shown in Figure 9.

Learning an interface consists of at least two critical steps: knowing *what* the buttons do, and knowing *the order* in which to use them. It never ceases to amaze us that software engineers often hide important interface controls

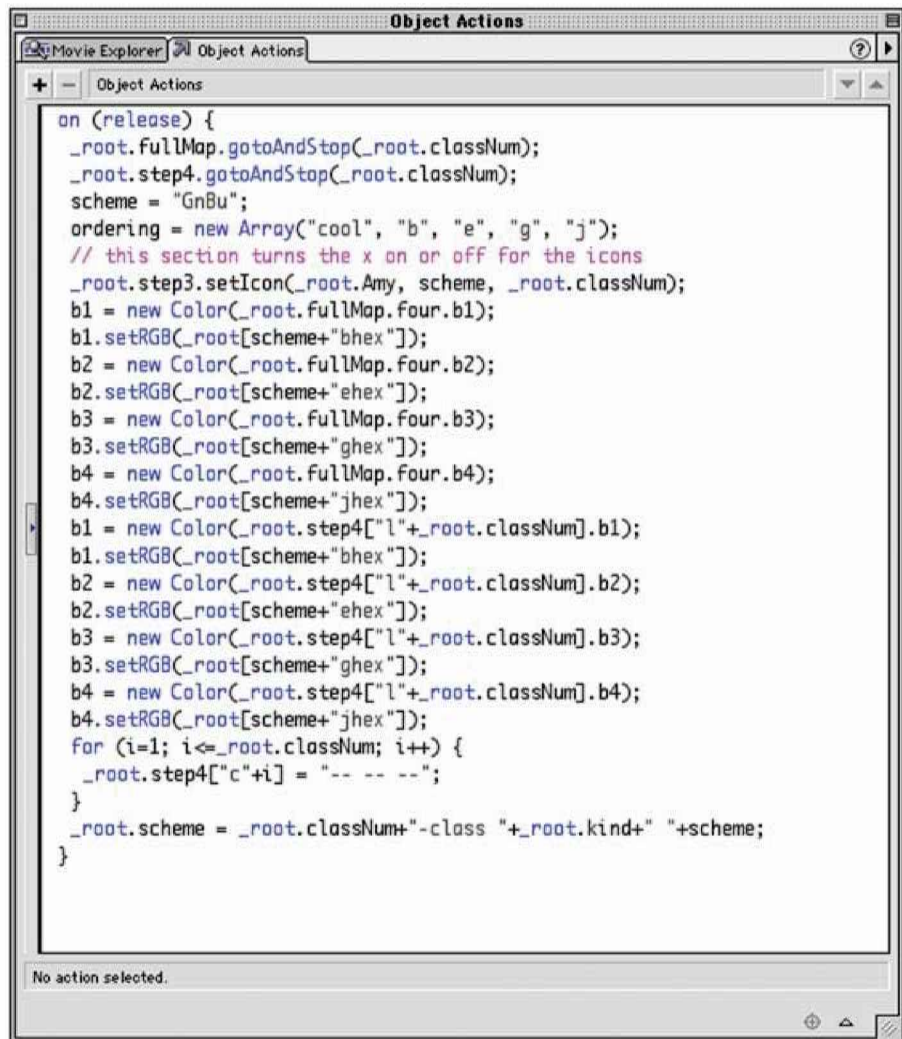


Figure 9. An example segment of Actionscript code. Actionscript operates behind the scenes and is used to load new colours into the diagnostic map. Flash changes the appearance of objects using hexadecimal codes, which are dynamically retrieved from a master list. This example sets states for a set of usability icons for a green-blue scheme

Table 3. Colour sets for diverging schemes

Colour	Number of classes								
	11	10	9	8	7	6	5	4	3
A	A	A							
B	B	B	B	B	B	B			
C							C	C	
D	D	D	D	D					
E					E	E			E
F	F	F	F	F			F	F	
G	G	G	G	G	G	G			
H	H		H		H		H		H
I	I	I	I	I	I	I			
J	J	J	J	J			J	J	
K					K	K			K
L	L	L	L	L					
M							M	M	
N	N	N	N	N	N	N			
O	O	O							

been a tremendous help in their own design work. Not inconsequentially, ColorBrewer is available for free, 24 hours a day, to anyone with a Web connection.

