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***Cartographic Iconography and the Internet:
A Study of the Use of Colour in Icon Design***

by

Anita Müller, B.A.

A thesis submitted to
The Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of

Master of Arts

Department of Geography

**Carleton University
Ottawa, Ontario
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The Faculty of Graduate Studies and Research
acceptance of the thesis

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Thesis supervisor, D.R.F. Taylor, PhD.

Chairman, Department of Geography

Carleton University
May, 2001

Abstract

Rapid development of the World Wide Web has facilitated response to the demand for geospatial information. As a result, a number of cartographic products and tools are becoming available through the Internet. These are becoming increasingly complex in terms of both their information content and representation, but the accessibility, efficiency, and effectiveness of these products strongly rely on graphical user interfaces (GUI). The research presented in this thesis deals with cartographic iconography for Web-based cartographic products. Based on cartographic and graphic design theories, the study identifies important issues associated with a particular aspect of interfaces, that is the design of icons, and concentrates specifically on the use of colour in an Internet environment. The main objective of the research is to develop guidelines and make recommendations for the use of colour in design and standardization of icons used in Web based cartography, while presenting theoretical reasoning, applications, and graphical examples.

Acknowledgement

It is fitting that the acknowledgments should come at the beginning of this thesis for without the help and support of many people this study would not have been possible. I would like to thank my supervisor Dr. Fraser Taylor, Department of Geography, Carleton University, and my adviser Dr. Eva Siekierska, Geomatics Canada, Department of Natural Resources Canada, for their guidance and support during the past two years. Dr. Taylor and Dr. Siekierska have been the people who always encouraged me to strive for the highest possible standards and individualistic expression in my research. The formal agreement between Carleton University and Geomatics Canada provided the facilities that helped with the preparation of the thesis.

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1. Introduction

*I found I could say things with color and
shapes that I couldn't say any other way--
things I had no words for.*

(Georgia O'Keeffe, 1887-1986)

1.1 Background

The end of the twentieth century has witnessed rapid development of computer technology and globalization of the public use of the Internet. With only the point and click of a mouse, incredible amounts of data can be accessed by individuals with a computer and Internet connection. With more data, the information available on the Internet is becoming increasingly spatial in its nature and graphic in its forms of representation. At the same time, a perfect opportunity has been created for the development of Internet mapping.

Computer cartography, already well established, is now finding new representations enabled by the Internet. World Wide Web technologies have triggered changes in various processes, namely data collection, map representation, distribution and usage. People are no longer dependent on paper maps, which with a fast changing infrastructure and economies become quickly outdated, but have the option of accessing up-to-date maps and other innovative cartographic products through the Internet (<http://www.icaci.org/>). Maps which a few years ago were available to a small portion of a society, now can be made available globally to anyone with a computer and an Internet connection, accessed

from anywhere, at anytime. An increased demand for geospatial products is driving the current cartographic developments, and thus increases the number of sites which offer interactive, multimedia maps, atlases and other related products.

Cartographic products are no longer limited to static maps but now offer interactive information resources available globally through the Web. With hyperlinked databases and multimedia output, map functionalities are greatly extended. Animated, interactive, vocal, and tactile maps, linked with short videos or real time streaming images from cameras are the new Web enabled cartography products (Kraak, 2000). Dynamic and interactive maps with transparent but powerful human-computer interface capabilities are beginning to emerge for a variety of geographical information (<http://www.icaci.org/>).

From the map user's perspective, the Internet improves the accessibility and potentially the quality of cartographic products. As some authors have argued, there is an incredible number of extremely poor maps, often produced by people who use desktop publishing software (MacEachren and Kraak, 2000; Cartwright, Peterson and Gartner, 1999; Cammack, 1999). These individuals rarely have cartographic training, and with access to a scanner, can easily upload to the Internet poorly scanned maps. However, for a skilful cartographer, the Internet opens the door to almost endless possibilities of cartographic presentation. With multimedia capabilities, geospatial data can be channeled to a number of different

human senses. Currently, data presentation is explored in visual, audio and also tactile formats. With quickly advancing technology there is even discussion about including other senses such as taste and smell to Internet technologies (Ebert and Clarke, 2000).

1.2 Research objectives

1.2.1 Problem identification

With an increasing volume of cartographic information available on the Internet, the cartographic community stresses the importance of developing effective user interfaces. Research in user interfaces and especially in application of colour in icon design is crucial to the dissemination and communicativeness of online cartographic products. However, the existing literature on this topic is sparse, and there are no standards for graphical user interfaces.

For instance, the research conducted in the area of human-computer interaction has concluded that from the five styles¹, direct manipulation interfaces are the most effective (Shneiderman, 1998). There is a need to explore, in more detail, direct manipulation interfaces, namely icons, as they are easy to learn and remember, as well as very intuitive, when designed with proper knowledge. They are based on pictorial representation, where icons are manipulated by the user with a pointing device (i.e. a mouse). Once a good visual expression of the concept is found, and a

suitable colour scheme chosen, the interaction through the interface is very intuitive and efficient. On the other hand, excessive or inappropriate use of colour can inhibit performance and confuse the user.

A major benefit of using icons in user interfaces is that they permit users to work more effectively by improving productivity (Horton, 1994). Icons save screen space and reading time by replacing some of the labels or headings. Since they are only a few pixels in size, they can conveniently fit on a computer desktop or in the menus. Icons also enhance search capabilities because distinctive shapes and colours are immediately recognized. Since visually encoded concepts are easier to remember than verbal or written messages, they are easier and faster for recall (Arnheim, 1974). An additional benefit of using icons in user interfaces is the reduction of the dependence on text. This is a very important issue as it contributes to overcoming reading disabilities, and helps the cartographic user interface to be understood by an international audience, and to cross language barriers.

1.2.2 Objectives

The first objective of this research is to explore colour in user interfaces and to suggest an alternative for extending the 216 Web-safe colour palette. The second objective is to develop a systematic way of using colour in the design of icons used

¹ Five styles of human-computer interfaces: menu selection, form fill-in, direct manipulation, command language (written syntax), and natural language (vocal command) (Shneiderman 1998).

in interfaces for Web based cartographic products. This objective is met through development of design strategies.

1.3 Methodology

In this research the following primary and secondary methods were employed:

- A comprehensive review of the published literature, including books, academic journals, conference proceedings and government documents;
- A comprehensive World Wide Web review of literature on Web design and technology. These resources include official Web sites of cartographic organizations (i.e. societies and associations); cartography related research and commercial institutions, and government online publications. Other resources, such as Web sites about Web design and private research were also employed;
- Communication with various individuals, such as cartographers, graphic designers and Web developers;
- The author's own observations and experience working in the field of cartography and Web development.

1.4 Research in Web based user interfaces

The demand for spatially based information represented graphically is met by continuous development of Web map related products. As the quantity and complexity of these products increase, the means for accessing, retrieving, and interacting with information becomes crucial. The importance of cartographic

research in user interfaces is growing because an interface is a critical mechanism for accessing Web information

(<http://maps.unomaha.edu/ica/Maps%26Internet/>,

<http://www.geovista.psu.edu/icavis/>). When the user interface is adequate, then the new map will be accessible to the user; if the interface is inadequate or poorly designed, then the user's access will be limited and maps and other cartographic information might become almost inaccessible.

1.4.1 Cartographic societies and associations

Increasingly complex Internet based cartographic products and visualization tools call for research into effective graphic user interfaces, which make the navigation and interaction with information more efficient and effective. Such research is gradually increasing in the cartographic community, and changes can be observed in recent publications and activities of various societies and associations. For example, the International Cartographic Association (ICA) now has two commissions concerned specifically with user interfaces; the Commission on Maps and the Internet, and the Commission on Visualization and Virtual Environments.

The research conducted by the Commission on Maps and the Internet is structured around Internet cartography. Topics discussed extend from basic static maps to multimedia cartographic services available online. The promotion of international user interfaces for maps on the Web is crucial, and involves developing design

guidelines and establishment of standards. Such standards would include specifications for all user interface elements such as colour, typography, symbology and others.

(<http://maps.unomaha.edu/ica/Maps%26Internet/Research/Questions.html>).

Also similar in approach is the development of guidelines for the design of web maps. Such guidelines would suggest ideal fonts and colour usage, as well as elaborate on the possibilities and limitations offered by the World Wide Web.

The Commission on Visualization focuses on the use of dynamic maps as a visual method designed to facilitate the exploration, analysis, synthesis, and presentation of georeferenced information (<http://www.geovista.psu.edu/icavis/>). Continuing technological and conceptual advances have been visibly reflected within the Commission through the research agenda, and the name itself which now reads the "Commission on Visualization and Virtual Environments". The research agenda, as articulated by MacEachren and Kraak (chair and co-chair) stresses that particular attention between 1999 and 2003, is placed on the "design and testing of new interface forms that take advantage of and support the changing nature of representation associated with virtual reality technology, interactive map animation, and others..." (<http://www.geovista.psu.edu/icavis/agenda/index.html>).

1.4.2 Canadian governments

In 1999, in response to opportunities and benefits which the Internet has the potential to offer, the Government of Canada established the Government On-Line initiative whose objective is to provide Canadians with electronic access to federal information and services (http://www.gol-ged.gc.ca/index_e.asp). With an increasing amount of government information available online, the Treasury Board of Canada Secretariat began developing standards for the organization of the Government of Canada Internet Web sites. The implementation of such standards will enable Canadians to distinguish federal programs and services from others and successfully navigate from one federal site to another to find information relevant to their circumstances. The Common Look and Feel (CL&F) standards are the key requirement for accessible design in the Government of Canada, and are based on the World Wide Web Consortium (W3C) guidelines for making Web sites universally accessible.

The CL&F guidelines specify the structure, graphical layout and graphics used on the government Web site to access textual information. However, there is also a large number of graphically represented products which vary from simple base maps through customized user-generated maps, to vector files and interactive mapping applications. There are no standards yet, that define user interfaces for such information access, but individual departments are beginning to develop cartographic user interfaces. For example, within the Mapping Services Branch,

the group working on the Internet Based Cartographic Visualization project (research and development) investigates new methods of cartographic visualization and geographic information handling suitable for Web-based communication. One of their products is the orthomosaic interface, which uses icons to show layers of information. Within the Earth Sciences Sector, the need for further standardization for graphical representations of geospatial data is recognized, and every effort is made to develop design guidelines for such interfaces.

1.5 Cartographic user interfaces

The increasing number of Internet based cartographic products and tools are becoming more complex in both their information content and representation, and require effective graphical user interfaces. Graphical user interfaces, commonly referred to as GUI are described in the National Atlas of Canada web site as a "method of interacting with a computer system by using a mouse to point-and-click on graphic symbols (icons, glyphs or menus), which are displayed on the computer monitor," (<http://atlas.gc.ca/english/carto/cartglos.html>).

Most of the cartographic literature devoted to innovations in computer and Web cartography use the term *(graphic) user interface* (Cammack, 1999; Cartwright, Peterson and Gartner, 1999). However, in more specialized articles, such as those pertaining to geospatial visualization, the term *visualization interfaces* is employed (Lindholm and Sarjakoski, 1994; MacEachren and Kraak, 2000). In this thesis the

term *cartographic user interface (CUI)* (not to be confused with Character-based User Interface) will be used for two reasons. First, the functionality of user interfaces for cartographic products is unique, and differs in some respects from general interfaces. This is to emphasize that a set of interface elements specific to online cartographic products is being employed. For example, a set of icons may be developed to give access to maps or map themes/topics. Such icons would be designed to include iconic symbols used in conventional cartography.. Second, the design of such interfaces should be based on cartographic principles to build on the existing cartographic knowledge of the user and to further communication and understanding.

1.6 Definition of icons

One of the most important elements of a user interface are the *icons*, which enable access to information. In the current era of computer technology, most people encounter the term icon as a computing term meaning a symbol or a graphic representation on a computer screen of a program, option or a window.

However, throughout the years the definition of this term has been slowly evolving.

Probably the earliest usage of the word icon is found in religion where it refers to "...a devotional painting or carving, usually of Christ, or another holy figure..."(Concise Oxford Dictionary, 1990: 584). In linguistics, an icon bears the meaning of "a sign which has a characteristic in common with the thing it

signifies" (Concise Oxford Dictionary, 1990: 584). The field of semiology has developed an extensive vocabulary to distinguish among visual items that represent meaning. In this field the term icon is often used for images that mimic or resemble the concept of objects to which they refer (Frutiger, 1989).

Cartographic literature refers to icons as "similar pictures incorporated on a map" (Fremlin and Robinson, 1998: 128). Furthermore, in cartography, one refers to either pictorial symbols or signs but not specifically icons. One reference to icons is made by Fremlin and Robinson in their Cartographic Monograph, "Maps as Mediated Seeing" from 1998. There, the authors discuss *Ideographs*, *Iconic Regions Maps* and *Iconic Inset Maps*.

Ideographs refer to small pictures on the map depicting a unique structure or a natural feature that is easily associated with a particular place (Fremlin and Robinson, 1998). Such pictures would be, for example, the Statue of Liberty for New York or Big Ben for London, England. An iconic regions map, on the other hand, is composed of realistic landscape pictures with physical features serving as a base map. The pictures depict significant elements of the mapped places. In iconic maps, pictures symbolize characteristic features rather than representing particular geospatial data. Fremlin and Robinson also distinguish *iconic inset maps* (1998). These are maps which are very similar to iconic region maps and

also use small pictures to communicate certain information, but which are not necessarily confined to specific location.

In this research an *icon* is defined as a small pictorial symbol used in a computer interface. It represents certain capabilities of the system, and serves as a navigational tool. Icons, often used as a synonym for any small visual symbols, vary. Often they are two dimensional symbols, monochromatic to colour, interactive, and sometimes they are animated and three-dimensional. Icons in computer user interfaces are used to activate menus, perform actions, select tools and toggle between modes. They can also be used to reveal system status or state of data through graphical indicators, to represent information, and to indicate formats in multimedia applications.

1.7 Presentation and organization of the thesis

Considering the nature of this research, it is fitting to present the thesis in an electronic format on the Web. A Web site was developed specifically to host research results and to expose the research to a larger academic community. At the time of thesis submission, the research has been made available on the Internet at [**http://chat.carleton.ca/~amuller/MA-Thesis/**](http://chat.carleton.ca/~amuller/MA-Thesis/), and every effort is made to maintain continuous availability of the research online. However, because the existing university regulations require submission of a hard copy, the thesis is presented on paper with an attached CD-ROM copy of the Web site. The two

copies, paper and CD-ROM, are complementary and should be read and viewed together. Some of the examples, such as rollover effects, cannot be demonstrated on paper and reference to the digital supplement is made. Also, because the nature of the thesis demands an on-screen viewing in hyperlinked environment, the content organization of the Web/ CD-ROM version differs from what is expected from a regular thesis.

