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A Social-Semiotic Approach to Color Analysis in Digital Media: Theory and Practice

Uma abordagem sociossemiótica para análise de cores em mídias digitais: teoria e prática

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Abstract: This article aims to discuss the study of color from a social-semiotic perspective. The article begins with an overview of Gunther Kress and Theo van Leeuwen's distinctive feature approach to color in their Grammar of Visual Design (2021) and concludes that the authors base their claims primarily on paintings and print media, which may skew the categories toward analog media. Drawing on color theory, mainly the contributions of Rhyne (2017), this article argues that social-semiotic analyzes can benefit from systematized and quantitative categories for color analysis, especially for digital media corpora. The article introduces several analytic categories, such as color harmony and the RGB color space, that are relevant to understanding how color works in digital spaces. The paper proposes the use of the free and open source software GIMP and ImageMagick for a qualitative and quantitative approach to the distinctive features of color and for a better understanding of the complexity of colors and their meaning potential. Based on these methodological procedures, the distinctive feature approach is revised with Rhyne's contribution. Finally, the categories are applied to two stock images as a case study.

Keywords: social semiotics; color theory; grammar of visual design.

Resumo: Este artigo visa discutir o estudo da cor a partir da abordagem sociossemiótica. Começando com uma visão geral da abordagem da cor por Gunther Kress e Theo van Leeuwen, na sua *Gramática de design visual* (2021), conclui-se que os autores baseiam as suas constatações principalmente em pinturas e mídias impressas, o que pode enviesar as categorias em direção aos meios analógicos. Baseado na teoria das cores, principalmente nas contribuições de Rhyne (2017), o artigo argumenta que as análises que partem da semiótica social podem se beneficiar de categorias especializadas para a análise da cor, principalmente para *corpora* de meios digitais. O artigo introduz uma série de categorias analíticas, tais como a harmonia de cores e o espaço de cor RGB, que são relevantes para compreender como funciona a cor nos espaços digitais. Para demonstrar as categorias aqui apresentadas, são utilizados os *softwares* gratuitos e de código aberto GIMP e ImageMagick. Eles permitem uma abordagem qualitativa e quantitativa das características distintivas da cor e permitem uma melhor compreensão da complexidade das cores e do seu potencial de significado. Com base nesses procedimentos metodológicos, a abordagem de traços distintivos é revista através das contribuições de Rhyne. Finalmente, como um estudo de caso, as categorias são aplicadas em duas *stock images*.

Palavras-chave: semiótica social; teoria das cores; gramática do design visual.

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1 Introduction

People's interest in understanding colors can be traced back to the 5th century B.C., at least in Western civilization. The works of Alcmaeon of Croton are among the earliest evidence of the ancient Greeks' attempts to understand visuo-spatial perception (Pavlidis, 2021, p. 7). In the millennia between Alcmaeon and modern society, many thinkers from a wide variety of perspectives have put forward theories about colors. Among them, we highlight two whose importance is still felt today: Isaac Newton (1642-1726/27) and Johann Wolfgang von Goethe (1749-1832). Newton is known, among other things, for his studies of light and color (Pavlidis, 2021, p. 35-38), from which he derived the idea that colored lights can be combined to produce other colors, as well as the claim that white light is produced by combining different colors (Rhyne, 2017, p. 3). Goethe, in turn, was also engaged in the study of colors outside of his literary works. In *Zur Farbenlehre*[1] (1810), he created the basis for the Red, Yellow, and Blue color model (Rhyne, 2017, p. 9), which is often taught in elementary schools. He also opposed Newton's color theory, focusing instead on a qualitative model that considered perception and the psychological and physiological effects of colors (Rhyne, 2017, p. 9; Pavlidis, 2021, p. 44). In this sense,

> Goethe rejected the 'sterilised' approach of a theory of colour, in which colour is deprived of its sensation, and is treated as an objective phenomenon even without the need for an observer to experience it. He was deeply certain that talking about colour has no meaning outside of the context of its perception, through the active sensation of vision (Pavlidis, 2021, p. 45).

We do not consider inconsistent the studies of color meaning and effects and the studies of its materiality[2]. Instead, we conceive these approaches as complementary. In this article, we will draw upon the social semiotic approach (Hodge; Kress, 1988) to discuss color as a meaning-making resource. As such, we move closer to Goethe's conception of color, since we cannot ignore the role of the observer in the semiotic process. At the same time, social semiotics places importance on the materiality and affordances of the semiotic resources (Jewitt; Bezemer; O'halloran, 2016, p. 160).

