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REFEREED PAPER

Colour Contrast in Cartographic Works Using the Principles of Johannes Itten

Jan D. Bláha[1] *and Zbyněk Štěrba*[2]

[1]Department of Geography, J. E. Purkyně University in Ústí nad Labem, Czechia. [2]Department of Geography, Masaryk University, Brno, Czechia
Email: jd@jackdaniel.cz

Colour is considered a key means of expression for use in cartographic works. This is because colours and the relations among them influence not only the aesthetic impression a map creates but also its overall utility. In addition to Newton's spectral colour theory, today theories with origins in artistic technique are gaining ground in cartography. This article introduces J. Itten's colour theory (first published in 1961 in The Art of Colour *[*Kunst der Farbe*]) with special attention given to his concept of seven colour contrasts. The article also discusses the suitability and unsuitability of their application in practical cartography, and it contributes original examples employing thematic maps, a discipline with broad possibilities for the application of these inventive methods by today's mapmakers.*

Keywords: colour in cartography, colour contrast, colour theory, Johannes Itten, thematic maps

INTRODUCTION

In the context of cartographic visualization, we may consider colour as the most important graphic variable or means of cartographic expression. We also know that colour has played an important role in the aesthetic perception of maps since the beginnings of cartographic production (see Bláha, 2011). Well chosen colours allow us to effectively accentuate and distinguish a map's contents. By the same token, the use of inappropriate colour combinations will significantly hamper the perception of the information depicted. Moreover, according to Chesneau *et al.* (2005), colours evoke certain emotions in a user that significantly affect his or her decisions, and this potential is considerably larger in colour than in other cartographic means of expression.

Individuals perceive colour very differently from one another, but these differences are difficult to measure. For this reason, it is almost impossible to establish methods for the use of colour in cartographic production that are both concrete and objective. Nevertheless, we may infer several generally applicable principles from colour theory and from what is generally known about colour perception (Christophe *et al.*, 2011). In particular, we may enable a viewer to distinguish between the elements known as 'figure' and 'background' through well chosen hues and their appropriate juxtaposition, that is, through overlying thematic information and an underlying layer, based on *Gestalt* theory's law of pregnancy (see e.g. MacEachren, 2004 or Stachoň *et al.*, 2013).

As Krygier and Wood note (2005), when creating any map it is necessary to take into consideration the role of colour contrast, and so it is essential to consider the use of any concrete hue in relation to its possible underlay. Failure to do so may lead to inconsistent contrast and thus cause uncertainty in the reception of particular elements of a map, since a user will be unable to correctly distinguish and interpret them.

There is considerable literature available on the theory of colour. The theory most often applied in cartography is that of Isaac Newton[1], although alternative theories such as those of J. W. Goethe (1970)[2] and his successors, Johannes Itten among them (1987), are equally applicable. Newton's theory mostly concerns explanations of the objective cause and relationships of colours (Newton 1704, cited in Welsch and Liebmann 2003). By contrast, Goethe and many of his contemporaries and successors were most concerned with the subjective effects of colour, basing their findings on both psychological and physiological principles (Goethe, Runge, Steiner, Hering, cited in Welsch and Liebmann, 2003). Johannes Itten's 'Kunst der Farbe' (1987, first pub. 1961), intended for students of the visual arts (and thus without an apparent relation to cartographic production), defines seven basic types of colour contrast. The perception of Itten's colour contrasts in an artistic image is very similar to how one perceives them in a cartographic work. Their appearance and effects, both positive and negative, are the subject of this article, in which all claims are illustrated with concrete applications in traditional thematic maps.

According to Ambrose and Harris (2006), today Itten's theory of colours is most often employed in the field of design. It is difficult for practicing cartographers to take

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Figure 1. Itten's 12-hue colour circle in paint colours; example of triad and tetrad (as published by Itten, 1987)

into account all the principles of this theory and all individual colour contrasts, and it demands aesthetic taste. Still, it is possible within cartographic production to apply some basic principles of selection, harmonization and composition of colours. Dent mentions Itten's theory in the margins of his cartographic publication (1996) within the context of the above-mentioned phenomenon of figure and background, which is a fundamental principle of cartographic visualization (Dent, 1996, pp. 303–304).

It is the goal of this article to establish the possibilities for applying Itten's colour theory in cartographic practice. The authors base this effort on the premise that appropriately selected colour composition in maps results in both greater usability and higher aesthetic value, and they attempt to demonstrate these applications in thematic and topographic maps with the help of illustrated examples.

COLOUR THEORY OF ISAAC NEWTON AND J. W. GOETHE

In basic cartographic literature (e.g. Arnberger, 1993; Brown and Feringa, 2003; Robinson *et al.*, 1995; Slocum *et al.*, 2005) and cartographic practice, one most often encounters commentary on and the use of colour theory based on the ideas of Isaac Newton. Although the psychological aspects of colours in cartography are often mentioned, painterly colour composition and related theories of J. W. Goethe do not appear in the publications. Some analysis and applications could be found in Chesneau's scholarly work, which accords the topic detailed attention (e.g. Chesneau, 2006). This fact is due to the widespread use of RGB and CMYK models in input and output devices of computers, which correspond to additive and subtractive composition of colours based on Newton's spectral colour theory. Newton based his theory on the optical decay of white daylight, which is part of electromagnetic radiation and has a wave length of roughly between 380 and 780 nm. His three basic discoveries (the decay of white light into seven basic spectral colours,[3] the capturing of monochromatic light and the re-composition of monochromatic light into white light) form the basic framework of his mathematical–physical theory of colours and explain the objective causes of colours as well as the physical relationships among them (Welsch and Liebmann, 2003).