ColorBrewer is an online tool that is designed to help mapmakers select effective colour schemes for thematic maps. ColorBrewer has been designed to fill existing gaps in the usability of GIS and graphics software by providing not only attractive colour schemes, but also recommendations on how to use those colour schemes most effectively. As such, it has found an audience with both map designers who rely on it to speed their work and college-level educators who use it in their classroom to demonstrate important concepts in colour use and design. Some of the valuable features in ColorBrewer include: (1) multi-hued perceptually ordered colour schemes; (2) 'learn more' features which advise designers on some of the theory behind colour use and map making; (3) the ability to check how well different colours schemes will 'hold up' when additional map information is present, or the colours of the background and enumeration unit borders are changed; (4) the ability to check how well different colours schemes will perform when the mapped patterns are both ordered (e.g. banded) and complex (e.g. heterogeneous distributions); and (5) colour output specifications in five commonly used colour systems (CMYK, RGB, hexadecimal, Lab and ArcView 3.x HSV). Perhaps the most valuable feature in ColorBrewer is the use guidelines for every colour scheme. In total, 385 unique colour schemes have been evaluated across different computer platforms and monitors (i.e. Mac and PC, projected LCD, laptop LCD and CRT), for possible colour-blind confusions, as well as in printed formats (both as colour and black-and-white prints). Given the importance of designing maps for the medium in which they will be used, these guidelines

will help cartographers avoid selecting colour schemes that look attractive in their *design medium* (usually a CRT monitor) but fail in their *display medium*.

ACKNOWLEDGEMENTS

This work was part of the Digital Government Quality Graphics project (www.geovista.psu.edu/grants/dg-qg/), which is funded by the National Science Foundation under Grant No. 9983451, 9983459, 9983461. We would like to thank members of the Penn State Department of Geography for their generous feedback and design advice. Special acknowledgement must be given to Penn State undergraduate student Amy Dean who tirelessly evaluated the usability of 385 colour schemes over a two-week period.

REFERENCES

- Bertin, J. (1983). *Semiology of Graphics: Diagrams, Networks, Maps*, University of Wisconsin-Madison, Madison, WI.
- Brewer, C. A. (1989). 'The Development of Process-Printed Munsell Charts for Selecting Map Colours', *The American Cartographer*, 16, 269-78.
- Brewer, C. A. (1997). 'Evaluation of a Model for Predicting Simultaneous Contrast on Colour Maps', *The Professional Geographer*, 49, 280-94.
- Brewer, C. A. and Suchan, T. A. (2001). *Mapping Census 2000: The Geography of U.S. Diversity*, Census Special Report, Series CENSR/01-1, US Government Printing Office, Washington DC, 108 pp.
- Devesa, S. S., Grauman, D. J., Pennello, G. A., Hoover, R. N. and Fraumeni, J. F. (1999). *Atlas of Cancer Mortality in the United States, 1950-1994*, NIH Publication No. 99-4564367, National Cancer Institute, National Institutes of Health, Bethesda MD, 367 pp.
- Hearn, D. and Baker, M. P. (1986). *Computer Graphics*, Prentice-Hall, Englewood Cliffs, NJ.
- MacEachren, A. M. (1994). *Some Truth with Maps: A Primer on Symbolization and Design*, Association of American Geographers, Washington DC.
- MacEachren, A. M. (1995). *How Maps Work: Representation, Visualization, and Design*, Guilford, New York.
- Muller, J.-C. (1976). 'Number of Classes and Choropleth Pattern Characteristics', *The American Cartographer*, 3, 169-76.
- Olson, J. M. (1987). 'Colour and the Computer in Cartography', in *Colour and the Computer*, ed. by Durrett, H. J., pp. 205-19, Academic Press, Boston.
- Olson, J. M. and Brewer, C. A. (1997). 'An Evaluation of Colour Selections to Accommodate Map Users With Colour Vision Impairments', *Annals of the Association of American Geographers*, 87, 103-34.
- Olson, J. M. (2001). 'Strategies for Map Colour Selection in the Age of GIS', *Proceedings 97th Annual Meeting of the Association of American Geographers*, New York, NY. 27 Feb-3 Mar 2001, 713 pp.
- Pickle, L. W., Mungiole, M., Jones, G. K. and White, A. A. (1996). *Atlas of United States Mortality*, National Center for Health Statistics, Hyattsville, MD.
- Slocum, T. A. (1999). *Thematic Cartography and Visualization*, Prentice-Hall, Upper Saddle River, NJ.

Copyright of Cartographic Journal is the property of Maney Publishing and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.

Copyright of Cartographic Journal is the property of Maney Publishing and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.