1.7.1 Hard copy

The thesis research presented in paper format is organized into seven chapters. Chapter 1 provides an introduction to the research, and includes problem identification, objectives and proposed methodology. Chapter 2 offers an introduction to the graphical design of the Internet based icon, through discussion of visual variables. In this chapter, the author explains the butterfly model, which was developed to illustrate graphical variables used in icon design and to contrast the application of these variables in design for paper and for computer display (specifically Web viewing). Chapter 3 discusses the fundamentals of colour, such as colour perception and taxonomy. Chapter 4 elaborates on functions of colour in design, and discusses these as they pertain to icon design. In Chapter 5 the author explains issues associated with the use of colour in a Web environment, specifically the limitations and possibilities of the Web-safe palette. Chapter 6 summarizes the research in the form of design recommendations for Internet based icons, richly

supplemented with illustrations. The research is concluded in Chapter 7 with a discussion of further research directions.

1.7.2 Web site

The Web site created to host the research results of the MA thesis is available at **<http://chat.carleton.ca/~amuller/MA-Thesis/>** and every effort will be made to preserve the Web location after the thesis defense. However, if this should not prove possible, the author will maintain the Web site at a different URL which can be found using any search engine, with keywords such as; Anita Muller, cartography, cartographic iconography, Web cartography, icons, colour, interfaces.

The research information presented on the Web site is divided into three sections; *About*, *Contents* and *Resources*. The *About* section (Figure 1-1) contains information typically found at the beginning of a printed thesis, such as abstract, acknowledgements and sign sheet, as well as short information about the author and contact information.

Figure 1-1: Screen capture of the About section
(<http://chat.carleton.ca/~amuller/MA-Thesis/about.html>).

The Contents section (Figure 1-1) is the main section of the Web site, containing the body of the thesis. Each chapter with accompanying illustrations is displayed on a separate page. There are also two pages which index all of the figures and tables. In addition, the viewers can download each chapter separately in Portable Document Format (PDF), available under the menu name *downloads*. The PDF format was chosen based on recommendations for the most accessible format for downloading via the Internet, suggested by the World Wide Web Consortium (<http://www.w3.org/>) and by the Treasury Board of Canada (<http://www.cio-dpi.gc.ca/>).

Figure 1-2: Screen capture of the Contents section
(<http://chat.carleton.ca/~amuller/MA-Thesis/content/index.html>).

The third section, called Resources (Figure 1-2), is the equivalent of references in the printed thesis. In this section, the printed, and Web references are divided into two subsections for better organization.

1.7.3 CD-ROM

The CD copy of the Web site is mounted on the back cover of the printed thesis. To view the content of the CD-ROM, viewers require an Internet browser such as Netscape or Internet Explorer. In order to effectively present the graphics, the Web site was designed for larger monitors and is best viewed at a screen resolution of 1024x768. To run the CD-ROM, **index.html** should be opened from an Internet browser.

Figure 1-3: Screen capture of the Resources section
(<http://chat.carleton.ca/~amuller/MA-Thesis/resources.html>).

2. Visual variables

*Cartographic communication can only be
successful if sound map design principles are
fully understood and used properly*
(Wood, 1992: 128)

2.1 Introduction

Icons are one of the integral parts of graphic user interfaces. Their design impacts the effectiveness and efficiency of human-computer interaction and for this reason their design must not be neglected. Although computer science deals with icon design and guidelines, these are primarily concerned with computer system interfaces. Within the field of cartography there is still very little research devoted to Internet based user interfaces and no published research on icon design. Since this study explores, in detail, the application of the colour variable in icon design, it is fitting to begin with a chapter which explains what role other visual variables play in graphical representation of data and information. It should be noted that all the illustrations are intended for computer viewing and that it is not possible to present some of them on paper. Hence, the viewing of the attached CD-ROM or the Web site (<http://chat.carleton.ca/~amuller/MA-Thesis/index.html>) is necessary.

2.2 Visual variables

Types of symbol can be differentiated using graphic variations called primary visual variables. The first person to introduce the term *visual variable* was the French cartographer Jacques Bertin in 1967. He distinguished six variables; shape, size,

orientation, colour, texture and value (Bertin 1983). In 1984, Robinson et al. modified Bertin's classification of variables and divided them into two groups, *primary* and *secondary visual variables*. Primary visual variables include shape, size, orientation, hue (colour), value (colour) and chroma (colour) while secondary variables include texture, orientation and arrangement (Robinson et al 1995). Dent, on the other hand, refers to visual qualities of symbols as "symbol dimensions" and describes them as shape, size, colour hue, colour value, colour saturation, pattern orientation, pattern arrangement, and pattern texture (1999). He also acknowledges the use of *location* as a graphic variable intrinsic to the symbol itself (Dent 1999).

Although visual variables were originally described for paper output, similar principles can be applied in the design for computer display. However, the application of principles must be modified since there are large differences between the two media. Since Internet technologies allow for new visual representation capabilities, such as graphic animation, an argument will be made for an addition of a seventh visual variable *motion*. All of the visual variables (both Bertin's and Robinson's formulations with an additional variable, motion) are graphically summarized in Figure 2-1 and Figure 2-2.

Shape
Orientation
Size
Hue
Value
Chroma
Motion

Figure 2-1: Primary visual variables for the design on computer displays (Adaptation of Bertin 1973 and Robinson et al. 1995).

Texture
Orientation
Arrangement

Figure 2-2: Secondary visual variables for the design on computer displays (Adaptation of Bertin 1983 and Robinson et al. 1995).

2.3 Butterfly model

To conceptualize icon design for the Web, a butterfly model (Figure 2-3) has been developed based on seven visual variables. The model has been developed graphically in order to emphasize differences between graphic design for paper output and for display in an Internet environment. The butterfly's wings in the model proposed represent these two output methods. Each of the visual variables is symbolized by a rectangle, which is coloured using a single hue. The intensity of yellow emphasizes the medium (print or digital display) which offers most possibilities. For example, there is a larger choice of colour (both hue and value) in print output. The computer display in Web environment, limits the colour usage to a 216 Web-safe colour palette.

Figure 2-3: Butterfly model of visual variables in icon design, developed by the author.

Although the same principles guide the design of icons for computer display as for paper output, different emphasis is placed on various variables according to the type of medium used. A symbol very suitable for an analog map might prove to be poor when applied to a map designed for a computer screen. The difficulties are rooted in the fact that paper has a continuous surface while a computer display is composed of small discrete and discontinuous dots called pixels. Colour, hue, value, and saturation, are probably the most obvious variables which require different design consideration for the computer screen as opposed to paper output. A designer has the option of almost unlimited hue and saturation for paper, but is limited to 216 Web-safe colours in the design for the Internet (see Chapter 5 for more details).

The size of graphic also differs significantly. Icons and symbols designed for the Internet are limited by the screen resolution, which is currently 72 dots per inch (dpi). Despite technological change, this is unlikely to match the resolution for printed output, which can exceed 1000dpi. Textures, or patterns used for computer displays, are also affected by the screen resolution, and the intervals between pattern elements are limited to one pixel. Shape and orientation have similar properties between paper and computer output, while the seventh, new variable *motion* applies only to computer displays.

2.4 Shape

Research in perception has indicated that it is easier to remember something that is at the beginning and at the end, rather than something that is in the middle (Sharpe 1974). When applied to cartographic symbols this translates to the fact that the outside elements of a symbol are perceived and recognized faster than the inside elements. Therefore, a symbol is more readable when the optical weight is moved to the periphery of the symbol (Ratajski 1973).

There are two types of icon shapes: regular, such as geometric shapes, and irregular, also called iconic (e.g. an aeroplane to represent an airport location). The regularly shaped icons are usually in the form of a square, rectangular or round button, to accommodate a range of images and to create flexibility in display arrangements. For example, simple navigation menus (toolbars) found in most software consist of a row or double row of square or rectangular icons. Among rectangular shapes the so-called *golden rectangle*, which has a width-height ratio of 1.618 or 0.618, is often used for icons as it can accommodate labels. The golden rectangle is also used because it resembles the human field of vision, as individuals most often look from left to right, on the horizontal plane, rather than up and down (Horton, 1994).

Regular edge icons can use different shapes for grouping icons with similar functionality or same category. Just as road signs communicate information

through shape (Figure 2-4), icons may use the same principles to speed up the search process and to improve the comprehension of an interface. However, a great variety of shapes in icon design may confuse the users, as they may not be able to register and remember each grouping. For example, it is easy to create two highly distinguishable shapes but more difficult to create 3, 4 or 5, etc.

Figure 2-4: Meaning of shapes in road sign system.

According to Ratajski, the content of each symbol should consist of the leading element (i.e. colour, shape) while its subsequent development should be based on its meaning (i.e. pictorial representation of an industrial building with a shoe placed in the middle for shoe factory) (1973). By the same token, the outside shape of the symbol could identify its distinguishing characteristics. Furthermore, basic shapes (such as a circle, square, triangle, etc.) can be combined with other pictorial symbols to develop more complex meanings and instructions. Colour is used for emphasis and instant recognition, such as red expressing prohibition or warning, and blue/green indicating permission.

Irregular shaped icons (Figure 2-5) can be divided into simply irregular, straight edge or rounded, and concave or convex (Horton 1994). Irregular shapes attract user attention and can appear as spontaneous or unplanned. Straight edge icons are usually those that represent man-made objects such as a computer or a file cabinet. On the other hand rounded shapes occur in nature and living organisms and thus might be associated with organic or fluid concepts. Concave shapes draw attention to enclosed space, and usually direct a user's eye into specific spaces within an icon, while convex shapes direct sight outward, away from the centre.

Figure 2-5: Samples of irregular shaped icons.

2.5 Orientation

The orientation of an image within an icon, or an icon itself, contributes to a feeling of action or stability. Similar to human activities, orientation of a symbol or an icon has a certain connotation. For example, when an individual sleeps, she or he is in a horizontal position (Horton, 1994). This implies that icons orientated horizontally symbolize stability, while vertical orientation suggests energetic potential. Symbols with diagonal orientation are often associated with instability.

Figure 2-6: Possible symbol and icon orientation.

2.6 Texture

Texture refers to the size and spacing of component marks that make up a pattern (Robinson et al., 1995). Moreover, texture varies by the scale of a pattern of marks and not the pattern form (Figure 2-7). This means that the texture of a line pattern, for example, varies through the distance between the lines and not the line orientation or form. Two types of texture can be distinguished: regular and irregular. Regular textures are referred to as lines per inch or centimetre. The use of texture and also pattern in icon design is very problematic due to the small size of icons and pixel dimensions. Coarse texture might appear to be incomplete at times, and gradual change in texture appears as edged. However, texture can be used to create the effect of a precise or refined image when fine, and suggest strength and crudeness when coarse. Also, texture can be used to create hybrid colour based on Web-safe colours and thus extend the limited web palette (see Chapter 5).

Figure 2-7: Variation in texture and pattern.

2.7 Size

Icons designed for computer display have been evolving since the introduction of graphic user interfaces. Over the years some icons have become standard and people using computers on a regular basis have learned to recognize them instantly. A collection of icons used for basic system operations are usually gathered in icon libraries. For example, Microsoft has its own libraries with icons which are 32 x 32 pixels, designed with 16 bit colours, and saved with an extension called .ico – a format developed especially for Microsoft icons (Figure 2-8). However, most common icons are 32x32 and 16x16 pixels (Figure 2-9).

Figure 2-8: Toolbar with icons used in word processor in Microsoft Word 2000.

Figure 2-9: Comparison between 32x32 pixels icons and 16x16 pixels.

A fundamental principle, which should be applied, is to design common icons at the same size to preserve consistency and ease of grouping. However, establishing an adequate size of an icon involves coordination of several factors, and the choice of size might be fixed or the opportunity to vary the size could be given to the user. The predetermined sizes of icons are usually in the form of formal guidelines for the design of user interfaces which are application or corporation specific. For example, the government of Canada, as part of the Government On-Line (GOL) initiative, is currently working on standardizing the *look and feel* of all government web sites to achieve common interfaces (http://www.cio-dpi.gc.ca/clf-upe/index_e.asp). Also, most software companies create documentation for the GUI system to ensure that software developers deliver a consistent look for all applications. Typical guidelines specify the types of graphical images to be used for representing items such as files, directories, etc.; specify the size usually in pixels; shape; and colour scheme among other interface characteristics (Apple Computer 1992; IBM 1991; Microsoft 1992; Sun Microsystems 1990).

When planning the size of icons, several issues need to be considered. These include legibility, available space, and ease of selection and consistency. Legibility

of an icon depends on the eyesight of the user, viewing distance and surrounding conditions, as well as the screen resolution and contrast of a display.

Viewing distance and other ergonomics pertaining to the viewing of computer display, also impacts the size on an icon. For example, laptop screens are usually 30 centimeters from the user's eyes, while for desktop computers 60 centimeters is the norm. Given this the icons for desktop computers should be twice as large as those for a laptop. Icons for a typical computer display vary in size between 16x16 and 32x32 pixels.

Another factor influencing legibility is the conditions under which the computer display is viewed. These include environmental factors such as visual and auditory noise, dust, wind, but also physiological and psychological factors such as eyestrain, fatigue, and anxiety. The risk of negative physical factors should be eliminated by ensuring that the environment where the computer is used has proper conditions, such as good lighting, monitor, keyboard and chair height proportions, etc. Both the environmental and physiological factors vary on an individual basis and unfortunately these cannot be controlled or be taken into account in the design of icons or any other computer graphics.

Ease of selecting icons is conditioned by the user and the device used for steering the cursor. Motor control will impact how precisely the user can point, and that is affected by experience and physiological conditions such as stress, age, or medical

conditions (Sellers, 1994). Also the speed of selection is affected by the size of an icon. The larger the icon, the easier and faster it is to point and click. On the hardware side, the ease of selection depends on the pointing device and its gain. Gain is a ratio of the movement of the cursor on the screen to the movement of the hand (Mayhew, 1992). A mouse or a trackball requires less movement to move the cursor across the display, while touch screen requires extensive hand movement. Therefore, for pointing devices with small gain, larger icons, would be most suitable and vice versa.

Larger icons will also improve access to information by special needs users. The two dimensional haptic devices (i.e. haptic mouse) can be used to aid visually impaired computer users by providing a slight resistance at the edges of windows and buttons so that the user can "feel" the Graphic or Cartographic User Interface. This technology can also provide resistance to textures in computer images, which enables blind users to "feel" pictures such as maps and drawings. Larger icons than the upper standard icons (32x32 pixels) would make it easier for the visually impaired to navigate with the haptic mouse and to interact with the interface.