Whereas Newton's physical theory of colour has been important to cartographers, that of Goethe (1990), who was the first to use the term 'colour effect' (*Farbwirkung* or *Wirkung der Farben*), has not. Goethe divided his work into four parts, the first of which is devoted to physiological, physical and chemical questions related to colour, as well as to psychology and aesthetics. The second part is a polemic with Newton which attempts to disprove his theory of seven spectral 'primary' colours, and the third is devoted to a history of colour and of its understanding since the ancient world. The fourth part consists of coloured illustrations, among other things. The most important contribution of Goethe's theory of colour is its broadening of the physical understanding of colour to include the question of how it is subjectively perceived by the viewer.

Ever since Newton and Goethe posited their theories of colour, other scientists have taken up or attempted to refute one or another part of these theories. Both have shown themselves to have firm roots and so they remain useful today. Newton's theory is most important to physics and mathematics, Goethe's to the traditional natural and human sciences. Both scientists employed a colour circle to represent their theories, although Newton preserved the proportional distribution of colours in the spectrum on the basis of his observations, whereas Goethe arranged the colours equally and supplemented his circle with 'complementary colour contrasts'.

JOHANNES ITTEN'S THEORY OF COLOUR

Johannes Itten (1888–1967), the Swiss Expressionist painter, teacher and Bauhaus theorist of graphic art, developed a far-reaching theory of colour that is taught at many art schools today. It takes up Goethe's idea and is based upon his six-hue (or 12-hue) colour circle, which contains all basic colours of the spectrum (Figure 1). Itten opposes Goethe's psychological term *colour effect* to the term *colour reality* (*Farbwirklichkeit*), which is by contrast based on physical and chemical principles. Itten argued that colour effect may come into conflict with colour reality, leading to disharmony, which he designated a dynamic-expressive, 'unreal' colour relation (Itten, 1987; Itten, 2004; Ford, 1998).

Itten's colour system

Basing his *12-hue colour circle* on his pedagogical experiences, Itten created it by arranging *primary colours* (yellow, red and blue) in a triangle, then placing this within a hexagram of *secondary colours* (orange, green and violet) produced by mixing the primary colours, and then placing this within an outer circle of *tertiary colours* (yellow–orange, red–orange, red–violet, blue–violet, blue–green and yellow–green) produced by mixing together the primary and secondary colours. It should be noted that the practice of naming individual hues is a rather subjective one that varying perceiving subjects may perform differently (see e.g. Berezhnoy *et al.*, 2006).

By creating his colour circle, Itten produced a visual aid for the demonstration of colour contrasts. To show more clearly that colour contrasts apply not only to pure hues, Figure 1 includes lighter hues (in the inner circles) and darker hues (in the outer circles) of the individual colour hues. The illustration also shows an example of a 'triad' (middle) and a 'tetrad' (right), the meaning of which is explained below.

Within the context of his theory Itten employs *mixture of paint colours*, sometimes also called *traditional theory of colours*, and this accounts for the difficulty of directly applying certain of his observations to cartography, which employs the mixing of Newton's spectral colours for output formats in monitors, printers and plotters. Goethe also used spectral colours in his colour circle, but since purple and azure were little known when he developed his theory, he used instead the equivalent red–violet and blue–green hues. These facts, however, have little effect on the significance of Itten's theory for cartography.

Itten's colour harmony

Itten gave particular attention to colour harmony, distinguishing harmonious colour from disharmonious, pleasant from unpleasant, etc. In Itten's colour circle, a harmonious relation exists among the colours in the basic triangle (circle on left in Figure 1). These colours have a typical and stable character, which means that they are essentially non-interchangeable and unchanging in the impression they produce. This is the result of both the physical nature of a colour mixture (which cannot be produced from a different group of colours) with its particular semantic payload (e.g. green may be regarded as blue–yellow, etc.), and the socio-cultural use of these colours (i.e. traditionally these are the most important colours). Other harmonious colour combinations are indicated in Figure 1 in the circles in the centre and right by basic geometric shapes: equilateral and isosceles triangles ('triads'), a rectangle and a square ('tetrads'). According to Itten, harmony occurs among the combinations in the accompanying illustrations when the shapes (triangles, squares, etc.) are turned, which is largely confirmed by additional theories concerning analogue colours. Of course, just as a painter may influence harmony through choice of colour, so also may the designer of a map. And just as such choices help determine the tone or aesthetic effect of a work of art, so may they also determine a map's thematic direction, simultaneously increasing its general utility.

Above all, a cartographer should focus attention on colour choices for surface areas, since they affect the map's harmony the most. It is also important to consider differences between the colour tones of surface areas and those of point and line symbols, which often make up the overlying elements of the 'figure'. On topographical maps this may include, for example, the colour differences among forest, water, residential and industrial areas as distinguished from those among point and line elements; on smaller-scale maps this would undoubtedly affect multi-colour hypsometry (see Imhof, 2007). The implications for thematic maps (e.g. in choropleth maps or when using the areal method) are unambiguous. Here colour combination is above all a matter of scale (see Brewer, 1996). Triads and tetrads may be employed in the context of various thematic combinations, such as in a complex choropleth map.