It bears mentioning that the relation between materiality and perception can be quite complex. Bateman, Wildfeuer and Hiippala (2017, p. 27) discuss that the immediate relation between the semiotic

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[1] In 1840, Charles Eastlake translated the book into English and called it *Theory of Colours*. It is worth noting that Eastlake omitted the parts where Goethe opposed Newton's observations (Possebon, 2009, p. 28-30; Rhyne, 2017, p. 11).

[2] To return to Goethe's proposal, although he opposed the scientific paradigm of his time, he also conducted experiments on color phenomena. In one of them, which sparked his opposition to Newton's approach, he claimed that "Newton's prismatic experiment was erroneous in that there is no green colour directly exiting a prism, but green is rather a composition of yellow and blue only after some distance from the prism, where the two colours overlap" (Pavlidis, 2023, p. 44). However, "his observation is false and depends on the topology of the experiment and typical light effects at boundaries" (2023, p. 44). Similarly, Eastlake emphasized that Goethe would have received more praise from the scientific community had he let others try to reconcile his findings with current theory rather than attacking it so directly (1840, p. ix).

modes and resources and sensory channels is misleading. The authors point out that understanding the material qualities of the object does not necessarily give us an understanding of how we perceive it (2017, p. 27). For example, when we hear a sound, we receive a variety of information outside of its physical properties: space, direction, distance, etc. Conversely, as we will show in this paper, our perception may not be able to comprehend many material properties of semiotic resources, in our case colors.

Therefore, we will discuss the meaning-making potential of colors, considering the fact that there are many aspects that may elude our perception. We consider colors as both quantitative and qualitative phenomena. Our proposal may help researchers systematize the analysis of colors as a visual resource, especially when it comes to digital media. To do so, we will first discuss how social semiotics, one of many approaches that attempt to systematize a perspective on colors, has historically analyzed them.

One cannot overestimate the importance of Gunther Kress' contributions to the social-semiotic approach to multimodality. Together with Theo van Leeuwen, they discussed fundamental concepts and tools that are still productive for the analysis of different modes and media. *Reading Images*, written in 1990, was one of the first systematic attempts to understand the complexity of meaning in images. The book was aimed at teachers and focused on children's drawings and illustrations in textbooks (Kress; Van Leeuwen, 1996, p. vi). The authors expanded their scope and wrote the first edition of *Reading Images: The Grammar of Visual Design* in 1996.

As the name implies, the authors intended to create a grammar for the visual mode to "describe the way in which we depicted people, places and things combine in visual 'statements' of greater or lesser complexity and extension" (Kress; Van Leeuwen, 1996, p. 1). The second edition of the book was published in 2006 and the third edition in 2021, with each edition adding to and expanding the authors' categories for visual grammar analysis. In this article, we will focus specifically on how Kress and van Leeuwen conceptualize color analysis.

In the first edition of *Reading Images: The Grammar of Visual Design* (1996, p. 165), the authors discuss color primarily as a modality marker under the categories of Saturation (a scale from full color to black and white), Differentiation (a scale from diversity to monochrome), and

Modulation (a scale from a diversity of shades of the same color to the use of a single shade). Color also appears briefly in the discussion of the materiality of meaning: In discussing the potential for meaning in brushstrokes, the authors cite, among other things, the use of color by Wassily Kandinsky and Pieter Mondrian (1996, p. 236).

Prior to the second publication of *Reading Images*, Kress and van Leeuwen published the article "Colour as a Semiotic Mode: Notes for a Grammar of Colour" (2002), which laid the foundation for their approach to color. As in their visual grammar, the authors introduce the possibility of a grammar of color (2002, p. 343). To this end, Kress and van Leeuwen discuss the meaning-making potential of color based on Halliday's (1978) metafunctions and provide a brief overview of the history of color studies. Following Kandinsky (1977), the authors distinguish two types of affordances[3] for color: association (or provenance) and the distinctive features of color (2002, p. 355).

Association refers to the meanings culturally and socially ascribed to colors (Kress; Van Leeuwen, 2002, p. 355). For example, Red may be associated with love, fire, or violence. These meanings come from the interests and use that sign makers have historically given to colors (Jewitt, Bezemer; O'halloran, 2016, p. 156-7), and as such we understand them even when they appear outside their original context. This in turn limits the way we interpret color.

> While the affordances of a colour may be limitless in theory, in practice they are not, and a plausible interpretation can usually be agreed on, provided the context of production and interpretation is taken into account (Kress; Van Leeuwen, 2002, p. 355).