2.8 Movement

A major advantage of computer technologies for icon design is that they allow interaction and the possibility of extending the communication through the addition of movement, which is another visual variable (Sharp and Sharp, 1994). Because

computers enable mobile presentation such as animation, graphic variables can be distinguished through movement. Types of movement applicable to icon design include animation and flicker.

2.8.1 Animation

Animation is a successive showing or positioning of images to create an illusion of movement when shown as a sequence. In the case of icon design, these animations are usually very simple, and limited to two or five changes in position of a symbol or icon as a complete object (Laurel, 1990). The reason for such short and limited animation is usually the small dimensions of an icon. Due to the scope of this research, animation as it pertains to colour in icon design will not be further discussed.

2.8.2 Flicker

Another possibility for extending the communicativeness of an icon is to create flickering. Flickering, for the lack of a better term, is used in this research to describe an effect caused by replacing one image with another, located at the same position. Such an effect is produced using a rollover. The term rollover originally comes from Macromedia Director's scripting language, Lingo, and it refers to a characteristic attached to a mouse function, using JavaScript (<http://www.macromedia.com/>).

The rollover behaviour works by swapping two images and is triggered by a computer mouse movement (Figure 2-10). When a user moves the mouse over an image (onMouseOver), a second image is called and displayed. Upon moving a mouse away (onMouse Out) from the image area the first image comes back (<http://hotwired.lycos.com/webmonkey/>). Such a functionality, referred to as behaviour, can also be added to other mouse functions such as onMouseDown (when pushing down the mouse button), onMouseUp, etc.

Figure 2-10: Square with a rollover effect (see attached CD-ROM).

The rollover effect can greatly extend communication by a graphic either by providing feedback or by extending information load. For example, user feedback can be achieved effectively using two swapping images. An icon in the shape of a button, created using the inner bevel effect can be swapped upon mouse movement with an image of a two dimensional rectangular shape to create the visual effect of pressing on a button (<http://www.macromedia.com/>).

Another method in which rollovers can aid communication is to create the second image of a swapping duo with altered symbology or additional information. For example, the first image could contain a symbol, while the second image could

contain a brief text or other indication which forecasts the information to be accessed.

The design of such interactive images for a graphic user interface does not require knowledge of scripting; however, such a skill is very useful in customizing and creating desired functionality. A script is a list of instructions that can be executed without user interaction, while a script language, such as JavaScript or VBScript, is a programming language with which one can write scripts. Currently there are several software packages available which have JavaScript built in.

The two most popular packages favoured by graphic designers and cartographers are Macromedia Fireworks and Adobe Photoshop. Fireworks is both raster graphics and vector graphics based software. Its functionality is geared towards computer display, and extended functionality allows for various image optimizations (<http://www.macromedia.com/>). Adobe Photoshop, originally designed for image processing for print, has in newer versions, similar functionality to Fireworks, which allows for the design of Web graphics.

2.9 Conclusion

The visual variables discussed in this chapter serve as background information to a broader discussion about colour usage in icon design. The butterfly model was developed to explain the visual variables which play an important role in

representing information through icons. Although this thesis is devoted mainly to the use of colour, the author wanted to emphasize that other visual variables must be used in addition to colour, to enhance the communication channels and to ensure that special needs users can interact with an interface.

3. Basics of colour

Color in a picture is like enthusiasm in life.
(Vincent Van Gogh, 1853-1890)

3.1 Introduction

Research on colour application in cartography has been substantial (see Brewer, 1994; Brewer, 1992; Mersey, 1990), but research in colour usage for Web based cartographic products has been minimal and is mostly limited to literature in computer science. Elaboration on colour choice in design of icons for cartographic user interfaces, requires innovative research based on already established cartography and graphic design theories and principles. This chapter discusses the fundamentals of colour. The information contained in this chapter is based on several authoritative text books: *Elements of Cartography* by Robinson, et al. (1985), *Cartography: Thematic Map Design* by Dent (1999), *Semiology of Graphics: Diagrams, Networks, Maps* by Bertin (1983) and other relevant sources such as academic journals and the Internet.

3.2 Colour vision

“Colour is the sensation produced on the eye by rays of light when resolved as by a prism, selective reflection, etc. in different wavelengths” (The Concise Oxford Dictionary, 1990: 223). Colour vision is an ability to distinguish among various wavelengths of light waves and to perceive differences in hue. The first active step

in vision is the absorption of light by a photosensitive substance, a visual pigment. Various devices within the eye assist vision by directing incoming light to this pigment; they act as light guides by refracting (bending), reflecting (turning back), or guiding light (Figure 3-1). Seeing colour involves stimuli caused by the action of light on the eye, a complex information processing in the nervous system (Brittanica, 2001).

A normal human eye can discriminate among hundreds of bands of wavelengths as they are received by the sensory cells (cones) of the retina. There are three types of cones; one cone absorbs red light, another green, and the third blue-violet (<http://www.britannica.com/>). A given colour stimulates all three types of receptors with varying degrees, while the pattern of these responses determines the colour perceived.

Figure 3-1: Eye anatomy adopted from Brittanica available at <http://www.britannica.com/>.

3.3 Colour vision deficiencies

Colour blindness affects about 8% of men, and less than 1% of women (Canadian Association of Optometrists, 2001). This means that, on average, one in every twelve males do not see colour in the same way as the majority does. Colour-vision deficiency is thought to arise from irregularities in the pigments of the cone cells. A colour-vision deficiency typically occurs when an individual lacks a sufficient number of cone cells of a particular type. Looking at a page with coloured symbols placed among different coloured backgrounds can test most common colour deficiencies. People who suffer from colour blindness confuse the images. An example of such an image is presented in Figure 3-2.

Figure 3-2: Tests for colour vision deficiencies
(<http://www.eyepanel.net/isroot/Eyepanel/web/eyetest.htm>).

3.3.1 Types of colour blindness

The most common type of colour-deficiency is dichromatism, when an individual is missing one of the three normal pigments. Absence of the red pigment is known as protanopia, absence of the green pigment as dueteranopia, and absence of the

blue pigment as tritanopia. Deuteranopes and protanopes cannot discriminate red light from green light on the basis of hue alone, whilst the tritanope has trouble in discriminating between blue and green combinations. In most forms of colour blindness blue and green appears similar to saturated green, yellow, red, pink and purple (Thompson, 1995). Total colour 'blindness' is rare, but can be found in both sexes and all racial groups. A complete failure to discriminate between any colours is known as 'typical' total colour blindness, and 'atypical' total colour blindness occurs when colour sensitivity is so low that only very clear colours are perceived.

3.3.2 The elderly and colour

The elderly see colours differently, but are not colour blind in the usual sense of the term. In fact it is somewhat surprising that designers worry so much about colour blindness, which is 1% (dichromatic) of the population, while they often ignore the much larger group of elderly, who almost always exhibit visual deficits. The aging population is increasing in Canada and world-wide and is expected to more than double in the next 30 years (Oyama, 2000).

Vision declines with age in several ways, but the most relevant for colour design is the yellowing and darkening of the lens and cornea and the shrinking pupil size.

Yellowing selectively blocks short wavelength light, so blues look darker. Moreover,

the elderly have difficulty discriminating colours, which differ primarily in their blue content: blue-white, blue-gray, green-blue green, red-purple, etc.

Aging also reduces the amount of light reaching the photoreceptors. All colours will be dimmer and visual resolution lower. For example, a moderately bright yellow may appear brownish and dimmer blues will appear black. When designing for the elderly, the designer should use bright colours and make sure that brightness contrast is especially high (and text larger) to help compensate for acuity loss. Visual acuity varies from person to person and is based on age and eye health. For example, maximum vision is reached on average at about 22 years of age and declines from then on as is demonstrated in Figure 3-3.

Figure 3-3: Loss of visual acuity in relation to age (Horton, 1994: 206).

3.4 Perceptual colour dimensions

There are three perceptual colour dimensions: *hue*, *value* and *chroma* (Figure 3-4). Hue is what is commonly referred to as colour and its characteristic is described

as red, blue, green, etc. Value is the quality of lightness or darkness of achromatic or chromatic colour (Dent, 1999; Robinson, 1995). In cartography, research suggests that not more than 4-5 values be used (Robinson, 1995). Chroma, also called saturation, intensity or purity, refers to the degree in which a hue departs in "colourfulness" from a gray tone of the same value (Brewer, 1994; Gerritsen, 1975). In other words it is the paleness or vividness of a colour. Chroma can be best understood by comparing a colour to a neutral gray. A zero percent saturation is neutral gray while 100 percent is the fully saturated colour.

Figure 3-4: Perceptual colour dimensions.

3.5 Graphical semiology

In order to understand how graphical variables such as colour can be applied to the design, it is important to know how they are organized perceptually. Four types of perception; associative, selective, ordered and quantitative are distinguished (Table 3-1). However, only associative and selective perceptions are used when distinguishing between colour objects.

Planar Dimension	✓	✓	✓	✓
Size		✓	✓	✓
Value		✓	✓	
Texture	✓	✓	✓	
Colour	✓	✓		
Orientation	✓	✓		
Shape	✓			

Table 3-1: Level of organization of graphical variables (Adopted from ITC MapTutor CD-ROM, 2000).

A perception which is associative (Figure 3-5) tries to level out a variation and ignores the differences in the information class (Robinson, et al., 1995; Dent, 1999). For example, icons with different shapes and sizes will be easily perceived as distinct classes if they are classified using a colour.

Figure 3-5: Associative perception of colour.

Selective perception is operative in obtaining an answer to the question: "Where is the given category?" (Green, 1991). The eye must be able to isolate all the elements of this category and if this perception can take place spontaneously, then

the variable is selective (Robinson, et al., 1995; Dent, 1999). Variables, such as colour and size are distinguished using selective perception; meaning that it is not difficult to isolate all blue or green symbols (Figure 3-6).

Figure 3-6: Selective perception of colour.

3.6 Primary colours

Primary colours are colours of the spectrum from which all of the other colours can be mixed. There are two types of primaries called additive and subtractive. The *additive primaries* refer to beams of light and these are red, green and blue (Figure 3-7). The three primaries are referred to as additive because when combined together create white light. On a computer screen the colours are created by varying the combination of the RGB colours.

Figure 3-7: Additive primaries.

In other words additive colours are produced by being placed closely together, or by being presented in very rapid succession, as illustrated in Figure 3-8.

Figure 3-8: Optical mixture achieved using additive colours (Adobe, 2001). See CD-ROM for animation.

Subtractive primaries refer to colour pigments which form other colours. The subtractive primaries are cyan, magenta, and yellow (Figure 3-9) and are used in painting, colour separation for printing and photography.

Figure 3-9: Subtractive primaries.

3.7 Colour models

Colour models are means of organizing colours in a systematic way. These are structured according to the three dimensional representation of colour. All of the colour models are divided into two main categories, perceptually based and display-based such as computer monitor (<http://atlas.gc.ca/english/>)

3.7.1 HSB model

HSB (*hue*, *saturation*, *brightness*) is a perceptually based colour model also referred to as HLS (hue, lightness, saturation) (Figure 3-10). This model allows a more intuitive method of designing colour icons as the model is organized similarly to human perception.

Hue is what is commonly referred to as colour, e.g., red or blue. Saturation, sometimes called chroma, is the strength or purity of the color. Saturation represents the amount of gray in proportion to the hue, measured as a percentage from 0% (gray) to 100% (fully saturated). Brightness is the relative lightness or darkness of the color, usually measured as a percentage from 0% (black) to 100% (white) (Dent, 1999, Robinson 1995).

Figure 3-10: HSB colour model.

3.7.2 RGB model

The RGB (*red*, *green*, *blue*) model (Figure 3-11) is the usual method of describing colours on monitors. The many colours available on computer displays are formed by varying proportions of red, green and blue (IBM, 1991). These proportions are defined in separate pixels with values from 0 to 255 for a total of 256.

Figure 3-11: RGB colour model.

3.7.3 CMY(K) model

The CMYK model is based on the light-absorbing quality of ink printed on paper. As white light strikes translucent inks, part of the spectrum is absorbed and part is reflected back to viewer's eyes. In theory, pure cyan (C), magenta (M), and yellow (Y) inks should combine to absorb all colour and produce black. For this reason these colors are called subtractive colors (Dent, 1999). Because all printing inks contain some impurities, these three inks actually produce a muddy brown and must be combined with black (K) ink to produce a true black (K is used instead of B to avoid confusion with blue) (Marcus, 1992). Combining these inks to reproduce color is called four-color process printing.

Figure 3-12: CMY(K) colour model.

3.8 Colour schemes

In the basic taxonomy of colour there are several types of colour schemes. These are presented using a colour wheel, which is often used by artists to demonstrate

the relation between hues. The colour wheel normally contains 12 to 24 hues and is shown in Figure 3-13.

Figure 3-13: Colour wheel.

3.8.1 Complementary scheme

Two complementary colours (if pigments) mixed together, produce a neutral gray-black, while complementary wavelength of light colour produce white light (Itten 1970). Using a colour wheel one can quickly distinguish complementaries, as they allow opposite to each other on a colour wheel (Figure 3-14). In a sense, blue is the "opposite" of orange; violet of yellow; green of red. In design, if a certain colour is predominant, the best way to control that colour is by using its complement. An over-abundance of orange is offset by using blue; yellow is offset by violet and vice versa. Many designers use a split-complementary method: after selecting the complement, they move one spot to the left or right of it and use that

colour to contrast the first colour. Split complementaries (Figure 3-19) are subtle and just as effective in creating a balanced approach.

Figure 3-14: Complementary colour scheme portrayed on a colour wheel.

3.8.2 Analogous scheme

An analogous, or harmonious, colour scheme (Figure 3-15) involves using a colour wheel. This colour scheme consists of two or three colours close to each other in colour space, such as blue and green (<http://www.adobe.com/>). The analogous colours promote colour harmony and work well when matching colours for continues colour schemes of icons and other interface elements. These are the colour schemes found in nature. For example, a field of grass, a sunset and an animal's fur coat each demonstrate an analogous blending of similar colours, but not a true "match."

Figure 3-15: Analogous colour scheme portrayed on a colour wheel.

3.8.3 Triad scheme

A triad colour scheme (Figure 3-16) organizes colours by purity. It uses three hues approximately equidistant in colour space: red-yellow-blue. To identify triad colour a spot should be selected on the colour wheel, for example red. To complete the triad, an equilateral triangle should be drawn. Wherever the points of the triangle meet, there is a relationship. With regard to red, the other points meet at blue and yellow forming the primary colours. When starting with orange, and tracing the equilateral triangle the remaining two points are violet and green. Orange, violet and green are secondary colours. As noted, this method creates relationships based on purity of colour. When trying to establish visual balance, a triad colour scheme should be considered. Triad schemes are often embedded in a generally neutral field, and therefore work well on a typical Windows gray background (Microsoft, 1992).

Figure 3-16: Triad colour scheme portrayed on a colour wheel.