Itten's colour contrasts

When we speak about contrast, we're speaking of manifest differences between two observable phenomena (Itten, 1987). We see contrast, for example, in differing sizes, temperatures and, of course, colours. At the same time, the observed difference becomes important only at the moment when two or more objects are compared. Perception of colours and of their mutual contrast is to a certain extent a subjective matter, and one that is very difficult to quantify or closely describe. Numerous authors have studied questions surrounding colour since the beginning of the nineteenth century (see Chesneau *et al.*, 2005), but Itten brought a greater measure of objectivity to his effort to define the laws of colour and the principles of their perception that remain useful to practicing cartographers today.

For cartographers, the most useful aspect of Itten's theory is the fact that a colour functions both alone and within the context of other colours in close spatial proximity (i.e. those that are adjacent on a map) or within a broader visual framework (i.e. either existing on the same map or as part of the design of a larger, complex work). In such a shared context, these colours form *mutual contrasts* and thus together broaden the space of colour harmony. Itten provides transparent and explicit definitions and descriptions for seven basic types of contrast that may be observed when perceiving colours (Table 1).

The existence of individual contrasts as illustrated in Figure 2 is reflected in their practical use in thematic maps.

Table 1. Colour contrasts according to J. Itten

Die sieben Farbkontraste	The seven colour contrasts
I. Farbe-an-sich-Kontrast	Contrast of hue
II. Hell-Dunkel-Kontrast	Light–dark contrast
III. Kalt-Warm-Kontrast	Cold–warm contrast
IV. Komplemantär-Kontrast	Complementary contrast
V. Simultan-Kontrast	Simultaneous contrast
VI. Qualitäts-Kontrast	Contrast of saturation
VII. Quantitäts-Kontrast	Contrast of extension
J. Itten (Itten, 1987)	*E. van Haagen (Itten, 2004)*

Figure 2. Colour contrasts according to J. Itten

Given Itten's purposes, it is logical that he offers examples of the use of individual colour contrasts only in fine art.

CONTRAST OF BASIC HUES

Since primary colours are considered the most stable, contrast of the three basic colours is strongest. Therefore it is most appropriate to use primary colours for the depiction of stable or essential phenomena on a map. Contrast among the secondary colours is weaker, and weakest of all is contrast among tertiary colours (see Figure 2, row I). Contrasting the three basic colour tones enables one to achieve differentiation among an image's contents, whether it is a work of art or a map. For this reason, this contrast has wide application in older paintings, above all in those with a religious theme, but also in modern art (e.g. Mondrian, Matisse, Miró, Picasso and Kandinsky).

In cartography this colour contrast is useful *primarily when depicting qualitative phenomena*, specifically when demarcating regions on political maps; basic colours are useful, for example, for differentiating continents on a map of the world. The principle of three basic colours might be joined to the four colour theorem (the colouring of any political map using only four tones), in which yellow, red and blue are joined by green (Figure 3a). To increase a map's variegation and attractiveness, we might add other transitional tones and offer the contrast of secondary colours (see Figure 2, second trio of colours in row I). In many cities, it is these colours that provide the colour differentiations among metro lines and similar things. On the other hand, this group is not appropriate when representing quantitative phenomena. In such situations, a user is incapable of unambiguously judging which colours represent lower or higher values without the aid of a legend (Figure 3b).

LIGHT-DARK (BRIGHTNESS) CONTRAST

The basic nature of brightness contrast is evident in the scale from white to black since it is based on differences in brightness and has applications in achromatic (as well as chromatic) colours. Of course it may be applied to any pure colour tone (see Figure 2, row II), but each tone has its own idiosyncratic disposition when it is lightened or darkened. Every hue has a specific 'optical weight' (darker, saturated colours are considered 'heavier'; among pure

Figure 3. Appropriate and inappropriate use of contrast of basic colours: (a) political divisions and (b) employment in agricultural sector (in % of economically active population)

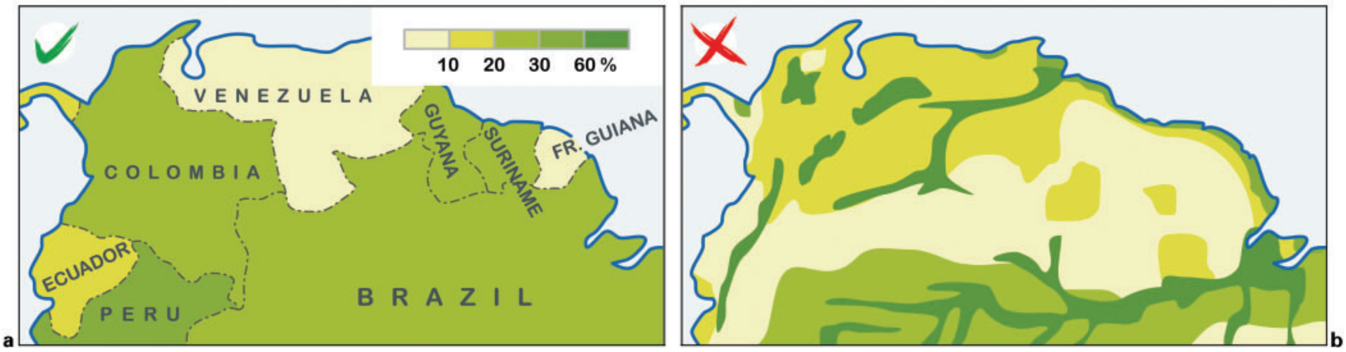

Figure 4. Appropriate and inappropriate use of brightness colour contrast: (a) employment in agricultural sector (in % of economically active population) and (b) soil types