The second affordance is a set of distinctive features based on Jakobson and Halle's (1956) phonology. For example, if we paint a heart with a pale Red color, we may interpret it differently from a bright Red heart. We may view the former as "sickly" or "fading," as if it were a perishing love, while we may view the latter as full of life.

In the second edition of *Reading Images*, color appears as a modality marker and in a separate section on the meaning of materiality

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[3] The potential uses of a semiotic resource are based on its material features and on the perception of the sign makers (Jewitt; Bezemer; O'halloran, 2016, p. 155; Van Leeuwen, 2005, p. 273;).

rather than under brushstroke analysis (Kress; Van Leeuwen, 2006, p. 225-238). Following their proposal in the 2002 article, Kress and van Leeuwen present their distinctive feature approach to color and its possibilities.

In the third edition of *Reading Images*, the framework given in the second edition and in Kress and van Leeuwen's 2002 article is largely maintained. Although the authors mention some digital media such as Microsoft PowerPoint, referring to an earlier work by van Leeuwen (Van Leeuwen, 2011), most examples still refer mainly to paintings and print media.

A fundamental aspect of social semiotics that the authors emphasize is the impact that technology has on the meaning-making process, particularly on "graphically realized semiotics" (Kress; Van Leeuwen, 2021, p. 227). Conversely, there are several digital methods for multimodal analysis. For example, Bateman, Wildfeuer, and Hiippala discuss several tools for multimodal analysis in their book *Multimodality* (2017), including computational methods such as neural networks for image description, color recognition, and labeling (Johnson; Karpathy; Fei-Fei, 2016, Karpathy; Fei-Fei, 2015).

Similarly, in this article, we will discuss how color theory and graphic design software can assist social-semiotics researchers, particularly in small-scale research. To this end, we rely primarily on Rhyne's (2017) propositions for color analysis in digital media. We consider that the author's detailed discussion of color theory is compatible with Kress and van Leeuwen's distinctive feature approach and can greatly improve the analysis of digital *corpora*. We also present methods for visual analysis using the free and open source software GIMP (gimp.org) and ImageMagick (imagemagick.org/). We selected both software based on previous works (Matumoto, 2022a, 2022b; Matumoto; Gonçalves-Segundo, 2022a, 2022b) and chose to discuss replicable and free methods for accessibility reasons.

We organized the article as follows: First, we discuss the distinctive features approach as proposed by Kress and van Leeuwen (2002; 2021). Then, we introduce some analytic categories as proposed by Rhyne (2017), the software GIMP and ImageMagick tools, and how they allow us to visualize the author's claims. We then apply the categories in a case study of two stock images, followed by the concluding remarks.

2 The distinctive feature approach to color

As mentioned earlier, we ground our considerations on the social-semiotic framework (Hodge; Kress, 1988), in particular on the Grammar of Visual Design and its contributions to color analysis (Kress; Van Leeuwen, 2002; 2021). Building on Rhyne's (2017) work, we intend to extend Kress and van Leeuwen's categories to the analysis of digital media and provide methods for color analysis.

Kress and van Leeuwen's distinctive feature approach (2002; 2021, p. 244-9) aims to analyze the meaning potential of colors based on their material properties, such as Hue and Saturation. Table 1 summarizes the properties of colors:

Table 1 – Color distinctive features

Distinctive feature	Description
Value	Refers to the scale from "maximally light (white) to maximally dark (black)" (Kress; Van Leeuwen, 2021, p. 245).
Saturation	Refers to the scale from saturated, or pure, colors to the softest and dullest colors (Kress; Van Leeuwen, 2021, p. 245).
Purity	Refers to the scale from color purity, such as bright Red, to color hybridity, such as Orange-red, a mixture (Kress; Van Leeuwen, 2021, p. 245).
Modulation	Refers to the scale from fully modulated colors, such as the many shades of Blue, to flat colors, such as a single shade of Blue (Kress; Van Leeuwen, 2021, p. 245).
Transparency	Refers to the scale from transparency to opacity (Kress; Van Leeuwen, 2021, p. 246).
Luminosity	Refers to the ability of a color to glow, to 'stand out' by itself (Kress; Van Leeuwen, 2021, p. 246-7).
Differentiation	Refers to the scale from monochromatic registers to a varied palette (Kress; Van Leeuwen, 2021, p. 247).
Hue	Refers to "the scale from Blue to Red" (Kress; Van Leeuwen, 247-8). Broadly speaking, it refers to what we often consider as the colors themselves, such as red, blue, green, etc.

Source: Created by the authors.