3.8.4 Other colour schemes

Monotone achromatic

A monotone achromatic colour scheme (Figure 3-17) consists of neutral colours such as white, black or gray. This scheme is easy to use in graphic design but requires expert care to avoid boredom.

Figure 3-17: Monotone achromatic colour scheme.

Monotone chromatic

A single chromatic colour ranging in brightness and saturation: red, pink, rose, etc. constitutes a monotone chromatic colour scheme (Figure 3-18). The scheme is easy to use but again there is a risk of monotony.

Figure 3-18: Monotone chromatic colour scheme portrayed on a colour wheel.

Split complementary

A split complementary colour scheme (Figure 3-19) consists of three colours, one base colour plus two, near but not directly across, in colour space: orange with blue and green. These colours work best when colours from opposite sides differ significantly in brightness, and when colours from one side are desaturated. This scheme usually produces a less garish feeling than a simple complementary scheme.

Figure 3-19: Split complementary colour scheme portrayed on a colour wheel.

Tetrad colour

Four hues at equal intervals in colour space, such as yellow-green-orange (or red)

-blue (or violet) form the tetrad colour scheme (Figure 3-20)

(<http://www.adobe.com/>).

Figure 3-20: Tetrad colour scheme portrayed on a colour wheel.

3.9 Conclusion

The discussion of colour in subsequent chapters is built on an understanding of basic colour and colour vision properties. The topic of colour vision was discussed to indicate how colour is perceived (eye physiology) and how some vision deficiencies will impact the design decisions discussed in later chapters.

Furthermore, colour basics such as primary colours were discussed to emphasize differences in colour based on the medium such as computer monitors versus paper production. Various colour schemes were briefly discussed to give an overview of possible colour combinations, which can be applied in the design of icons.

4. The function of colour in design

I cannot pretend to feel impartial about colours. I rejoice with the brilliant ones and am genuinely sorry for the poor browns.

(Sir Winston Churchill, 1874 - 1965)

4.1 Introduction

Colour is one of the most indicative visual variables. It is used in everyday life for both aesthetic and guidance purposes. Colour convention in road signs is probably one of the most established systems. Because, in interface design, consistency of graphic elements and efficient usage is desirable for ease of operation (Laurel, 1990; Hix and Hartson, 1993), the design of icons may be based on already established colour conventions. The principles developed by graphic artists for using colour in books, magazines, highway signs, and television are now being adapted for computer displays (Shneiderman, 1998).

Potentially, principles and conventions from road sign systems and from cartography can be applied to improve communication and interaction with an interface. Furthermore, the complexity of colour usage in icon design may be gradually increased if it is assumed that the user has a general knowledge of various conventions based on everyday usage of signs (e.g. road signs) and maps (e.g. street maps). This chapter will discuss aspects of colour conventions in road

signage and cartography relevant to the design of icons. Specific functions of colour and their application to icon design will be developed in more detail.

4.2 Colour conventions in road signs

In contrast to all other kinds of signs, a road sign has a function that departs from the field of merely passive communication and information (Frutiger, 1989). Being in the nature of a direction, an order, a warning, a prohibition, or an instruction, a road sign has the purpose of not simply communicating but rather producing an immediate reaction from the viewer. Since road signs and signals are designed to guide travelers in their trip, while clickable icons are used for navigation in the Web environment, conventions such as colour, used in road signs can potentially be applied to icon design. There are common colour conventions for grouping or categorizing information in road signs. The following is an overview of the application of standardized colours used in the traffic guidance system based on the United States Manual on Uniform Traffic Control Devices (<http://mutcd.fhwa.dot.gov/>). These signs and colour conventions are used more or less globally with some variations in colour saturation and value as well as in detail in the case of pictorial symbols (<http://www.ideamerge.com/motoeuropa/>).

The primary colour red is chosen as the most meaningful of all hues for prohibitions, instructions and warnings of danger. Quantitatively speaking, red is present in the landscape only in dots, never in wide areas. The use of red is therefore derived from the fact that this most obtrusive of all the colours of nature exists only in this exceptional way, but always as a primary colour, for example in flowers. In road signs it is used as a background colour for *stop* and *wrong way* signs, *do not enter* messages, parking prohibition signs and the circular outline with diagonal bar in prohibitory symbols.

Green is used as a background colour for guide signs (other than those using brown or white), and sometimes as a legend colour with a white background for permissive parking regulations.

Blue is used as a background colour for information signs related to motorist services, including police services, rest areas, hotels, gas stations, restaurants, hospitals, campgrounds or picnic areas, and physically-impaired-parking signs.

Yellow is used as a background colour for warning signs, except where orange is specified, and for school signs.

White is used as the background for route markers, guide signs, and regulatory signs, except where red is specified.

Orange is used as a background colour for construction and maintenance signs exclusively (i.e. road workers, road repair vehicles, etc.).

Black is used as a background on *one-way* signs, and some weigh station signs.

Black is also used as a message on white, yellow and orange signs.

Brown is used as a background colour for guide and information signs related to points of recreational or cultural interest. These signs point out parks, historical landmarks and scenic/recreation areas found nearby.

4.3 Colour in cartography

Cartographers use colour in the creation of maps for specific purposes. As summarized by Robinson (1967), one of the main purposes of colour is clarifying and simplifying (Dent, 1999; Robinson, 1995). Because mapped information, especially complex information, needs to be communicated in chunks for easier processing, cartographers use colour properties. Warm colours for instance are used for figure as they advance, meaning appear closer, while cold (dark) colours are used for the background. Robinson further states that colour is also used to improve legibility, visual acuity and clarity. In addition, colour can elicit subjective reactions based on colour associations, which is further discussed in the next section (Dent, 1999; Robinson, 1967).

4.4 Colour associations

The concept of colour harmony by the colour wheel is an objective conclusion arrived at by intellectual activity. The response to colour, on the other hand, is emotional; thus there is no guarantee that what is produced in a purely intellectual manner will be pleasing to the emotions. Man responds to form with his intellect and to colour with his emotions; he can be said to survive by form and to live by colour.

(Sharpe, 1974: 123)

Individuals make colour associations based on culture and experience (Dent, 1999; <http://www.atlas.gc.ca/>). Based on the exposure to road signage, motorists learn that a certain colour conveys a specific meaning such as warning (red), caution (orange or yellow), or safety (green), etc (U.S. Department of Transportation, 2001). There are some standards on the assignment of colours and research has identified the following meanings signaled by colour (Table 4-1):

	Connotation
Yellow	Cheerfulness, dishonesty, youth, light, hate, cowardice, joyousness, optimism, spring, brightness; strong yellow-warning, caution
Red	Action, life, blood, fire, heat, passion, danger , power, loyalty, bravery, anger, excitement; strong red-warning
Blue	Coldness, serenity, depression, melancholy, truth, purity, formality, depth, restraint; deep blue-silence, loneliness, notice
Orange	Harvest, fall, middle life, tastiness, abundance, fire, attention, action; strong orange-warning
Reddish, brown (earth colours)	Warmth, cheer, deep worth and elemental root qualities; can be friendly, cozy or dull, reassuring or depressing
Green	Immaturity, youth, spring, nature, envy, greed, jealousy, cheapness, ignorance, peace; mid-greens-subdued, safety
Purple (violet)	Dignity, royalty, sorrow, despair, richness; maroon-elegant, and painful
White	Cleanliness, faith, purity, sickness
Black	Mystery, strength, mourning, and heaviness
Gray	Quiet and reserved, controlled emotions, can be used to create sophisticated atmosphere

Table 4-1: Connotative meaning of colour (adapted from Dent, 1999: 295).

Beyond specific colour-meaning relationships, colour can produce an environment for the users on the computer screen and give them a feeling of reality. There are also some general interpretations such as creation of certain emotions in the audience with the use of cool and warm colours. A designer who is to design graphics for promotional material for rock music CDs intended for a young audiences probably would use warm, highly saturated, bright colours. On the other

hand, graphics which would appeal to older, more affluent individuals would have cooler, more sedate colours (Laurel, 1990).

Colours can be very symbolic. The use of colour to convey meaning in global interfaces is very challenging because the psychological reactions to colour are based on individual colour preference, cultural background, and behavioural mood (<http://www.atlas.gc.ca/>). Moreover, colour associations and meaning may be culture specific and should be used with care. Western culture, for example, associates black with death, while the Japanese associate white with death (Berlin and Kay, 1969). Furthermore, colour meanings can conflict. For example, blue can mean power or melancholy, two ideas which do not seem compatible.

Another example of a conflicting meaning of colour is use of red. Many emergency exits or escape routes are marked in red. One way of interpreting this colour is to assume that the exit or the route should be avoided when signaled by the colour red which alarms and conveys a message to stop.

In addition to understanding native colour meaning and association, the user can learn, through repetition, that a certain colour symbolizes a specific task or articulates an idea (Laurel, 1990). For example, in North America, when the term "Pepto-Bismol" is mentioned many individuals automatically associate the term with a very specific pink. Likewise, the yellow boxes at the film counter are immediately recognized as Kodak boxes, or the yellow-rimmed magazine in the

mailbox is most likely the *National Geographic*. People can recall the colour of a magazine advertisement and the part of the page it appeared on, very little other details (Laurel, 1990). Therefore, it seems possible that we could use distinctive colours within computer programs and that colours which appear in certain contexts could aid recognition and recall.

4.5 Functions of colour

4.5.1 Perception of space and size

The eye automatically interprets blue/violetness and loss of sharpness as signs of distance. Conversely, "warm" colours such as red, yellow and orange appear closer. In icon design, these colour properties can be applied to add a three dimensional feeling to a flat display and enhance separation of foreground and background. For example, brightly coloured objects generally appear larger than dark ones of equal size, and thus people will judge yellow larger than blue (Figure 4-1) (Dent 1999).

Figure 4-1: Yellow and blue comparison.

4.5.2 Perception of similarities and differences

Hue is often used in cartography for showing categorical (nominal scale) distinctions (Dent, 1999; Robinson, 1995). When viewing colour graphics, people naturally break the hues into categories, which they quickly and easily judge as being the same or different. This makes colour an ideal way to signal that objects have similar or different meaning, function, importance, etc, since it leads to rapid recognition and identification (Schneiderman, 1998; IBM, 1991). In cartography, colour is used to enhance a map's effectiveness in communicating the mapped information by colour coding information. For example, a map uses colours to indicate vegetative zones by showing deserts in yellow and tropical rain forest in green.

The same method of colour usage can be applied to icon design for grouping similar icons. Such a grouping may be based on functionality (e.g. icons linking to multimedia presentations versus text based pages), or based on a theme (e.g. icons used to access and navigate through physical versus human geography topics). Also, based on perceptual grouping of colour, colour coding of icons can be used to create visual colour hierarchy and may improve visual search time (Hix and Hartson, 1993; Laurel, 1990). However, because designing a visual hierarchy for the interface requires an intellectual plan and the eventual graphic solution that satisfies the plan, colour for icon design should not be separated from the interface design.

Figure 4-2: Colour grouping.

4.5.3 Perceptual organization and colour

Colour perception is fast, accurate, automatic, and effortless and a designer should strive to capitalize on these perceptual capabilities whenever possible (Horton, 1994). When a viewer first looks at a display, there is so much information that it cannot be perceived effectively (processed cognitively) as a whole (Hix and Hartson, 1993) . Instead, the eye's general strategy is to use a divide and conquer strategy; meaning to decompose the image into pieces that are examined one at a time (Green, 1992). By making different areas of the field different colours, the designer is telling the attentional system two things. First, the colour layout indicates that parts of the image form distinct areas. Second, if the same colour appears in different parts of the image, the designer may be linking those areas together and saying that they have something in common.

Similar colours suggest a similarity relationship, and different colours a difference relationship, between objects and areas of the screen. It could be that names or

icons representing all image files are red and all text files are in green or that last year's sales are blue and this year's sales are green. At first, the viewer will not know that colours refer to different files or sales classes, but will automatically assume that similar colour represents similar type (Oyama, 2000). Suppose that the viewer focuses attention on some data on last year's sales (perhaps a graph or table). The user will be dimly aware that there are other blue areas on the screen. The viewer will easily find all the other information about last year's sales, because the eyes will make a fast movement to the other blue area (Oyama, 2000). If there were no such coding, the user would have to scan each bit of information, examine it, perhaps read some text and then decide whether it was last year's sales. Objects of different colour are automatically divided into different categories.

Mixing a large number of colours can confuse the viewers (Green, 1992) and distinguishing foreground from background becomes difficult. Using warm colours on a cold background are effective as they help enhance foreground-background separation. Inconsistent use of colour also confuses the user. Suppose that some of each year's sales were in blue and others in green. There would be no automatic grouping of similar types. In fact, this is worse than simply making both sales years the same colour. Attention would have to work harder to break through the natural grouping which colour produces.

4.5.4 Attracting attention and creating emphasis

A designer can use colours to automatically draw attention to specific areas within the interface, without needing to rely on the viewer to scan and move attention to the right location. This is sometimes called the "pop out" effect (Figure 4-3), where a viewer examining an entire display has his/her attention automatically drawn to a particular area (Wang, et al., 1994).

Figure 4-3: "Pop out" effect using colour.

A smaller area of one colour will stand out in a uniform larger area of different colour. The effect is best if the colour is only used at that one location. Brighter colours will stand out from darker ones. Warm colours (closer) stand out more on a cool background (distance) and highly saturated colours are more noticeable than desaturated colours (Green, 1992). A skilful designer can use these properties and automatically draw the user's eye to a desired location and control, to some extent, the movement of the eye around the image.

One of colour's principal uses is to signal to the viewer that some information is more important. The "pop out" effect described earlier will draw attention and create emphasis. Generally, emphasis is created by: more size, more saturation, more brightness, etc. (naturally, more is a relative term). A highly saturated object on a highly saturated background will not stand out as well as the same object on a neutral background. Lastly, using a light colour on a blue background will cause figure-ground separation that emphasizes the foreground object.

4.6 Conclusion

Understanding how colour can be used and for what functions is crucial in the design of maps and user interfaces. Through colour, cartographers and designers can emphasize information to improve communication and in the case of user interfaces can greatly improve usability. In addition, skilful colour application can also result in graphics that creates a certain feeling in users or connote a message, which further improves the graphical communication.

5. Colour in a Web environment

*The real problem is not whether
machines think but whether men do.*
(Skinner, 1904 - 1990)

5.1 Introduction

The design for the computer screen differs from a design for paper output, especially when one is concerned with Web graphics. Not only must the design be adapted to computer viewing, but also, to ensure uniform appearance of colour must use the limited palette of the 216 Web-safe colours. There are ways in which a designer can extend the colour palette but these require training, skills and knowledge of colour schemes. In this chapter the author discusses the Web-safe palette and elaborates on how colour choices can be extended using hybrid colours.