tones these include, for example, violet or blue). Whereas pure yellow, thanks to its low optical weight, may really only be darkened (on a twelve-degree scale from lightest to darkest tones, it occupies the fourth place), pure blue may really only be lightened, since on the same scale it occupies the ninth place (Itten, 1987, pp. 54–55). This is very important in cartography (e.g. in choropleth maps), in which colour tone is chosen on a thematic basis (choice is based on associative and conventional principles, e.g. green for agriculture, red for population, blue for hydrological features, etc.). For this reason, a cartographer should know the limits of particular hues (e.g. on a choropleth map, pure yellow should be used only for lower values). This type of colour contrast is traditionally favoured by painters to depict darkness and light and it has applications in various other techniques, including pencil and charcoal, line drawing, woodcut and lithography. Practitioners have included Rembrandt, Goya and Picasso.

In maps themselves it is used for light and dark shading, as well as for certain degrees of colour hypsometry by, e.g. Sydow and Hauslaub. In thematic maps, this type of contrast is *typical for quantitative phenomena* (i.e. for the above-mentioned choropleth maps), in which light tones are used for lower values and dark tones for higher values (Figure 4a). The question of colour scale in choropleth maps is investigated in detail by Brewer (1994, 1996) and Mersey (1990). The classification of scales might employ differing optical weights or varying degrees of brightness. Light contrast may be applied to a contour map, in which areas between isolines (e.g. isochrones on an availability map) are often coloured according to the principle of light contrast. One advantage of the contour method over the choropleth is that it allows for smaller light gradients among neighbouring colour tones.

On the other hand, use of light contrast is not appropriate for differentiating among *qualities* of phenomena – e.g. when using the areal method in geological, pedological or topographical maps (Figure 4b). One may use light contrast for the purpose of creating contrast among point or line symbols and for printing text on a map's area (dark figure against light background or vice versa – see the names of countries in Figure 6b) or on political maps (e.g. varying degrees of regionalization), but generally only on combination with other colour contrasts (e.g. contrast of basic colours, or complementary or qualitative contrast).

CONTRAST OF WARM AND COLD COLOURS

This contrast provides cartographers an exceptionally strong means of expression. It is based on the varied ways in which colour warmth is perceived. Warm and cold colours (in Figure 1 warm colours occupy the top halves, cold colours the bottom halves of the colour circles) help to convey a great many opposing characteristics of spatial phenomena, such as cold/warm, shady/sunny, transparent/opaque, positive/negative, important/unimportant, sparse/dense, aerial/terrestrial, far/near, light/heavy, humid/dry (Itten, 1987, p. 65). This is very useful in thematic maps, in which a cartographer is often required to work with the above spatial characteristics, whether it's a question of cold vs warm sea currents, positive vs negative effects of industry on an environment, far vs near destinations, etc. A range of other possibilities are provided by contrasting red and blue, which are a typically representative warm/cold pair. Colours existing on the border between cold and warm (Figure 1) create a warm or a cold impression as a function of their proximity to other colours in Itten's circle (see violet in Figure 2, row III). This contrast, used in stained glass and painting perspective, was employed by Renoir, Monet and Cézanne, for example.

The contrast of warm and cold colours is closely *associated with differing perceptions of heat*. For this reason it is no surprise that it is the contrast most employed in climate and meteorological maps (above all in distinguishing high temperatures and precipitation or its absence – Figure 5b), just as in historical maps warm colour (red) is generally used to represent 'our' armies whereas cold (blue) is for 'them'. It follows that neutral colours (i.e. transitional colours between warm and cold, perhaps even achromatic colours) are used to represent neutral countries. This contrast is also useful in certain coloured hypsometric scales and in perspective maps. Red and blue might also be associated with differentiating gender or even with low (often unfavourable) and high (often favourable) values (Figure 5a). According to Brewer's classification (1994), these are divergent scales that are also connected to brightness and qualitative colour contrasts. These colours may even have political associations, indicating on a map one or another political party (e.g. in the USA. representing Republicans and Democrats). In other words, the contrast of warm and cold colours joins qualitative and quantitative phenomena.

It is inappropriate to use this contrast on maps that do not involve polarities (e.g. population density without indicating