These features are a robust set of categories for color analysis, and as the authors note, it is important to keep in mind the fact that all these features work together and therefore the meaning potential of a particular color (or set of colors) depends on the configuration of the individual features (Kress; Van Leeuwen, 2021, p. 247). Moreover, signs function as "complex constellations" (Bateman; Wildfeuer; Hiippala, 2017, p. 116). This means that the composition and the participants[4] represented are as important as the colors used to represent them. From a social-semiotic point of view, we should always consider the context for the creation of the image and the relationship between the semiotic choices and the discourses and ideologies (i.e., the association that results from the semiotic choices).

Returning to our example of the two hearts painted Red, we can confirm that our meaning hypothesis is based on the Red hue, its Saturation, the associations we attribute to these features, *and* the fact that we have drawn a heart, often associated with love. If we were to draw a campfire or a bloody landscape instead, we would no longer associate Red with love (but with fire and violence), but we might still interpret Saturation in a similar way (for example, as a signifier of intensity).

Thus, as Kress and van Leeuwen noted, the possibilities of colors are not unlimited: They arise from culturally recognized uses, physical properties, and the way we perceive colors. Given the interplay of these aspects, especially perception, color analysis can be particularly challenging because what a color "is" may not be readily recognized in its entirety. This is noteworthy when we consider the way the authors formulate their categories:

> These distinctive features indicate, as in Jakobson and Halle's (1956) distinctive feature phonology, a quality which is visual rather than acoustic, and is not systematized, as in phonology, as structural oppositions but as values on a range of scales (Kress; Van Leeuwen, 2002, p. 355).

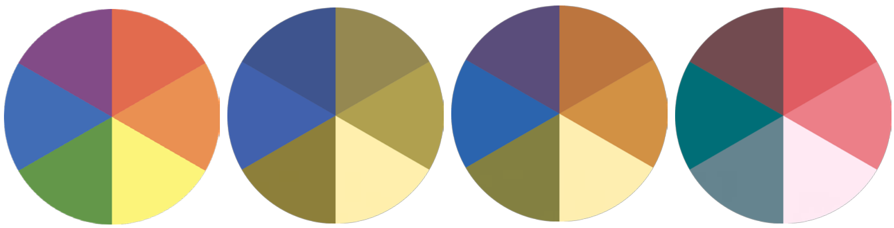
In contrast to the phonology of Jakobson and Halle (1956), Kress and van Leeuwen consider that each feature are values on a scale, such as "light to dark," rather than oppositions (such as [+voiced] and [-voiced]).

[4] A generic term for people, places, and things represented in the semiosis (Kress; Van Leeuwen, 2021, p. 45, 113–5).

However, the authors do not provide specific measures to determine, for example, what is "maximally light" or "maximally black" (Kress; Van Leeuwen, 2002, p. 355).

This means that the analyzes may depend largely on perception, which does not always provide the most accurate representation of the colors of the image (Figure 1). In addition, in some cases only a few particularly salient colors are fully discernible, which can turn the categories into contrasts rather than scales. For example, different screens (e.g., computer monitors and cell phone screens) can slightly alter the colors displayed, which can affect how we interact with colors and, more importantly, how we analyze them.

Figure 1 – Hue examples



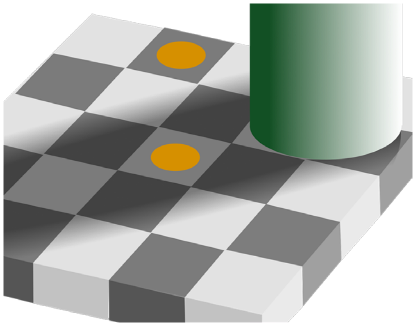
Source: Created by the authors.

Figure 1 shows four sets of colors that we have created using four color wheels based on Rhyne (2017, p. 33). The first is the original file, while the other three simulate color deficiencies (from left to right): Protanope, Deuteranope, and Tritanope. To most people, all four wheels will look different, while some people[5] will have difficulty perceiving the differences between the first wheel and the other three.

Even outside of color deficiency, other factors can affect color perception, such as lighting conditions, positioning of the color, or what we focused on previously. This is particularly noticeable in optical illusions, such as the example in Figure 2.

[5] According with the NHS (National Health Service), 1 in 12 men are and 1 in 200 women have some type of color vision deficiency.

Figure 2 – Optical illusion



Source: Wikimedia commons (2007).

The two Orange spots are the same color, but we perceive them differently (we might say one is darker than the other). Unlike the naked eye, software such as GIMP, as we will demonstrate, can show us not only that they are the same, but also what they are in terms of Saturation, Brightness, and so on.