5.2 Web-safe colours

Computer displays use the RGB colour model as already discussed in section 3.7.2. Although both Macintosh and Windows platforms use 256 RGB colours only 216 are similar between the two computer platforms. These 216 colours are known as the Web-safe palette, meaning that the colours will appear the same on all computers (Figure 5-1). This is not necessarily true and there are two views on the subject.

Some argue that the high colour (15,16 or 24- bit depth) and true colour displays have no colour limitations and they display colours consistently. Others, based on user surveys, emphasize that the true Web-safe palette consists of fewer than 216 colours. These results vary from 22 to 125 safe colours (Lehn and Stern, 2000; Stein, 2000). Some individuals are very optimistic and state that future developments will solve the colour limitations. However, at the current time designers should use and research the effective usage of the 216 Web-safe palette since the computer technology does not solve global inequalities and thus the hardware of Internet users varies significantly.

Figure 5-1: 256 colour palette for Windows and Macintosh and 216 colours forming the Web-safe palette (produced using Macromedia Fireworks 3.0).

Most computer graphics software offers the 216-colour palette through swatch libraries. These are presented either with their RGB values or the hexadecimal

equivalent. Hexadecimal (Hex) colours are a mathematical way of explaining RGB colours in HTML (Hypertext Markup Language) for Web browser recognition. The hexadecimal values consist of three pairs of 00, 33, 66, 99, CC and FF, where FFFFFFFF is white and 000000 is black (e.g. blue; 3366CC).

5.3 Web-safe palettes

From the designer point of view, it is important to mention that there are various arrangements of the Web-safe palette, which makes the design process more efficient and easier. For example, many Web-safe colour swatches are arranged according to their hexadecimal progression (Figure 5-2 and Figure 5-3). Such a palette is difficult to use as the hues are spread across the palette and their perception is influenced by other nearby colours.

Figure 5-2: Macromedia Fireworks Web-safe colour palette with colour arranged according to hexadecimal progression (Macromedia Fireworks 3.0).

Figure 5-3: Adobe Illustrator Web-safe colour palette with colour arranged according to hexadecimal progression (Adobe Illustrator 8.0).

There are also other arrangements of Web-safe colour which are easier to use. A good example is a colour swatch designed by VisiBone (Figure 5-4) where each color is shown once, except for white, grays and black, which are repeated. Within the confines of these grids, the palette is not precisely symmetrical by hue, but all complementary colors are diametrically opposite the center. This colour swatch is offered by VisiBone free of charge at <http://www.visibone.com/swatches/>, and can be downloaded to products by Adobe, Macromedia, Allaire and others. In fact the VisiBone color arrangement are included in Adobe Photoshop 5.5, The Gimp 1.2 and BBEdit 5.1.1. Moreover, VisiBone also offers palettes with colour-deficiency simulation (Figure 5-5), which is a very useful when designing for a

global audience where some user are colour deficient (more information about how this palette was created can be found at <http://www.visibone.com/>).

Figure 5-4: Colour arrangement of Web-safe palette (<http://www.visibone.com/swatches/>). Reproduced with permission.

Figure 5-5: Colour palette with common colour deficiency simulations (<http://www.visibone.com/colorblind/>). Reproduced with permission.

5.4 Hybrid colours

Although there are conflicting views concerning the Web-safe palette it is always good practice to use the 216 colours to ensure colour consistency. Also, there is a method by which a designer can create more colours. Hybrid Web-safe colours are made by combining alternating pixels of two Web-safe colours in a 2x2 checkerboard pattern (Figure 5-6). This means that a palette of up to 1,331 extended Web-safe colours can be used rather than the simple 216 colours of the Web-safe palette.

Figure 5-6: Samples of hybrid colours created using Web-safe palette (300% enlargement).

When viewed in a browser, the two Web-safe colours effectively 'merge' into one (Figure 5-7). The regular pattern of pixels creates this optical illusion and the impression of a single colour.

Figure 5-7: Appearance of hybrid colours when viewed in Web browser.

Hybrid colours can also be produced using combinations of patterns. For example, a line pattern, with a one pixel line produces a semi uniform texture (Figure 5-8), while a hybrid produced with randomly placed pixels results in a medium fine texture (Figure 5-9). Such a visual effect can be applied successfully in interface design and also in cartography. In icon design, most desirable is the checkerboard pattern as it creates a uniform colour, adequate for the design of small icons.

Figure 5-8: Semi uniform texture produced with one pixel line pattern.

Figure 5-9: Semi uniform texture produced with randomly placed pixels.

5.5 Hybrid colours and colour schemes

Cartographers and web designers often look for new ways to improve their design possibilities in an Internet environment. Hybrid colours are thus worth exploring as with their use the Web-safe colour palette can be expanded to over a thousand colours. They enable creation of delicate value or saturation progression and sometimes create interesting effects. The following are some examples of hybrid colours created using the colour schemes discussed in Chapter 3.

5.5.1 Monotone achromatic

The monotone achromatic combination, or black and white, creates a very interesting effect (Figure 5-10). The resulting colour is gray with a sensation of dynamic movement, an almost vibrating result. Monotone achromatic colour scheme is better for the use in other interface elements than icons, such as backgrounds and borders.

Figure 5-10: Monotone achromatic combination of white and black to produce hybrid gray.

5.5.2 Monotone chromatic

Monochromatic colour schemes consist of chromatic colours ranging in brightness and saturation (i.e. red, pink, rose, etc.). Figure 5-11 demonstrates how this scheme can produce a delicate value progression. This is very useful especially in a Web-safe palette, as often it is difficult to find a suitable colour progression. Hybrid colour extends the value or saturation progression effectively. Furthermore, this scheme can be used not only in general colour application in interface design but also in Web maps, specifically choropleth maps where limited to a 216 colour palette may often prevent effective choice of colour (Figure 5-12).

Figure 5-11: Monotone chromatic combination of two values to produce hybrid intermediate orange.

Figure 5-12: Choropleth maps designed using hybrid colours (Hybrid colours are used in the middle polygon).

5.5.3 Analogous

An Analogous colour scheme consists of two or three colours close to each other in colour space, such as blue and green (Figure 5-13). The resulting hybrid, similar to the monotone chromatic scheme produces a delicate progression.

Figure 5-13: Analogous combination of two hues producing hybrid colour.

5.5.4 Complementary

A complementary colour scheme of contrasting hues, when combined (i.e. blue-orange, red-green) produces intermediate colour which, is similar to monotone

chromatic scheme, produces a sensation of dynamic movement which might be desirable in some maps and various interface elements (Figure 5-14). This scheme works best when the two significantly differ in hue or brightness.

Figure 5-14: Complementary combination of two contrasting hues to produce hybrid colour.

5.5.5 Split complementary

Three colours, one base colour plus two, near, but not directly across, colour space hues make the split complementary scheme (Figure 5-15). Unfortunately this scheme does not work well in the creation of hybrid colour, as the resulting colour appears “muddy” and unattractive.

Figure 5-15: Split complementary combination of three hues; one base colour plus two, near, but not directly across, colour space.

5.5.6 Triad

A triad colour scheme consists of three hues approximately equidistant in colour space, such as red, yellow and blue (Figure 5-16). Triad schemes are often embedded in a generally neutral field, and thus create good visual colour combination on a typical Windows gray background. However, the resulting colour, as with the split complementary scheme, does not produce an interesting or, some might say, aesthetic colour.

Figure 5-16: Triad hues approximately equidistant in colour space.

5.5.7 Tetrad

Four hues at equal intervals in colour space such as yellow, green, red and blue, produce the tetrad colour scheme (Figure 5-17). Again, the resulting hybrid is unattractive and produces a vibrating effect, which might not be desirable for icons nor for interfaces.

Figure 5-17: Tetrad hues of equal intervals in colour space.

5.6 Conclusion

The Web-safe palette is a subject of a debate between the two groups, which are for and against restricting design choices to 216 colours. Even though technology advances, and high-resolution monitors are widely available, in order to ensure uniform colour display and cross-platform compatibility for users world wide, designers should use the Web-safe palette. Good alternatives to extending colour choices for web designs are hybrid colours. Although creating the colour pattern

(hybrid colour) is more time consuming, than the simple selection of colour from a colour wheel, it ensures that the graphics produced will be viewed the same way by most users. The author strongly encourages other cartographers to use hybrid colours, not only in the design of user interfaces but also in the design of maps for the Web. Because the 216 Web-safe colours are not limiting cartographers in terms of quantity but quality of colour choice, the hybrid colours allow for better colour choices for Web maps. Hybrid colours are applicable to maps and often, when created with a careful eye and a skilful hand (mouse), may result in very interesting visual effects.

6. Design strategies for the use of colour in icon design

Creativity is allowing yourself to make mistakes. Art is knowing which ones to keep.
(Scott Adams 1957 -)

6.1 Introduction

Developing guidelines for colour usage in icon design is very challenging since the perception of colour icons is highly dependent on the context. In any given situation, there are large number of complex, interacting variables influencing the viewing of icons on a computer display (see section 2.7 and 3.2). Few design guidelines hold true in all circumstances. Furthermore, not only do circumstances and goals vary, but also design rules change when the audience is a special needs group (e.g. visually impaired and the elderly), or new technology or a new medium is introduced. In cartography the design decision is based on a series of controls, such as purpose, audience, conditions of use, etc (Robinson, 1995). The same approach can be applied to the design of icons used in cartographic user interfaces, where a series of controls determines the best colour scheme. The author's approach to developing guidelines is to form a series of questions concerning the product, interfaces, and icons. The design profile, obtained through answers to these questions, provides recommendations for a colour scheme for icons used in cartographic user interfaces and is applicable to other types of user interfaces.

6.2 Controls on icon design

The following questions serve as design controls in designing user interface icons.

1. Is there a colour scheme dictated by the party who commissioned the product?
2. Is there a colour scheme that could be employed to emphasize the nature of the product?
3. What background will be used in the interface (i.e. single hue or a pattern)?
4. What is the function of the icons and can they be classified or grouped?
5. What type of symbology is used for the icons (e.g. pictorial or abstract symbols)?
6. What are the estimated sizes of the icons?
7. What are the shapes of the icons?
8. What type of user feedback is required for interaction with the icons?

6.2.1 Corporate or product identification colour scheme

The colour scheme chosen for icons and also for the whole interface is often determined by the person or company who commissioned the product or the company who developed it. In such a case, the employer may request that an interface carries the corporate colour characteristics throughout the product. This is a common practice for many large company web sites. For example, IBM's corporate colour is blue (Figure 6-1), while Enterprise Car Rental uses green (Figure 6-2). The individual or the company commissioning the product can also request that the product has its own colour identity. Each Macromedia product, for example, has a separate colour identification: Fireworks uses orange and red in

their logo, introductory screen, and advertising material, Freehand uses blue, while Dreamweaver is characterized by green (Figure 6-3).

Figure 6-1: IBM web site available at <http://www.ibm.com/>

Figure 6-2: Enterprise - car rental company web site available at <http://www.enterprise.com/index.jhtml>

Figure 6-3: Screen captures of Macromedia products; Fireworks, Dreamweaver and Freehand.

Although corporate or product colour identification may be limited to two or three colours, often there are ways in which a designer can take into consideration the imposed requirement. The author suggests that the colours which are obligatory may form a grouping for content. Hypothetically, if a product is to carry the red, green and blue characteristics, these colours might be assigned to icons for the main sections or themes of a product, and be further emphasized by using the same colour, within the appropriate section, for secondary navigation and graphics. Another approach to incorporate imposed colours in icon design is to use different degrees, values and colour saturation of the imposed colours. This method is very effective, and does not demand additional perceptual processing of extra hues (for more information on assigning colours, see section 6.7 on *icon symbology*).

If there is a specific hue that should be used in the interface, the author recommends that the icons either use that specific colour for its background (as is the case in text based navigational buttons), or reverse the colours and use the hue, value, or saturation, for the icon's symbol. In many cases, the corporate colour will be reflected in the background image or non-navigational graphics (i.e. logo). In cases where there is a set of hues to be used, one may use them to advantage in communication of information.

6.2.2 The nature of the product

Some products require that the colour scheme reflects their nature or the product's content. This is very true for Web sites where colours can emphasize the party's objectives or goals. Furthermore, experienced Web users planning to visit a specific Web site, usually come with expectations or assumptions about the *feel and look* of the site. For example, when thinking about a Web site for environmental organizations such as the World Wildlife Fund for Nature (Figure 6-4) or Greenpeace (Figure 6-5) the assumption may be that the colour scheme used will include many greens, blues and browns, as these are the colours most often found in nature. It is the author's experience that employing a colour scheme which is indicative of the content or the nature of the product helps in communicating information. This can be linked to connotations of colour, and certain conventions. In cartography, there are numerous examples of conventions using colour association. For example, rivers on maps are portrayed as blue line features, while moist vegetation is symbolized using a green dot or a green area symbol.

Figure 6-4: World Wildlife Fund for Nature homepage available at <http://www.panda.org/>.

Figure 6-5: Greenpeace homepage available at <http://www.greenpeacecanada.org/>.

6.2.3 Background colours of an interface

User interfaces for cartography related products, by nature, use colour graphics extensively. In order to achieve good graphical communication, visual harmony must be developed between the icons and the content of an interface, as well as the settings in which the information is presented, meaning the background. The most common choice for a Web site background is white. In such a case, creating a colour scheme for the icons is simple, as white is a neutral colour. White is especially easy to work with, as people are used to presentations on white paper, be it a text document or a map. The most colour freedom and probably the most experience a cartographer or a graphic designer will have, is in producing graphics for single hue (white) backgrounds.

The choice of adjacent colours can have significant impact on the perception of an

individual colour. A light colour next to a dark one will cause the lighter colour to appear lighter than it actually is, while the darker colour will appear darker. The author suggests that in Web pages with black or dark backgrounds, the colours which should be avoided are dark hues with rich saturation. On white or light backgrounds, the colours which should be avoided are light hues with low saturation. In cases where a pattern is used for a background, it is difficult to suggest any colour scheme for the icons, since patterns can vary greatly. However, it is good Web design practice to use plain, single hue backgrounds, and use graphic variables, such as colour, to develop visual content. Figure 6-6 demonstrates colour combinations for the development of figure-ground in thematic maps, emphasizing the pair of colours that are most and least effective. This illustration can be used to guide design of colour schemes for icons and Web page backgrounds.

Figure 6-6: Graphical representation of colour combinations for figure and ground organization on the Thematic Map (adopted from Dent, 1999: 299, and presented graphically).