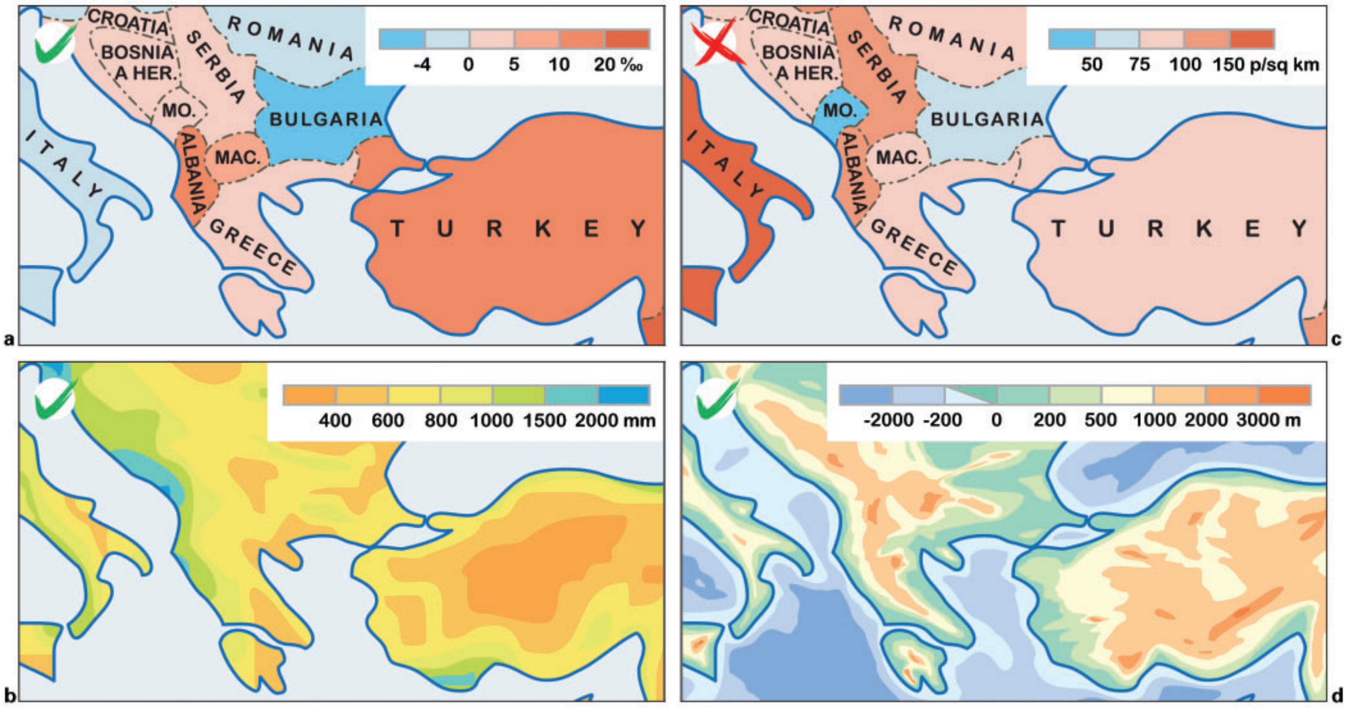

Figure 5. Appropriate and inappropriate use of warm/cold colour contrast: (a) natural population growth; (b) average annual precipitation; (c) population density and (d) elevation (hypsometric and bathymetric tone)

an average – Figure 5c); in such a case, red and blue would create the false impression that lower density is unfavourable and higher density favourable. It is also inappropriate in association with phenomena to which heat may be detrimental, thus suggesting a falsely negative interpretation of the map's contents. We might recall, for example, Cold-war era maps in which red and blue were used to represent the respective blocs but were interpreted in varying ways[4]. One final, important phenomenon that might be depicted using the warm/cold contrast and which has been employed in painting perspective is an object's *plasticity*. This feature is based on the fact that cold (far) and warm (near) tones are commonly perceived by a viewer as representing varying distances (see Figure 5d). As research on the perception of traditional colour hypsometry has shown (e.g. Patton and Crawford, 1977), these colours function according to the principle of the warm/cold colour contrast and thus convey information regarding elevation in a comprehensible fashion. Nevertheless, Patton and Crawford (1977) have determined that these colours are also associated with additional characteristics and features (e.g. vegetation is associated with green), and some users do not agree that warm tones indicate higher elevation and colder tones indicate lower. Therefore, it is useful to enhance plasticity by employing other cartographic methods, such as shading, which underscore a given colour contrast and distinguish corresponding elements (see Kennely and Stewart, 2010).

COMPLEMENTARY CONTRAST

Colours located across from one another in a colour circle (Figure 1) form a complementary contrast[5]. This is a strong contrast, indeed the strongest of them all, and for this reason it has been and still is often used in painting (van Eyck, della Francesca, van Gogh) and design. The same is true in cartography. We may say that, for complementary colours, the effect corresponds to the reality ('what you see is what you get'). Their contrast is stable in nature, and they 'look good together'. It is necessary to consider the possible side effects of other types of colour contrasts, which may to an extent counteract this stability. Orange and blue, for example, amount to a warm/cold colour contrast (we see this in climate and meteorological maps – Figure 5b, or in hypsometric tone or perspective maps), while yellow and violet amount to a quantitative contrast (rarely used in maps, since the yellow/violet contrast is too strong – Figure 6b; when they are used, it is important that they not be pure tones). These two pairs are suitable for depicting contradictory phenomena on a map. Correct complementary colour pairs are shown in Figure 1 in the circles on the right side. In certain combinations, however, e.g. when they are placed directly beside one another on a map, they may cause a 'painful' effect on the eyes, particularly during periods of longer exposure. The complementary contrast of primary and secondary colours is shown in Figure 2, row IV.