These factors illustrate the complexity of color and color analysis. Kress and van Leeuwen's scale approach is one way to account for the idiosyncrasies of color, although it does not present specific methods for accurately analyzing color data. However, we should remember not to downplay the role of perception in the semiotic process. Most people who interact with images (whether on the internet or on print media) will not have these tools to properly measure what color is. Designers, however, have a deep understanding of how color works and how to use it to convey what they want to communicate. Just as Kress and van Leeuwen (2021, p. 238) inform us about the deeply material history of color, we argue in this article that to understand the current semiotics of color, we must understand the processes by which they are created.

With this in mind, we propose categories and methods that allow us to quantify and systematize the properties of color, particularly in digital media. With the aid of color theory, we can better understand what colors are and how they work. Using GIMP and ImageMagick, we can describe the various parameters that make up colors. Thus, we can effectively use the distinctive feature's scales to analyze the meaning potential of colors. Therefore, our proposal introduces concepts and methods currently used by sign makers, which allows us to generate hypotheses based on tools used in the semiotic process. This opens the door to comparable and reproducible results for color analysis, which is particularly useful for understanding the use of color by different groups in different contexts.

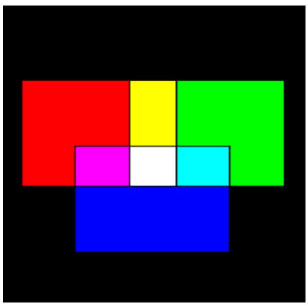
3 Basic concepts of color theory

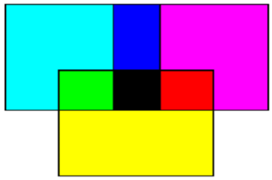
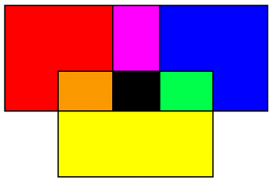
From the perspective of color theory, the concept of the color model is particularly important. According to Rhyne (2017, p. 1), a color model is "a structured system for creating a full range of colors from a small set of defined primary colors." Also,

> There are three fundamental models of color theory. […] these models are as follows: (1) the Red, Green, and Blue (RGB) color model of lights and display originally explored by Isaac Newton in 1666; (2) the Cyan, Magenta, Yellow, and Key Black (CMYK) model for printing in color originally patented by Jacob Christoph Le Blon in 1719; and (3) the Red, Yellow, Blue painters model fully summarized by Johann Wolfgang von Goethe in 1810 (Rhyne, 2017, p. 1).

In Table 2, we briefly summarize these three models:

Table 2 – The color models

Color model	Description	Visual representation
RGB	"The RGB color model assembles the primary lights of Red, Green, and Blue together in various combinations to produce a broad range of colors […]. The RGB color model is termed as an additive color model in which the combination of the Red, Green, and Blue primary lights produces White light […] The RGB color model is used in various technologies producing color images, such as conventional photography and the display of images in electronic systems" (Rhyne, 2017, p. 1).	

Color model	Description	Visual representation
CMYK	"The CMYK color model is designed to support color printing on White article. The CMYK color model is termed as a subtractive color model in which the starting point begins with a White or light surface. Color pigments Reduce the reflection of the original White light. The color inks thus subtract from the original White surface. Typical output devices for the CMYK color model include color inkjet, laser, and dye-sublimation printers" (Rhyne, 2017, p. 5).	
RYB	"The RYB color model is a subtractive color model for mixing painting pigments […]. Starting with White paper, RYB color pigments when combined together yield Black, similar to the CMYK color model […] The RYB color model is used in the arts and arts education" (Rhyne, 2017, p. 7).	

Source: Created by the authors. Images adapted from Rhyne (2017, p. 2).

Since we will be using a digital *corpus*, we will focus mainly on the RGB system. First, we can visually represent colors on a *color wheel*, which we can use to analyze how hues relate to each other (Rhyne, 2017, p. 79). We can represent the RGB and CYMK models with the same color wheel[6], while the RYB model is different from the two, as shown in Figure 3:

[6] As seen in the visual representations in Table 2, the RGB and CYMK models are complementary, since their primary and complementary colors are the same but inverted for each model (Rhyne, 2017, p. 82).

Figure 3 – Color wheels

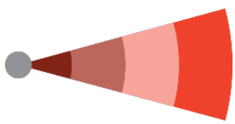
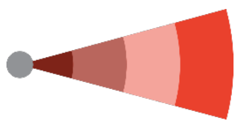
Color wheels for RGB and CYMK   Color wheel for RYB

Source: Adapted on Rhyne (2017, p. 83).