Since the objective of the icon-background or figure-ground relation is to create sufficient contrast to distinguish between the two, the following colour contrasts should be considered. For computer displays, the most legible colour combinations have a high level of contrast and are black or dark blue on white or yellow, and vice versa. Low contrast combinations such as blue on green or green on yellow are very difficult to read. Certain combinations, particularly involving red, green and magenta, produce unpleasant visual 'vibrations' and should be avoided (Laurel, 1990) (Figure 6-7). This is not to say that all of these combinations will produce negative visual reactions, and thus the same colour scheme (i.e. green on yellow or

red on green) might produce pleasant effects when different saturations and values are to be used.

Figure 6-7: Examples of low contrast colour combinations which should be avoided.

Johannes Itten, considered one of the greatest teachers of the art of colour described six possible colour contrasts (1970); contrast of hue, value, cold and warm colours, complementary contrast, contrast of saturation (intensity or chroma) and extension.

6.2.3.1 Contrast of hue

Contrast of hue is the simplest type of the six described by Itten. This type of contrast does not make demands on colour vision because of the intense luminosity. The strongest contrast of hue is said to be between yellow, red and blue (Itten, 1970). In the case of icon design for the CUI, one has to consider the colour scheme employed in the overall design of an interface and icons themselves. Because interfaces are designed with a specific colour scheme in mind (specifically interface elements in relation to the background colour, pattern or an image),

creating contrast within an icon using hues must coincide with the global colour scheme. In CUI, the safest option is to use two or three principal hues and if needed, add variations of value or chroma. In addition it is important to remember that the colours perceived as pleasant are hues in the green and blue range, or other hues containing little gray" (Dent 1999).

6.2.3.2 Contrast of value

Contrast of value works well in icons which do not require high visual attention, such as some the navigational icons of an interface. Navigation icons are usually in a dominant location, either at the top or on the sides (usually on the left hand side) of a Web page. Because these are standard positions for primary navigation, users are accustomed to scan the display in these areas, and it is not necessary to have icons with colour which is highly attractive or attentive. Also, because these icons will most likely show on most of the pages, the user will quickly learn their location and no other visual cues are required. It is better to reserve strong visual cues for distinct interface icons. Furthermore, large differences in lightness are considered to be pleasant (Dent, 1999), since the eye strain is minimal, and the value progression offers a harmonious play of colour. For this reason dark and light combination of icon's background and elements are most desirable.

6.2.3.3 Contrast of cold and warm colours

The contrast of warm and cool colours is often used in cartography for the purposes of connotation. Warm colours are those hues with longer wavelengths (i.e. red, orange and yellow) which are associated with heat, while cool colours are the opposite, being associated with low temperatures (i.e. green, blue and violet). This subjective feeling of heat has been proven by a number of experiments (Itten, 1970; Dent, 1995; Wilkinson, 1999). Artists often use this warm-cool colour combination in creating visual depth, where cool colours are used for distant objects and warmer ones for objects appearing nearby. Therefore, to emphasize the main feature of the icons, a designer should use warmer colours for pictorial symbols, and cooler hues for the icons' and interface background.

The cold-warm property can be verbalized in a number of other contrasting terms: cold-warm, shadow-sun, rare-dense, airy-earthly, far-near, light-heavy, wet-dry (Itten, 1970). Because of these associations, cartographers often use cool-warm contrast for thematic maps. For example, one map convention is to the use of hue in weather maps where red symbolizes warm temperature while blue indicates cold. The warm-cold contrast of cartographic conventions is well suited for colour icons in cartographic user interfaces.

6.2.3.4 Complementary contrast

Complementary contrast is desirable in icon design especially for those icons that need more emphasis. A colour scheme using pure complementary colours is preferred because pure hues (without grey) are perceived as more pleasant (Dent, 1999).

6.2.3.5 Simultaneous contrast

Simultaneous contrast is produced when the eye spontaneously produces the complementary colour of a viewed colour (Robinson, 1995). For example, if a small gray patch is placed inside a box of pure colour (Figure 6-8), then after looking at the surrounding colour, the gray square begins to appear like the surrounding colour's complementary colour (Dent, 1999). The author suggest not to use such a contrast as the visual effect may become confusing for the viewer.

Figure 6-8: Simultaneous contrast; effects of the environment of the colour perception.

6.2.3.6 Contrast of saturation

Contrast of saturation for Web icons is very limited as the colour palette itself is restricted to 216 colours. Similar to contrast of value, contrast of saturation is very effective especially for grouping of navigational icons.

6.2.3.7 Contrast of extension

Contrast of extension involves the relative areas of two or more colour patches (Itten, 1974). It is the contrast between much and little, or great and small. Because pure colours contain various degrees of brilliance, a colour balance is created in such a way that large areas of colour do not overpower the smaller areas. Such balance can be calculated using simple numerical proportions (Itten, 1974), but in the case of icon design, the contrast of extent is difficult to identify because of irregular shapes and small area coverage.

6.2.4 The function and classification of icons

Clearly identifying the function of an icon is an important task in icon design as it will affect the decisions made in the development of a colour scheme. The function of an icon is dictated by the navigational complexity of a product/Web site. In this research the author uses the term *product* and *Web site* interchangeably, because the Web based cartographic product consists of a series

of web pages forming a Web site. The most common functions of Web icons are: basic navigation through pages and navigation within a page. Basic navigation through pages can be categorized as primary, secondary and tertiary, depending on the complexity of the Web site. Primary navigation usually includes links to the main sections of a web site and often includes basic links such as a link to the home page and the contact page, as well as facilitating navigation between next and previous pages. Secondary navigation includes sub pages of main web site sections, while tertiary navigation refers to subsections of subsections, etc (Figure 6-9). For the purpose of usability, developing a web site involving more than three levels of navigation is not recommended. However, an exception can be large, complex web sites for international corporations, or chain stores (Nielson, 1994).

Figure 6-9: Example of web site with three levels of navigation.

Colour coding of icons speeds recognition for many user interface tasks (Shneiderman, 1998; 1999). Thus, it is important to identify the types and levels of navigation as based on these groupings one can develop a colour scheme which emphasizes hierarchy or grouping of similar icons. Construction of a colour scheme which would differentiate levels of navigation, can be approached in two possible ways, using either a progressive or a regressive colour scheme. A progressive colour scheme would mean that the colour value increases with the increasing hierarchy of navigational icons. For example, top-level navigation would have a high value (dark). In addition to changes in value, two other perceptual dimensions of colour, such as hue and saturation, may be manipulated. The objective of a progressive colour scheme is to direct user perception to lower levels of navigation.

A regressive colour scheme does just the opposite, meaning that the colour emphasizes the top level navigation. For example, icons used for primary navigation would employ a colour scheme which has visual dominance over colours used in other levels of navigation. The decision on which colour scheme to use will depend on the objective of the navigational system. If the product is structured in a way that the top-level navigation offers a gateway to main sections, than the regressive colour scheme should be used. In cases where the product is very complex and content rich with a complex navigation, a progressive colour scheme is the ideal, as it encourages exploration.

In many Web based cartographic interfaces (both CD-ROM and the Web), icons are used to turn on and off layers of information, such as road networks or built-up areas on a base map. Icons for this type of navigation will have to use a separate colour scheme to be differentiated from regular navigation (see section 6.10 for more details). In addition to colour, other visual variables (e.g. shape, size, etc.) and methods of emphasis (e.g. positioning) can also be applied to differentiate between different sets of navigation icons.

Colour strengthens perceptual grouping by similarity (Dent, 1999). For this reason any grouping or possible classification of icons, such as by function or theme, may be emphasized using colour. For example, the main sections of the web site might be colour coded, as in the digital version of this research (see CD-ROM or the web site). The web site created for this thesis consists of three main sections; *about*, *content* and *resources*. The icons used for each are colour coded using blue, yellow and green, respectively. The graphical elements of pages within each section reflect one of the three colours which depend on belonging (e.g. the page with the bibliography is found in the references section coloured green, and therefore the buttons on that page use green navigation buttons, etc.).

Although colour coding is very effective in improving graphical communication, designers should be aware of common expectations associated with colour coding (Shneiderman, 1998). Expectations of specific colour coding are an extension of

conventions learned in everyday life (e.g. colour coding in road signage) and from cultural colour associations. Also, for ease of use and to reduce the amount of information the user must process, it is extremely important to use consistent colour coding rules throughout the product (Buckingham and McKnight, 1997).

6.1.1 Icon symbology

The type (e.g. iconic, abstract) of symbol used for an icon, and thus the amount of detail, will influence the choice of colour. Simply, the more detail an icon has, the more hues, value variation and contrast will be required to make an icon legible and understandable. In cartography there are two basic symbol designs which may be used to portray information on maps; *pictorial* and *abstract*

(<http://www.atlas.gc.ca/>). The same terminology applies to iconic symbols for user interface icons. Pictorial symbols, sometimes referred to as *mimetic*, reflect the colour and the shape of the feature (Robinson, 1995). For example, a symbol for an airport would be an airplane, or a symbol for forested area may be a green polygon. Symbols described as abstract have geometric shapes which represent features. For example, a black rectangle may represent a building or a group of buildings, depending on scale.

In cartographic user interfaces, the most common icons will most likely consist of pictorial symbols. Furthermore, one can assume that these icons will be used to link or display specific information, which can be cartographically represented,

given the nature of the product. For this reason, the author suggests that icons like map symbols, use colour to emphasize symbolized information. This can be done by using cartographic and international symbol colour conventions. An icon will be much more effective if the information is symbolized using a pictorial symbol and reinforced using a hue that is characteristic of its meaning. For example, an icon symbolizing drainage would have a pictorial element consisting of lines and polygons using various values of blue (Figure 6-10).

Figure 6-10: Icon representing “drainage”.

In addition, there are two methods for using hue to emphasize symbolized information: to colour the symbol within an icon, or colour background (Figure 6-11). The author gives preference to using colour to indicate the symbol, as it is more visually associative with an actual map symbol.

Figure 6-11: Two methods for using colour to emphasize nature of information.

6.2.6 Sizes of icons

Another factor which influences the choice of colour is the size of icons and their abundance within a page. The larger the icons the more careful the design must be to avoid colours that can overpower the interface and detract from the principal objective. The author recommends the avoidance of bright hues on a dark background, and vice versa. Light colours for larger icons, meaning larger than the upper standard of 32x32 pixels, should also be avoided since brightly coloured objects tend to appear larger than dark ones of equal size. Generally, the icons should be simple and legible, covering minimal area, in order to leave sufficient space for other interface elements and to allow visual appreciation of the main focus of an interface.

Of the two styles of icons, iconic symbol by itself and iconic symbol with a background, the latter usually occupies more space. To economize on the area occupied by an icon, the author suggests that the space between iconic symbol and the icon's border should not be more than half the width of a symbol. When the background of an icon is relatively large to other interface element, the colour space overpowers the icon's symbol and the user's attention may be shifted to the icons (Figure 6-12). The number of icons will also drive the decision concerning the choice of colours. The visual attention devoted to colour icons should be proportional to the number of icons within the interface. This means that in order to maintain perceptual harmony, where there are large numbers of icons less

attention demanding colours should be used, with a low figure-ground contrast.

Figure 6-12: Example of an interface where the user's attention shifts to icons (Historical Evolution of Canada, 1995).

6.2.7 Shapes of icons

Interface icons use various shapes, from regular, such as square, rectangular, or circular, to irregular, such as concave or convex (see section 2.4). These two types of shapes should be approached differently in terms of planning the colour scheme. It is crucial for communication and usability that the colour of an icon and the interface background are not confused. For this reason, the author advocates the use of borders for iconic symbols. The borders usually have a rectangular or round shape which helps identify the boundaries of a clickable icon and aids visual search (Figure 6-13).

Figure 6-13: Examples of icons with definite edge boundaries/borders.

Often, icons with geometrically shaped background/borders will have colour fill.

These icons are more difficult to design, as the colour harmony must be maintained not just between the symbol and the interface background, but between the symbol, the icon background, and the interface. The author's recommendation is to use no background colour, or if necessary to use a neutral colour such as white or gray. Also, good effects are achieved where both iconic symbol and icon background use variations in value or saturation of a single hue or employ an analogous colour scheme (Figure 6-14).

Figure 6-14: Example of using fill and border to emphasize shape of an icon.

Icons, which use geometric shapes for their background, are usually referred to as buttons. Buttons can be designed using different effects such as inner bevel, feathering, or hard edge. An inner bevel creates a 3D effect, which is a most common shape among interface icons (Figure 6-15). Feathering, also known as *Gaussian blurring*, is the blending of edges into a background, (in cartography this

is called a vignette (Dent, 1995)). This effect creates a very pleasant visual appearance between the icon and the interface. Finally, a basic, hard edge button usually consists of a background colour with a one pixel border. This bounding border is often black and creates a solid visual definition of an icon.

Figure 6-15: Sample of three designs use for icons edges.

6.2.8 User feedback through icons

Heuristic usability evaluation, developed by Nielsen and Molich (1990), is one of the most popular of the usability evaluation methods. Its goal is to identify the usability problems in the design so that they can be addressed as part of an iterative design process. The principles of heuristic usability evaluation are fundamental to the design and implementation of effective user interfaces, whether for traditional GUI environments or web based CUI (Nielsen, 1994). One of the principles is *visibility of system status* “which states that the system should always keep users informed about what is going on, through appropriate feedback within reasonable time” (http://www.useit.com/papers/heuristic/heuristic_list.html).

An example of user feedback is a visual indication of hyperlinked text status. In

default settings, a blue hyperlinked text changes to red when it is being accessed, and later changes to purple to indicate the link has been visited. Similarly, icons use various effects to indicate the status of interaction between the user and the computer. The rollover function, discussed in section 2.8.1, is used for communicating feedback to the user. The most common is two image rollover which indicates feedback by removing an icon's shadow, flattening the 3D effect or by a minimal distortion of the graphic, such as change in size (Figure 6-16).

Figure 6-16: Rollover indicating selection.
From the top; removal of shadow, removal of
3D effect, change in size.

The author suggests that a change in colour can be used as another method to communicate feedback. In bicolour icons, the colours of the image that replaces the original graphic (the swapped image) can be reversed. Thus, a green background with a black symbol becomes a black background with green symbol (Figure 6-17). In cases where there are more than two hues, complementary colours as an indication of change may be used (Figure 6-18). However, probably the most effective method to observe change without visual disruption is change in

value or saturation. This means that the colours used in the icon become either lighter or darker in the swapping image (Figure 6-19).

Figure 6-17: Reversal of colours.

Figure 6-18: Change to opposite colours.

Figure 6-19: Change in colour saturation and value.