When creating maps, complementary colour contrast may be used very effectively to distinguish between two qualitatively different phenomena (especially between opposites), whether it concerns membership/non-membership, participation/non-participation, or the differentiation among warring parties on a historical map. A pair of complementary colours may also be employed when designing the legend for a topographical map, e.g. to harmonize the brown used for contour lines with the blue used for water, etc. Since this contrast emphasizes the differences between two colours, it is

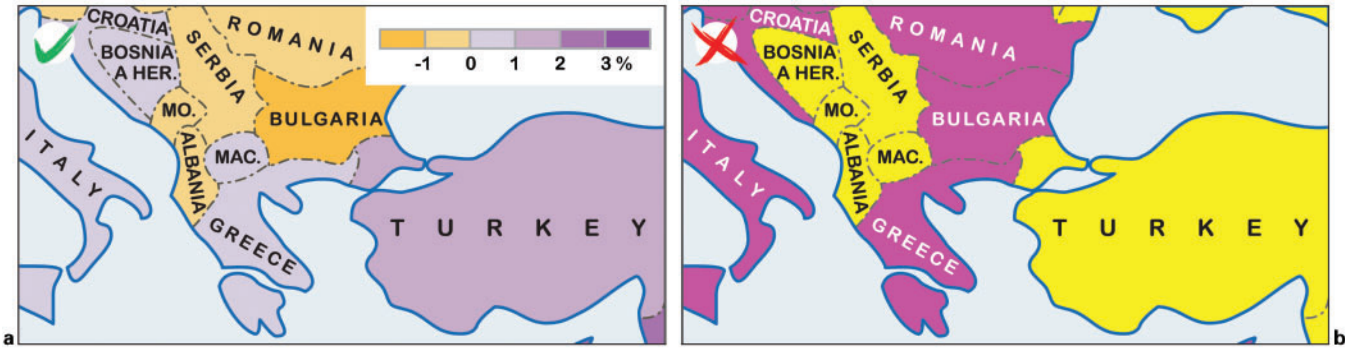

Figure 6. Appropriate and inappropriate use of complementary colour contrast: (a) average annual population growth 1995–2000 and (b) member states of European Union

also useful for distinguishing figural elements from background. Finally, this contrast is often used in choropleth maps (again for depicting opposites) in which a pair of complementary colours stand at opposite ends of a divergent colour scale (Brewer, 1994; Mersey, 1990) – see Figure 6a. In such a case, this contrast is combined with both brightness contrast and warm/cold contrast. Thus complementary contrast is *one of the most frequently used colour contrasts* in cartography. To repeat, it is important when selecting purity (saturation) of colour tones that this contrast not be too strong.

SIMULTANEOUS CONTRAST

Like complementary contrast, simultaneous colour contrast may be categorized among those that function according to physiological principles (Robinson, 1967, p. 54), which is to say it is affected by the perceiver's vision. The eye has a tendency to supplement each colour with its complement, and when this second colour may actually be found in close proximity the image's overall impression is a stable one (see above on colour harmony). In all other situations, the effect is simultaneous colour contrast of varying degrees, which manifests itself as displacement by another colour. In the case of chromatic colours, the effect is a shift to the complementary colour or *simultaneous tonal contrast* (Figure 2, row V, right) and *periphery vibration*. In cartography, this effect may be produced by inappropriate colour combinations, especially when applied to surfaces to depict qualitative phenomena in combination with hachure (Figure 7a).

In the case of achromatic colours, the effect is a shift in perception toward lighter or darker tones, a phenomenon known as *simultaneous brightness contrast* or *induction* (Figure 2, row V, left), in which the same grey hue seems lighter when placed next to a darker tone and darker when placed next to a lighter tone (which means that a colour can

Figure 7. Effects of simultaneous colour contrast: (a) expansion of European Union (*periphery vibration*); (b) employment in agriculture (*effacement of neutral tones*); (c) and (d) percentage practicing dominant religion: (c) *Bezold effect*; (d) *mitigated by white borders*

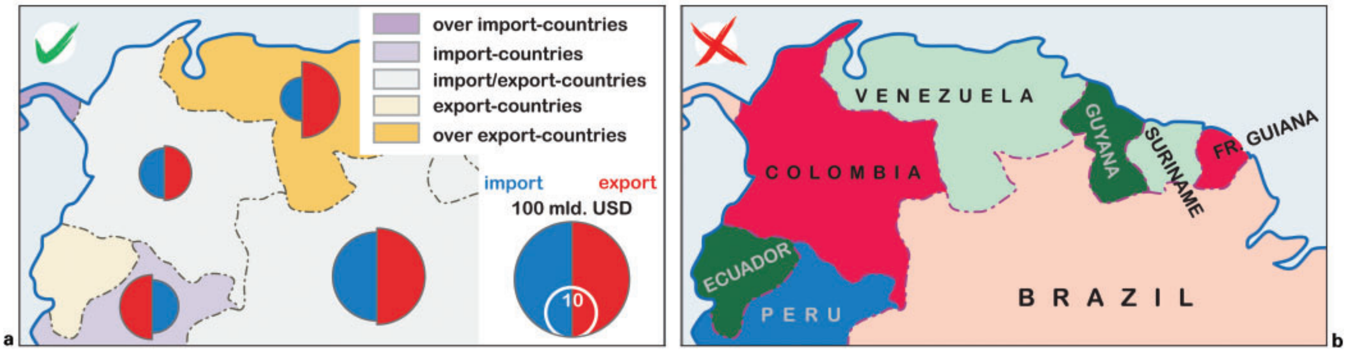

Figure 8. Appropriate and inappropriate use of qualitative colour contrast: (a) foreign trade and (b) political divisions

have differing effects depending on whether it is seen on a monitor or on paper). We encounter this phenomenon in cartography most often when a colour's placement adjacent to lighter or darker tones on a map cause a user to perceive the colour differently than he or she perceives it on the map's legend (Figure 7c). It is clear that this phenomenon cannot be completely eliminated, yet it may be mitigated by increasing the differences in brightness among individual tones. *Simultaneous saturation contrast* is similar, occurring when a tone surrounded by a pure colour gives the effect of being less saturated than when it is surrounded by a less saturated colour.