Both wheels present *hues*[7], *tints*, *tones*, and *shades*. In the outer area are the *hues*, the purest, most saturated colors. *Tints* are hues mixed with *white* and are placed next to them. *Tones* are mixed with *gray* and are placed in-between tints and *shades*, hues mixed with *black*. The innermost region is the neutral gray (Rhyne, 2017, p. 83-5).

The color wheel allows us to detect *color harmonies*. Kress and van Leeuwen (2021, p. 238) mention the concept but do not elaborate on it. Harmonies are a way to systematize how colors can work well together based on a main (or key) color (Rhyne, 2017, p. 86). In Table 3, we present the possible color harmonies for both color wheels, using Red as the main color:

Table 3 – Color harmonies

Color Harmony	RGB/CYMK color wheels	RYB color wheel
Monochromatic: a harmony between a hue and its tints, tones, and shades (RHYNE, 2017, p. 87).		

[7] We will utilize the term "hue" to refer to one of color's distinctive feature as well as to pure colors.

Color Harmony	RGB/CYMK color wheels	RYB color wheel
Analogous: a harmony between three colors adjacent to each other, of which the middle one is the main color (Rhyne, 2017, p. 88).		
Complementary: a harmony between one color and the color opposite to it in the color wheel (Rhyne, 2017, p. 89).		
Split complementary: a harmony between the main color and the two colors adjacent to its complementary color (Rhyne, 2017, p. 90).		

Color Harmony	RGB/CYMK color wheels	RYB color wheel
Analogous complementary: a harmony between the key color and an analogous harmony of its complementary color (Rhyne, 2017, p. 89).		
Double complementary: a harmony between two adjacent colors and their respective complementary colors (Rhyne, 2017, p. 92).		
Tetrad-Rectangular: a harmony between four equally distant colors (Rhyne, 2017, p. 93).		
Tetrad-Square: a harmony between four equally distant colors, three steps from each other (Rhyne, 2017, p. 94-5).		

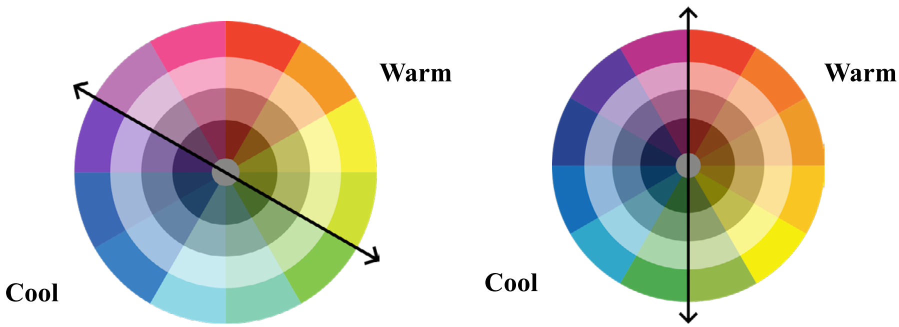
Color Harmony	RGB/CYMK color wheels	RYB color wheel
Diad: a harmony between two colors, two steps from each other (Rhyne, 2017, p. 95).		
Triad: a harmony between three equally distant colors (Rhyne, 2017, p. 96).		

Source: Created by the authors. Images based on Rhyne (2017).

In addition, the color wheel provides a visual representation of *warm* and *cool* colors (Figure 4), which also influences the relationship between colors and their potential for meaning:

> The color wheel can be divided into warm and cool colors. In general, Green, Blue, and Purple are defined as cool colors, while Yellow, Orange, and Red are grouped as warm colors. Warm colors tend to advance and expand in space. Cool colors tend to recede and contract in space. White, Gray, and Black are considered to be neutral in this regard. As a result, colors can have physiological and psychological effects on people (Rhyne, 2017, p. 85).

Figure 4 – Cool and Warm colors



Source: Adapted from Rhyne (2017, p. 86).

The meaning-making potential that arises from color harmonies and the dichotomy of cool and warm colors is expansive. For example, complementary harmonies can be linked with associative affordances, such as Red contrasting with Blue and Cyan (e.g., in a contrast between fire and water). They can also lead to what we might call "emergent meanings," or new possibilities based on the properties of colors. For example, in Matumoto (2022b), we discussed how the games *Aero Fighters 2* (VIDEO SYSTEM, 1994), *Sonic Wings 2* (VIDEO SYSTEM, 1996), and *Strikers 1945 II* (PSIKYO, 1997) use color harmonies to make Brazil stand out among the other countries, reinforcing the representation of Brazil as a forest in contrast to the representation of most other countries in the game.