6.3 Moderation in colour usage

Using an unlimited number of colours is very tempting when designing any type of graphic, especially a graphic produced on a computer display where the palette is potentially unlimited. However, it is author's experience that using less means more in terms of visual esthetics. Instead of showing meaningful relations, inappropriately coloured fields mislead users into searching for relations that do not exist (Gerritsen, 1975). Literature on designing user interfaces suggests the use of four to a maximum seven colours in a single display (Shneiderman, 1998; Hix and

Hartson, 1993; Apple Computer, 1992; IBM, 1991). In cartography, Robinson advises using eight to a maximum 15 hues on thematic maps (1995). Other common ranges for number of colours used are 4-6, 3-7 and 5-11. Derefeldt and Marmolin (1981) showed that the time required to search for information slowed after the use of 6 colours, but Smallman and Boynton (1990) found it possible to increase the number to nine colours, as long as they were widely separated in colour space.

The Atlas of Canada section on colour usage in Internet maps suggests limiting the number of colours to seven, plus or minus two. Their recommendation is based on studies which showed that seven is the optimum number for short term memory (<http://www.atlas.gc.ca/>). Using too many different colours in icons, and consequently in the whole interface, will prevent the user from developing an effective mental model of data interrelationships (Sharpe, 1974). Although situational factors vary, the ideal number of colours used in icon design will depend on the hues, their relation, distribution, function and other factors discussed in this chapter. The author recommends using no more than five hues for icon design due to the relatively small size of an icon.

6.4 Conclusion

The design of any graphic such as a map is controlled by a series of influencing factors. In this chapter, the author's intention was to formalize these controls and

offer guidance in the application of colour, through discussion and graphical examples. The design controls influencing the use of colour for icons are based on cartographic principles as well as graphic and usability principles used in the design of graphical user interfaces.

7. Conclusions

*Iron rusts from stagnant water loses its purity
and in cold weather becomes frozen; even so
does inaction sap the vigor of the mind.*

(Leonardo da Vinci, 1452 - 1519)

7.1 Research overview

The focus of this research was to explore how colour can be used in user interfaces for Web based cartographic products and to develop design guidelines for the use of colour in interface icons. The design of graphical user interfaces is usually done by graphic designers, but the author argues that the user interfaces designed specifically for cartography related sites or Web products differ in their content and presentation, and thus their design should utilize and reflect cartographic principles and conventions.

The first chapter provided a background to icons for Web based user interfaces. It discussed the importance of effective user interfaces, as these are crucial in accessing and interacting with data and information. The argument was supported by showing that cartographic societies and associations, as well as government institutions, place an increasing emphasis on research in developing guidelines and standards for graphic design of user interfaces. Furthermore, the author advocated use of the term cartographic user interface stressing that such interfaces are unique in nature and it will aid communication if their design is based on already

established cartographic principles. The background to icon design was presented by defining icons and emphasizing the importance of their design. It was also stressed that icons, unlike any other navigational device (e.g. the pull-down menu, and hypertext) cross language barriers and enable interfaces to be understood globally.

Chapter two discussed visual variables which were presented in the form of the butterfly model developed by the author. The butterfly model shows the different emphasis which is placed on visual variables in two contrasting media: paper and computer display (specifically the Web environment). The model indicates that icon design for Web products is limited in terms of colour (hue, value and saturation) size and texture. Colour is limited to the 216 Web-safe palette, size is limited by the display and icons are often restricted to a 32x32 pixel dimension. Texture, due to the resolution, is very difficult to manipulate in Web graphics, because of the small dimensions of icons and resolution. Other visual variables such as orientation and shape are limitless in the Web environment. The author introduced the additional variable, motion, which consists of animation and flicker. Flicker is described as two alternating images triggered by mouse movement, and this is often referred to as the rollover effect, used widely in Web interfaces.

Chapter three was devoted to fundamentals of colour. It discussed how colour is perceived and how perception discrepancies might exist among users. This was to

emphasize that the graphics designed for the Web, or any other medium, will not be perceived identically by all viewers and that the design should be adjusted to the needs of special groups such as the elderly and the visually impaired. The chapter continued with a discussion about colour dimensions and described various colour models and schemes which can be used in graphic design.

Continuing the discussion from chapter three, the functions of colour were elaborated in chapter four. The usage of colour in road signage and in cartography was discussed. The author emphasized that colour conventions in road signage and colour conventions in cartography could be used effectively in the design of icons for cartographic user interfaces. The discussion pointed out that colour can be used to show similarities and differences, create hierarchical organization of icons, attract user attention and communicate a message or evoke a feeling.

Chapter five discussed the issues of colour in a Web environment. Although computers can display thousands of colours, every user interface, map or any other graphic, should be designed with the 216 web-safe colours which are the only colours likely to be uniformly displayed on all computer platforms. The author also suggested that hybrid colours could extend the limited palette. Such colours, created by combining alternating pixels of two Web-safe colours in a 2x2 checkerboard pattern can be used in icon design and can also be used effectively in the design of maps for the Web.

In chapter six, the author summarized the research into guidelines for the use of colour in icon design. These design guidelines were developed based on questions asked about the interface, the cartographic Web product for which the icons are to be developed, and questions about icons. The chapter concluded that in addition to the eight guidelines, icons should have sufficient contrast to maintain legibility, and that the use of colour should be moderate in small user interface elements such as icons.

Overall, this research showed that there is a strong need to develop design guidelines for cartographic user interfaces. More specifically there is a need to develop an iconic language which can be used effectively in such interfaces. This research is the first known attempt to develop guidelines for the colour design of icons used in cartographic user interfaces. In summary, the guidelines developed state that the colour scheme used will depend on any colour restrictions identified by the party commissioning the cartographic product for which interfaces are to be developed (i.e. corporate identification colours). The colours should also reflect the nature of the product and apply cartographic colour conventions.

The guidelines also state that the background of the interface will greatly impact the colours of icons, and should be used according to expressive figure-ground organization. Colour can also be used to classify or group icons based on their function or type. Symbology used in icons should reflect meaning through the

colour scheme. In this case, colour conventions from cartography or any other relevant convention should be employed (e.g. icons with green trees symbolizing wooded areas).

Sizes and shapes will also determine the colours. Large, regularly shaped icons should use more neutral colours while small, irregular icons should employ lighter colour with more contrasting colours to improve perception. Finally, the guidelines developed state that colour be used for user feedback. To indicate that the icon is chosen with a mouse cursor, the colour of the second, swapped image can change by reversing colours (based on a complementary colour scheme) or by modifying colour dimensions.

7.2 Directions for further research

It was this author's goal that this research yield results leading to improved strategies for colour application in the Web environment. As this research is one of the very first in the area of user interface design from a cartographic perspective, there are many issues that should be addressed in the future research. Future research should concentrate on testing to validate colour design guidelines. Such research would require the establishment of a Web site with sample cartographic user interfaces. A user survey of icons designed using developed by the author guidelines could be conducted over the Internet very efficiently and with

a larger and more diverse user sample. Such a survey was not part of this research: it was beyond the scope due to time restrictions.

Future research directions should also include studies on how different colour schemes influence interface usability and identify how different groups of people interact with interfaces. Such a research should specifically investigate how colour influences their interaction in terms of usability and personal preferences. For example, how does the colour coding of icons and other graphic information influence the pattern of visual scanning. There is also a need for greater understanding of visual perception of interface graphics, such as icons in colour computer displays.

Because this research is one of the first of its kind, the author hopes that more research will be conducted by cartographers not only in the area of Web map design but also in the area of cartographic user interfaces. The cartographer's experience in designing maps, which are in themselves interfaces between the user and the data, should be used in this new Web medium which opens doors to almost endless possibilities of graphic representation of the physical world and world issues.

References

- Adobe.** (2001). *Technical Guide*. Retrieved February 20, 2001 from the World Wide Web: <http://www.adobe.com/>.
- Apple Computer.** (1992). *Macintosh Human Interface Guidelines*. Reading, MA: Addison-Wesley.
- Adrienko, G. and Adrienko, N.V.** (1999). Interactive Maps for Visual Data Exploration. *International Journal of Geographic Information Sciences*, 13, 4, 355-374.
- Armenakis C.** (1996). Mapping of Spatio-Temporal Data in an Active Cartographic Environment. *Geomatica*, 50, 4, 401-413.
- Arnheim, R.** (1974). *A psychology of the creative eye*. Berkeley: University of California.
- Artimo, K.** (1994). The Bridge Between Cartographic and Geographic Information Systems. In A.M. MacEachren and D.R.F. Taylor (Eds.), *Visualization in Modern Cartography* (pp. 45-61). Toronto: Pergamon.
- Baker, R.** (1981). *Human Navigation and the Sixth Sense*. New York: Simon and Schuster.
- Berlin B. and P. Kay.** (1969). *Basic Color Terms: Their Universality and Evolution*. Berkeley: University Press.
- Bertin, J.** (1983). *Semiology of Graphics: Diagrams, Networks, Maps*. Madison, Wisconsin: University of Wisconsin Press.
- .** (1977). *Graphics and Graphic Information Processing*, Berlin: Walter de Gruyter & Co.
- Laurel, B.** (ed.) (1990). *The Art of Human Computer Interface Design*. Addison Wesley, Massachusetts.
- Birren, F.** (ed.) (1969). *A Grammar of Color; a Basic Treatise on the Color System of Albert H. Munsell*. Toronto: Van Nostrand Reinhold Co.
- Brewer, C.A.** (1994). Colour use guidelines for mapping and visualization. In A.M. MacEachren and D.R.F. Taylor (Eds.), *Visualization in Modern Cartography* (123-147). Oxford: Pergamon.

- . (1992). Review of colour terms and simultaneous contrast research for cartography. *Cartographica*, 29, 3-4, 20-30.
- Britannica** (2001). "Anatomy of the visual apparatus". Anatomy, Physiology and Pathology of the Human Eye. Retrieved January 5, 2001 from the World Wide Web: <http://www.britannica.com/>.
- Buckingham S. and C. McKnight.** (1997). World Wide Web usability: introduction to this special issue. *International Journal of Human-Computer Studies*, 47, 1-4.
- Buttenfield, B. P. and C.R. Weber.** (1994). Proactive Graphics for Exploratory Visualization of Biogeographical Data. *Cartographic Perspectives*, 19, Fall, 8-19.
- Cammack, R.G.** (1999). New Map Design Challenges: Interactive Map Products for the WWW. In W. Cartwright, M.P. Peterson and G. Gartner (Eds), *Multimedia Cartography* (Chapter 1). New York: Springer.
- Canadian Association of Optometrists.** (2001). *Canadian Journal of Optometry*, 61, 1. Retrieved February 23, 2001 from the World Wide Web: <http://www.opto.ca/>.
- Cartwright, W.** (2000). Metaphors, the GeoExploratorium and the 'discovery' of geographic information. RMIT University. Retrieved October 20, 2000 from the World Wide Web: <http://www.ls.rmit.edu.au/landinfo/geoexpl/backgrnd.htm>.
- . (1999). Extending the Map Metaphor Using Web Delivered Multimedia. *International Journal of Geographic Information Science*, 13, 4, 335-353.
- Cartwright, W., Peterson, M.P. and Gartner, G.** (1999). *Multimedia Cartography*. New York: Springer.
- Cartwright, W.E. and Hunter, G.J.** (1996). Design and Authoring of Interactive Map Products. *Geomatica*, 50, 2, 59 - 68.
- Chernoff, H.** (1978). Graphical representations as a discipline. In Ed. Wang, P. C.C. (Ed), *Graphical Representations of Multivariate Data* (pp. 230-258), New York: Academic Press.
- City of Ottawa.** (2001). Retrieved March 2, 2001 from the World Wide Web: <http://city.ottawa.on.ca/>.

- Clarke, Keith C.** (1995). *Analytical and Computer Cartography* (2nd ed.). Englewood Cliffs, N.J: Prentice-Hall.
- Clarke, L.M.** (1989). An experimental investigation of the communicative efficiency of point symbols on tourist maps. *Cartographic Journal*, 26, 2, 105-110.
- (1990). *Concise Oxford Dictionary*. Oxford University Press: Toronto.
- Crampton, J.** (1995). Cartography Resources on the World Wide Web. *Cartographic Perspectives*, 22 Fall, 3-11.
- . (1998). The Convergence of Spatial Technologies. *Cartographic Perspectives*, 30, Spring, 3-5.
- DeLucia, A. A. and D. W. Hiller.** (1982). Natural legend design for thematic maps. *Cartographic Journal*, 19, 1, 46-52.
- Dent, B.D.** (1999). *Cartography: Thematic Map Design*. (5th ed.). Toronto: McGraw-Hill.
- . (1990). *Cartography : Thematic Map Design*. (4th ed.). Dubuque, IA: W.C. Brown,
- DiBiase, D.** (1994). Designing animated maps for a multimedia encyclopedia. *Cartographic Perspectives*, 19, 3-7, 19.
- Dodge, M.** (1999). Measuring and mapping the geographies of cyberspace: a research note. *NETCOM - Networks and Communications Studies*, 13, 1/2, 53-67.
- Durrett, H.J.** (Ed.). (1987). *Color and the Computer*. Austin: Academic Press.
- Ebert, R. and Clarke A.C.** (2000). What's Ahead on the Web: The Five Senses. *Yahoo Internet Life*, 6, 12.
- EyePlanet.** (2001). Eye Tests. Retrieved January 30, 2001 from the World Wide Web: <http://www.eyeplanet.net/isroot/Eyeplanet/web/eyetest.htm>.
- Forrest, D. and A. Pearson.** (1990). Map Design. In C.R. Perkins and R.B. Parry (Eds.), *Information Sources in Cartography* (pp.169-188). London: Bowker-Saur Ltd.

Fremlin, G. and A.H. Robinson. (1998). Maps as Mediated Seeing. *Cartographica*, 35,1,2, Monograph.

Frutiger, A. (1989). *Signs and Symbols: Their Design and Meaning*. Dreieich, West Germany: Weiss Verlag.

Gartner, Georg. (1998). About the Quality of Maps. *Cartographic Perspectives*,30, Spring, 38-46.

Gooding, K. & D. Forrest. (1991). An Examination of the Difference between the interpretation of screen based and printed maps. *The Cartographic Journal*, 27, 1, 15-19.

Government of Canada. (2001). Common Look and Feel for the Internet. *Treasury Board of Canada Secretariat*. Retrieved January 22, 2001 from the World Wide Web: http://www.cio-dpi.gc.ca/clf-upe/index_e.asp.

--- . (2001). Serving Canadians in Digital World. *Treasury Board of Canada Secretariat, Government On-Line*. Retrieved February 21, 2001 from the World Wide Web: http://www.gol-ged.gc.ca/index_e.asp.

--- . (2001). Natural Resources Canada, Centre for Topographic Information. Retrieved September, 2000 from the World Wide Web: <http://maps.nrcan.gc.ca/>.

---. (2001). Natural Resources Canada, Geogratis. Retrieved February 21, 2001 from the World Wide Web: <http://geogratis.cgdi.gc.ca/index1.html>.

---. (2001). Natural Resources Canada, National Atlas of Canada. Retrieved February 21, 2001 from the World Wide Web: <http://atlas.gc.ca/>.