A very common example of simultaneous contrast is the effacement of neutral (achromatic) tones by colours that are complementary to a colour that is in close proximity (Figure 2, row V, middle). This is encountered in cartography when achromatic linear symbols (such as national borders – see Figure 7b) are used in close proximity to pure colour tones. Another effect, known by the German term *Nachbild* (afterimage), occurs when a subject views a colour and immediately afterward perceives its complement against a neutral background (Welsch and Liebmann, 2003, p. 39; Itten, 1987).

Simultaneous contrast holds a privileged position in the theories of Goethe and Itten, and it cannot be ignored in cartographic products. In graphic art we may speak of ideal colour combinations, which create a provocative impression and produce tension (El Greco, van Gogh). Of course, this is something cartographers should be careful to avoid since it causes difficulty when reading maps, distracting the user's attention and subverting the effects of colour (Dent, 1996, p. 304). The greatest complication is encountered when it coincides with contact between neutral colours and distinctive, pure tones. This can be prevented by lining areas in white or black, thereby eliminating the erroneous perception of the colour of neighbouring surfaces associated with *the Bezold effect* (Robinson in Dent, 1996, p. 297) – see Figure 7d.

There is little reason to search for opportunities to exploit simultaneous colour contrast in cartography. An author wishing to design a map that is user-friendly must instead *eliminate manifestations of this contrast to the greatest possible extent*, primarily through careful colour selection, whether for qualitative or quantitative objects and whether a map is thematic or topographic. Simultaneous contrast worsens a map's readability by making it difficult to distinguish among its symbols and contents. Figure 7 contains examples of the most common effects of simultaneous colour contrast, i.e. periphery vibration and the effacement of neutral tones (note the printed script and lines representing national borders).

CONTRAST OF SATURATION (QUALITATIVE CONTRAST)

Qualitative contrast is generated by contact between pure and turbid colours, even within the confines of a single colour tone (Figure 2, row VI). This contrast corresponds to the purity or saturation of a colour and is thus not simply a question of the qualitative phenomena depicted on a map, but of the 'quality' of a colour itself. Colours acquire very different characters depending on whether they are mixed with white (which creates a fresh, genial pastel) or black (losing their luminosity and creating a repellent, even threatening quality), while grey's effect is rather neutral. Instead of adopting these more or less psychological connotations, cartography takes advantage of the attendant heterogeneity. This contrast has been used in painting by e.g. Matisse and Klee when dealing with colour perspective; it is similarly useful in perspective maps (see the cartographic works of E. Imhof).

Qualitative colour contrast has applications in cartography above all in *improving the formation of figure and background* (figural and linear elements may be addressed by pure or saturated colours on surfaces coloured in less saturated tones) – Figure 8a, primarily in conjunction with brightness contrast, which it supplements well. Another possible application is for *differentiating special terrain* (pure and saturated tones) from other terrain (suppressed tones). On topographical maps it might be useful for the visual balancing of large geographic phenomena, such as forests or lakes, with smaller objects, such as listed points or isolated structures. This corresponds to the above-mentioned figure-background principle. This contrast is also applicable in conjunction with brightness colour contrast on choropleth maps for distinguishing the quantity of a given phenomenon (e.g. varying frequency of occurrence). On the other hand, this contrast is ineffectual on maps depicting phenomena that exist on the same qualitative level; on topographical maps, for example, this contrast would be inadequate to the purpose of accentuating certain

Figure 9. Examples of quantitative colour contrast: (a) political divisions (*relatively balanced image*) and (b) political divisions (*relatively unbalanced image*)

content over other content. Maps depicting political divisions are another example of an unsuitable application (Figure 8b).

CONTRAST OF EXTENSION (QUANTITATIVE CONTRAST)

Quantitative contrast concerns the diverse effects of equal amounts of different colours as a result of their varying optical weights. If an appropriate proportion of surface area for individual colours is maintained, the general effect of the image is one of calm and balance, whereas a lack of proportion creates an unsettled effect. Goethe determined the following basic ratio of primary and secondary colours for an image to appear balanced and harmonious: yellow : orange : red : violet : blue : green=9 : 8 : 6 : 3 : 4 : 6. This ratio cannot be perfectly achieved in cartography, since a map's contents are determined by the position of objects as they appear in the world. Figure 2, row VII shows complementary pairs in their correct proportions according to this ratio (Welsch and Liebmann, 2003, pp. 39–40; Itten, 1987). While this ratio applies only to pure, fully saturated colours, quantitative contrast has general application and demonstrates that colour contrasts are significantly affected by changes in surface area. Quantitative contrast becomes important as specific content in an image or map is suppressed or emphasized.

It is not possible to speak of the appropriate or inappropriate use of quantitative contrast, but rather about whether a given map does (Figure 9a) or does not (Figure 9b) approach the balanced colour ratio mentioned above. Either a map's effect is balanced and calm or the attention of its user is improperly drawn to a particular area or object on the map. An experienced cartographer will apply the ratio subconsciously through colour combinations and a harmonious use of colour in a map's legend. Elements taking up larger proportions of the map's field might employ yellow and orange hues, while elements taking up smaller proportions might use blue and violet. For these purposes, green and red may be said to be neutral. The overall impression may be similarly balanced by decreasing or increasing the brightness and saturation of the colours used. Naturally, the geographic locations of objects appearing in a map have the greatest influence on this particular contrast. Thus it is easier to create a visually balanced map when there are fewer elements, when the terrain depicted is smaller and when the objects represented allow a broader choice of colours (e.g. political divisions) than when a map's contents are more variegated.