Cool and warm colors evoke associative meanings simply by their names. They also have practical uses, for example in interior design: warm colors are perceived as closer, while cool colors are perceived as further away. We can use this to make a room seem more inviting, cozy, or spacious and relaxing, depending on the "temperature" of the color used.

Apart from the color wheel, we can represent web colors (colors for digital applications) by their *RGB values* or in *hexadecimal format* (HEX triplet) (Rhyne, 2017, p. 66). RGB values refer to the values of Red, Green, and Blue, from 0 (lowest value) to 255 (highest value), that each color has for each of these three parameters. The HEX triplet "is a six-digit and three-byte hexadecimal number used to represent a color"

(Rhyne, 2017, p. 67). See Table 4 for a range of colors and their RGB values and HEX triplets.

Table 4 – Examples of RGB values and HEX triplets

Color	RGB values	Hex triplets
	255, 0, 0	#FF0000
	0, 255, 0	#00FF00
	0, 0, 255	#0000FF
	255, 0, 100	#FF0064
	0, 100, 0	#006400
	50, 150, 255	#3296FF
	100, 90, 90	#645A5A
	255, 255, 255	#FFFFFF
	0, 0, 0	#000000

Source: Created by the authors.

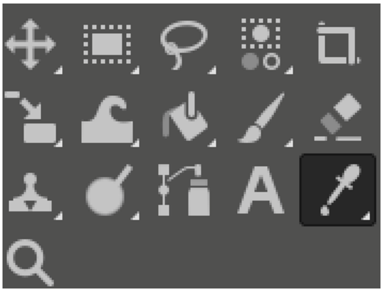
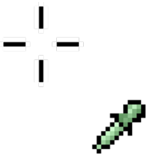
We represent the RGB notation of a color as three values separated by commas. The first refers to the value of Red, the middle to the value of Green, and the last to the value of Blue. This means that the RGB color space includes a total of 16,777,216 colors (or 256 to the 3rd power). In Table 4, we have modulated different values of each parameter to create nine RGB configurations. The first three are each pure Red, Green, and Blue, while the next three are mixtures. The seventh has no dominance between the three parameters, resulting in a grayish color. The last two have equal values for all three parameters but do not result in gray. This is because the lowest possible RGB values result in pure black, while the highest result in White. The HEX triplets represent the same information, but in a way that is easier for computers to process[8]: the first two digits refer to Red, the middle two to Green, and the last two to Blue.

[8] Cf. Rhyne (2017, p. 67) for a summary of how to read HEX triplets.

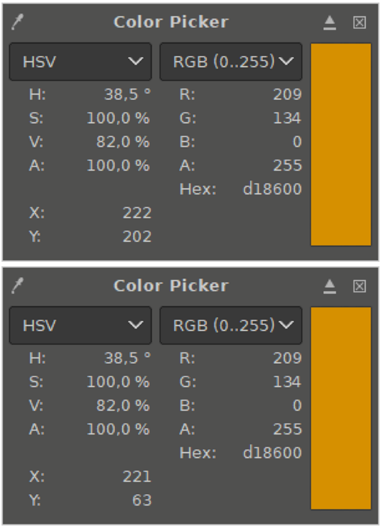
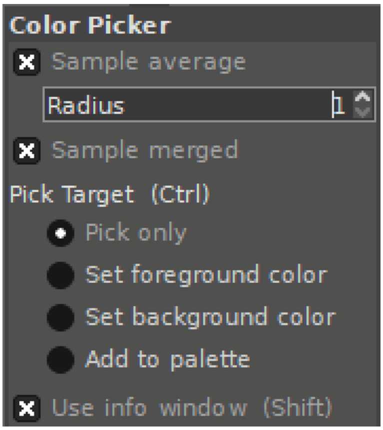
4 Analyzing colors with GIMP and ImageMagick

An in-depth analysis based on RGB values and HEX triplets makes it possible to precisely locate the colors under investigation. For this purpose, the Color Picker Tool[9] in GIMP can be used to collect this type of data (Table 5).

Table 5 – Color picker tool on GIMP

Image	Description
	In the Toolbox of GIMP (on the left side of the program) we will find several tools10, including the color picker tool (highlighted by a gray box).
	When we select it, the cursor turns into an eyedropper and crosshairs. If we click on the place where the crosshairs point, a small window will open.