---. (2001). Natural Resources Canada, Toporama. Retrieved February 1, 2001 from the World Wide Web: <http://toporama.cits.mcan.gc.ca/>.

Government of Ontario. (2001). Ministry of Transportation. Official Road Map of Ontario. Retrieved January 5, 2001 from the World Wide Web: <http://www.mto.gov.on.ca/>.

Green, D. R. (1997). "Cartography and the Internet." *The Cartographic Journal*. 34, 1, 23-27.

Green, M. (1992). "Visual Search: detection, identification and localization". *Perception*, 21, 765-777.

- Hix, D. and H.R. Hartson.** (1993). *Developing User Interfaces: Ensuring usability through product and process*, New York: Wiley.
- Hasebrook, J. P.** (1999). Searching the Web Without Losing the Mind: Travelling the Knowledge Space. *WebNet Journal*, April-June, 24-32.
- Helander, M.** (1988). *Handbook of Human-Computer Interaction*. Amsterdam: Elsevier Science.
- Horton, W.** (1994). *The Icon Book: Visual Symbols for Computer Systems and Documentation*. Toronto: John Wiley & Sons, Inc.
- Howard, D. & A. M. MacEachren.** (1996). Interface design for geographic visualization: Tools for representing reliability. *Cartography and Geographic Information Systems*, 23, 2, 59-77.
- IBM.** (1991). *Common User Access Guide to User Interface Design*. Cary, NC:IBM Coporation.
- International Cartographic Association.** (2001). Retrieved December 10, 1999 from the World Wide Web: <http://www.icaci.org/>.
- . (2001). Web site of the Commission on Maps and the Internet. Retrieved January 16, 2001 from the World Wide Web: <http://maps.unomaha.edu/ica/Maps%26Internet/>.
- . (2001). Web site of the Commission on Visualization and Virtual Environments. Retrieved January 4, 2001 from the World Wide Web: <http://www.geovista.psu.edu/icavis/>.
- Institute Vienna Circle.** (2000). Society for the Advancement of the Scientific World Conception. Retrieved October 20, 2000 from the World Wide Web: http://hhobel.phl.univie.ac.at/wk/index_e.htm.
- International Institute for Aerospace, Survey and Earth Sciences (ITC).** (2000). *Map Tutor*. CD-ROM. Enschede: Netherlands.
- . (2001). Geoinformatics, Cartography and Visualization. Retrieved March 15, 2001 from the World Wide Web: <http://kartoweb.itc.nl/webcartography/webbook/index.htm>.
- Itten, J.** (1970). *The Elements of Color*. New York : Van Nostrand Reinhold Co.

- Keates, J.** (1996). *Understanding Maps* (2nd ed.). Essex: Addison Wesley Longman Ltd.
- Kraak, M.J.** (2000). *Web cartography*. Toronto: Taylor and Francis.
- Kraak, M.J. and F.Ormeling.** (1998). *Kartografia: Vizualizacja Danych Przestrzennych*. Warszawa, Poland: Wydawnictwo Naukowe PWN.
- Kraak, M.J. and van Driel, R.** (1997). "Principles of Hypermaps", *Computers & Geosciences*, 23, 4, 457-464.
- Kraak, M.J. and F.Ormeling.** (1996). *Cartography: Visualization of Spatial Data*, Addison: Wesley Longman Limited.
- Laurel, B.** (ed.) (1990). *The Art of Human Computer Interface Design*. Addison Wesley, Massachusetts.
- Lee, Y.C. & F.L. Chin.** (1995). An iconic query language for topological relationships in GIS. *International Journal of Geographical Information Systems*, 9, 1, 25-46.
- Lehn, D. & H.Stern.** (2000, September 6). Death of the Websafe Color Palette. Webmonkey, The Web Developer's Resources. Retrieved November 19, 2000 from the World Wide Web: <http://hotwired.lycos.com/webmonkey/00/37/index2a.html>.
- Lindholm, M. and Sarjakoski, T.** (1994). User Interfaces for Cartographic Visualization. In A.M. MacEachren and D. R. F. Taylor (Eds.), *Visualization in Modern Cartography* (pp.167-184). London: Pergamon.
- MacEachren, A. M. and Kraak, M.J.** (2000) Research Agenda of Commission on Visualization and Virtual Environments, Retrieved February 15, 2001 from the World Wide Web: <http://www.geovista.psu.edu/icavis/>.
- MacEachren, A. M.** (1998). Cartography, GIS and the World Wide Web. *Progress in Human Geography*, 22, 4, 575-585.
- (1997). Exploratory Cartographic Visualization: Advancing Agenda. *Computers and Geosciences*, 23, 4, 225-243.
- (1995). *How Maps Work: Representation, Visualization and Design*. New York: Guilford Press.

—. (1994). *Some Truth with Maps: A Primer on Symbolization and Design*. Washington, D.C.: Association of American Geographers.

MacEachren, A.M., Battenfield, Campbell, Dibiase and Monmonier (1992). Visualization. In R.F. Abler, M.G. Marcue, and J.M. Olson (Eds.), *Geography's Inner Worlds* (pp. 99-137). New Jersey: Rutgers University Press.

MacEachren, A. M. & D. R. F. Taylor. (Eds.). (1994). *Visualization in Modern Cartography*, Oxford: Pergamon.

Macromedia. (2001). Resources. Retrieved February 25, 2001 from the World Wide Web: <http://www.macromedia.com/>.

Marcus, A. (1992). *Graphic Design for Electronic Documents and User Interfaces*. New York: Addison-Wesley.

Mayhew, D. (1992). *Principles and Guidelines in Software User Interface Design*. Englewood Cliffs, NJ: Prentice Hall.

Medyckyj-Scott, D. and C. Board. (1991). Cognitive Cartography: A New Heart for a Lost Soul. In Muller (Ed.), *Advances in Cartography* (pp. 201-230). London: Elsevier Science Publishers Ltd.

Mersey, J.E. (1990). "Colour and thematic map design: the role of colour scheme and map complexity in choropleth map communication." *Cartographica* 27, 3, Monograph 41.

Microsoft. (1992). *The Windows Interface: An Application Design Guide*. Redmond, WA: Microsoft Press.

Nielsen, J. (1994). Heuristic evaluation. In Nielsen, J., and Mack, R.L. (Eds.), *Usability Inspection Methods*, New York, NY: John Wiley & Sons.

Minsky, M. (2000). Commonsense-based interfaces. *Communications of the ACM*, 43, 8, 67-73.

Molich, R., and Nielsen, J. (1990). Improving a human-computer dialogue, *Communications of the ACM* 33, 3 (March), 338-348.

Monmonier, M. (1996). *How to Lie with Maps*. (2nd ed.). Chicago: University of Chicago Press.

Moto-Europa. (2001). Free Resource for European Motor Travel. Retrieved February 20, 2001 from the World Wide Web:
<http://www.ideamerge.com/motoeuropa/>.

Muehrcke, P.C. (2001). *Map use : reading, analysis, and interpretation*. Madison, WI: JP Publication.

Müller, J.C. & Wang, Z. (1990). A knowledge-based system for cartographic symbol design, *The Cartographic Journal*, 27, 1, 24-30.

Nielsen, J. and D. Norman. (2000). Web Site Usability: Get the Right Answers From Testing. *Information Week*, February 14, 2000, Issue 773, Section: Labs. Retrieved February 20, 2001 from the World Wide Web:
<http://www.techweb.com/se/directlink.cgi?IWK20000214S0034>.

Open GIS Consortium. (2001). Retrieved January 18, 2001 from the World Wide Web: <http://www.opengis.org/>.

Oviatt, S. (1996). Multimodal interfaces for dynamic interactive maps, *Proceedings of the Conference on Human Factors in Computing Systems (CHI96)*, pp. 95-102.

—. (1997). Multimodal interactive maps: Designing for human performance. *Human-Computer Interaction*, 12, 93-129.

—. (1999). Ten myths of multimodal interaction. *Communications of the ACM*, 42, 11, 74-81.

Oyama, S. (2000). *Evolution's eye: a systems view of the biology-culture divide*. Durham, N.C.: Duke University Press.

Parker, H. D. (1995). What Does the Internet's Future Hold? *GIS World*, November, 118.

Ratajski, L. (1973). *Metodyka Kartografii Społeczno-Gospodarczej*. Warszawa: PPWK.

Richardson, A. R., Montello, D. R. and M. Hegarty. (1999). Spatial knowledge acquisition from maps, and from navigation in real and virtual environments. *Memory and Cognition*, 27, 741-750.

- Rickel, J. and W. L. Johnson.** (1999). Animated agents for procedural training in virtual reality: Perception, cognition, and motor control. *Applied Artificial Intelligence*, 13, 4/5, 343-382.
- Robinson, A. D. et al.** (1995). *Elements of Cartography* (5th ed.). New York: John Wiley & Sons, Inc.
- . (1985) *Elements of Cartography* (4th ed.). New York: John Wiley & Sons, Inc.
- . (1967) "Psychological aspects of colour in Cartography," *International Yearbook of Cartography* 7: 50-59.
- Ruddle, R. A., S. J. Payne and D. M. Jones.** (1999). Navigating large-scale virtual environments: What differences occur between helmet-mounted and desk-top displays? *Presence*, 8, 2, 157-168.
- Saliszczew, K.A.** (1998). *Kartografia Ogolna*. Wroclaw Poland: Panstwowe Wydawnictwo Naukowe.
- Sellers, D.** (1994). *ZAP! How your computer can hurt you – and what you can do about it*. Berkley, CA: Peachpit Press Inc.
- Scaife, M. and Y. Rogers.** (1996). External cognition: How do graphical representations work? *International Journal of Human-Computer Studies*, 45, 185-213.
- Sharp L. and Sharp L.** (1994). Interface design aspects for educational multimedia, paper presented at Multimedia and Design Conference, Maher, M.L., Coyne, R. and Newton, S. Eds, Sydney: University of Sydney.
- Sharpe D.** (1974). *The Psychology of Color and Design*. Chicago: Nelson-Hall.
- Shneiderman, B.** (1999) Universal Usability: Pushing Human-Computer Interaction Research to Empower Every Citizen. Retrieved August 7, 2001 from the World Wide Web: http://www.isr.umd.edu/TechReports/ISR/1999/TR_99-72/TR_99-72.phtml.
- . (1998). *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. (3rd ed.). Reading, MA: Addison-Wesley.
- . (1987) *Designing the User Interface*. Reading, MA: Addison-Wesley.

- Shum, S. J. B. et al.** (1997). Graphical argumentation and design cognition. *Human-Computer Interaction*, 12, 267-300.
- Smallman, H. and R. Boynton.** (1990). Segregation of basic colors in an information display. *Journal of the Optical Society of America*, 10, 1985-1994.
- Smyth, M. and Knott, R.** (1994) The Role of Metaphor at the Human Computer interface. Proceedings OZCHI94, pp. 287-291.
- Sorell, P.** (1974). Map design-with the young in mind. *Cartographic Journal*, 11, 82-91
- Stein B.** (2000). VisiBone. Colour Laboratory. Retrieved January 8, 2001 from the World Wide Web: <http://www.visibone.com/>.
- Suchan, T. A. & C. A. Brewer.** (2000). Qualitative methods for research on mapmaking and map use. *Professional Geographer*, 52, 1, 145-154.
- Sun Microsystems, Inc.** (1990). *Open Look Graphical User Interface Application Style Guidelines*. Reading, MA: Addison-Wesley.
- Taylor, D.R.F.** (1999). Future Direction for Multimedia Cartography. In W. Cartwright, M.P. Peterson and G. Gartner (Eds.), *Multimedia Cartography* (pp. 315-326). New York: Springer.
- . (1994) "Perspectives on Visualization and Modern Cartography", In A.M. MacEachren and D.R.F. Taylor (Eds.), *Visualization in Modern Cartography* (pp.99-137). Oxford: Pergamon.
- . (1991). *Geographic Information Systems: The Microcomputer and Modern Cartography*, Oxford: Pergamon.
- Thompson, Evan.** (1995). *Colour vision; a study in cognitive science and the philosophy of perception*, London: Routledge.
- Tufte, E.R.** (1997). *Visual Explanations: Images and Quantities, Evidence and Narrative*, Cheshire, Connecticut: Graphics Press.
- . (1990). *Envisioning Information*. Cheshire, Connecticut: Graphics Press.
- . (1983). *The Visual Display of Quantitative Information*. Cheshire, Connecticut: Graphics Press.

- U.S. Department of Transportation.** (2001). Manual on Uniform Traffic Control Devices. Retrieved November 18, 2001 from the World Wide Web: <http://mutcd.fhwa.dot.gov/>.
- Useit.com: Jacob Nielsen's Website.** (2001). Papers and Essays by Jakob Nielsen. Retrieved March 17, 2001 from the World Wide Web: <http://www.useit.com/>.
- Van Niekerk, M.** (1996). The face behind logical interface. *The Age*, March 12, C3.
- Wang, Q., Cavanagh, P., and Green, M.** (1994). Familiarity and pop-out in visual search. *Perception & Psychophysics*, 56, 495-500.
- Watters, C. & Wu, Z.** (1999). Interactive lateral Maps: Using the Web for Collaborative Analysis. *WebNet Journal*, July-September, 34-39.
- Webmonkey.** (2001). The Web Developer's Resources. Retrieved October 17, 2001 from the World Wide Web: <http://hotwired.lycos.com/webmonkey/>.
- White, J.** (1990). *Color for the Electronic Age*. New York: Watson-Guption Publications.
- Wilkinson, L.** (1999). *A Grammar of graphics*. Telos: Springer-Verlag.
- Wood C.H.** (1992). The Influence of figure and ground on Visual Scanning Behavior in Cartographic Context (unpublished PH.D. dissertation, Department of Geography, University of Wisconsin-Madison, 1992).
- Woodhead, N.** (1991). *Hypertext and Hypermedia: Theory and Applications*. New-York: Addison-Wesley.
- Woodward, D.** (1999). Touch the Past. In P. Keller (Ed.), *Touch the Past, Visualize the Future, Ottawa ICA 1999 Conference Proceedings* Vol.1.
- World Wide Web Consortium.** (1999). Retrieved October 10, 2000 from the World Wide Web: <http://www.w3.org/>.
- Worth, C.** (1989). Problems with Experimental Research in Map Design – a Case Study. *The Cartographic Journal*, 26, 148-153.
- Wright, J.K.** (1955). 'Crossbreeding' Geographical Quantities. *Geographical Review*, 45, 52-65.

Youngblut, C., et al. (1996). Review of Virtual Environment Interface Technology. Institute for Defense Analyses, Alexandria, Virginia Retrieved November 7, 2000 from the World Wide Web:
<http://www.hitl.washington.edu/sciww/sciww-ftp/publications/IDA-pdf/COVE>.