Additional observations by Itten

Itten also considered colour mixing (1987) on a 'mixture band', a 'mixture triangle' (the primary colours of paint mixing) and a 'mixture square' (two complementary colours, white and black or four random colours). Such mixing may be employed when creating a colour scale for mapping quantitative data, whether with one or more variables.

He also employs as a model a *coloured sphere* in which the equatorial plane is formed by a 12-hue colour circle, with colours meeting in white at the upper pole and in black at the lower pole. As in Munsell's model, the purer tones are located furthest from the line connecting the poles (Munsell, 1905). As a result, there are five directions on the sphere along which colour patterns appear: to the right, to the left, upward, downward and inward. Itten's colour theory also includes observations on the relation of colour to form, on colour's effects on space and on composition. However, these observations are of greater interest to graphic art, which strives to remove caprice in the placement of colour on the canvass, than they are to cartography.

CONCLUSION – USE OF ITTEN'S THEORY IN CARTOGRAPHY

Today cartographers employ many of Itten's observations in a relatively spontaneous manner. The authors of this article are convinced that cartographers would use them more effectively and integrate additional methods employed by Itten if they knew the theoretical background of those observations. The establishment and activity of the Working Group/Commission on Art and Cartography under the auspices of the International Cartographic Association testifies to the fact that the joining of art and cartography is, moreover, a matter of current interest. In February 2008 it sponsored an Art and Cartography symposium, and in 2009 a book of the same title and a special issue of *The Cartographic Journal* (Art & Cartography, 2013) were published. Two papers at the symposium were devoted to the application of artists' (Monet's and Matisse's) colour schemes to problems relating to colour in cartographic works. One paper concerned their application to topographic maps (Christophe, 2009), and the other concerned the creation of colour scales in thematic maps (Friedmannová, 2009). These contributions demonstrate that there is plenty of interest and inspiration in the works of the great masters.

Colour theories and their application in cartography are also the concern of cognitive cartography (under the ICA Commission on Cognitive Visualization). A task that is of interest to this discipline is the investigation of the relation between subjective and objective aspects when assessing the usability of maps with respect to use of colour composition and contrast for the design of individual cartographic symbols. Christophe (2009, 2011) has performed an algorithm for the creation of colour compositions for individual elements of a topographical map on the basis of user preferences. It is based on the hypothesis that compositions based on individualized preferences will be easier for a user to read and more usable to a given task. Chesneau (2005) has written about improving the resolution of discrete cartographic symbols by automatically increasing their colour contrast, an idea based on findings from Itten's colour theory (although the colour circle on which the resulting model is based was somewhat different).

Today most experts agree that the methods, by which colour is used in cartography have a significant influence upon a map's resulting usability as well as on its aesthetic effect. The authors of this article have analyzed the importance of colour and colour contrast in cartography, basing their findings on colour theories that originated in art and artistic technique. Apart from their application in painting, the colour contrasts of J. Itten provide an exceptionally useful basis and an inspiration for working with colour in the context of cartographic work. The examples provided can serve as guides for the effective practical use of this theory and as warnings for what to avoid. Given this, we may say that the use of colour in maps is an area of cartography that deserves further exploration.

BIOGRAPHICAL NOTES

Jan D. Bláha is currently an Assistant Professor in the Department of Geography at J. E. Purkyně University in Ústí nad Labem. He has degrees in Geography and Cartography with specializations in Cartography and Geoinformatics, as well as a degree in Culturology with a specialization in Cultural Anthropology from Charles University in Prague, where he also earned a PhD in Cartography, Geoinformatics and Remote Sensing. His research concerns the aesthetic and cultural anthropological aspects of cartographic creation and assessment of cartographic works from a user perspective. Above all, he is interested in the relations between maps' utility functions and aesthetic functions, and he studies their mutual influence as it relates to map usability.

Zbyněk Štěrba is a post-doctoral researcher in the Department of Geography at Masaryk University in Brno. His research interests focus mainly on cognitive aspects of cartography, the role of particular graphic variables on map usability and differences among individual users in map perception processes with an emphasis on crisis management applications.

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NOTES

[1] Isaac Newton published his theory of colour in detail in 1660, and he provided a summary of his findings in *Optics* in 1704.

[2] Johann Wolfgang Goethe began intensively investigating colour in 1777 and he published *Farbenlehre* (*Theory of Colours*) in 1810.

[3] Newton's work described and constructed a colour wheel containing the seven primary colours (red, orange, yellow, green, blue, indigo and violet) in the proportions inferred by his experiments. He also surmised that these 'primary colours' cannot be further optically divisible (Harkness, 2006).

[4] The Eastern bloc understood red to be a symbol of Communism but also of the fraternal alliance that warmed comrades' hearts, whereas capitalism was associated with cold, unfriendly colours. The West, on the other hand, associated the red of the Eastern bloc with bloody, repressive dictatorships.

[5] According to traditional colour theory ('colour mixing'), a complementary colour pair consists of a primary colour and the secondary colour that contains none of the primary. The result when two complementary colours are mixed together is thus an achromatic tone. When another colour wheel model (RGB $\times$ Itten) is used, however, the corresponding complementary pairs are somewhat different (with greater differences for some pairs and smaller differences for others, due to the lack of proportionality in Itten's wheel).

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