[9] Whenever we introduce a new tool or option, we will provide a link to the GIMP Team Documentation Page, which describes the tool and how to use it.
[10] Tools with a small triangle in the bottom-right corner are swappable with a related tool by right-clicking its icon. In the color picker's case, we can swap it for the measure tool, which functions similarly to a ruler.

<table>
<tr><th>Image</th><th>Description</th></tr>
<tr><td>
</td><td>In this window, we will find several pieces of information. In the columns, the researcher can choose which color model to display. In this case, the left column is the HSV color space and the right column is the RGB model. HEX refers to the HEX triplet, and finally, X and Y refer to the coordinates of the selected pixel. Pixels are the smallest units in digital images.
We return to Figure 2 to verify that the two Orange spots are indeed made up of the same color. The difference between the examined pixels is their positions (X and Y values).</td></tr>
<tr><td>
</td><td>If we want to sample more than one point (or pixel) of the image, we can select the sample average option in the Tool options, which are located under the Toolbox by default. The Radius options refer to the area that will be sampled by the tool.
When this option is selected, GIMP displays the average color of the selected area instead of the exact pixel selected.</td></tr>
</table>

Source: Created by the authors.

Using the color picker tool of GIMP, we can identify specific colors in the composition or select a group of colors to determine the overall color in a specific area of the image. This means that we do not have to consider colors as a comparative category, in the sense that Hue, Saturation, Brightness, etc. are understandable and quantifiable on their own, not in comparison to the rest of the composition.

The HSV (Hue, Saturation, and Value) and the HSL (Hue, Saturation, and Lightness) are three-dimensional representations of the RGB color model[11] (Rhyne, 2017, p. 58). In Table 6, we briefly discuss the individual parameters:

Table 6 – HSV and HSL color spaces

Parameter	Description
Hue	Refers to color gradations shown in a circle that begins and ends at the color Red, at 0 degrees. The color wheel shown earlier follows this organization, and starting from Red, Cyan, for example, is at 180 degrees, directly opposite to Red (Rhyne, 2017, p. 61).
Saturation	Refers to the distinction between a particular hue and the neutral gray in the center of the color wheel, where no hue dominates. For this reason, the purest and most saturated colors on the color wheel are in the outer areas farthest from the center (Rhyne, 2017, p. 61).
Value	Refers to the brightness of a particular hue and varies with Saturation in the HSV color space. It ranges from 0%, pure black, to 100%, colors are present (Rhyne, 2017, p. 62).
Lightness	Refers to the degree of illumination of a given Hue in the HSL color space. It ranges from 0%, or no light, to 100%, or full illumination (Rhyne, 2017, p. 62).

Source: Created by the authors.

If we return to the example in Table 5, we find in the left column the HSV description of the Orange used in the image: for Hue, it is 38.5º (Figure 5) of Red; for Saturation, it is 100, since it is a pure color; and finally, for Value, it is 82%, which means that it is not a totally light color.

As for Lightness, we can use the following mathematical formulas to calculate the Lightness of a color (Saravana; Yamuna, 2016, p. 464):

[11] Cf. Rhyne (2017, p. 63-66) for a discussion regarding both models and their visual representations.

$$R' = \frac{R}{255}; G' = \frac{G}{255}; B' = \frac{B}{255}$$

$$C_{max} = MAX\,(R', G', B')$$
$$C_{min} = MIN(R', G', B')$$

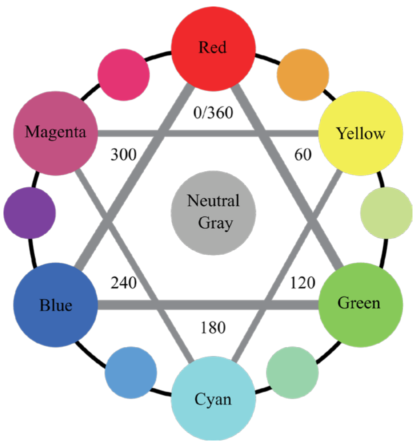
$$L = (C_{max} + C_{min})/2$$

The first three equations convert the RGB values from a scale of 0..255 to a scale of 0..1. We will again use the example from Figure 2. Since we need the maximum and minimum values of RGB, we omit Green and use only Red (209/255 = 0.81) and Blue (0/255 = 0). We can now use these values in the last equation:

$$L = \frac{0.81 + 0}{2}$$

This gives us ≈ 41%. So the Lightness of #D18600 is 41%. For comparison, #FFFFFF (pure white) has a Lightness of 100% and #000000 (pure black) has a Lightness of 0%.

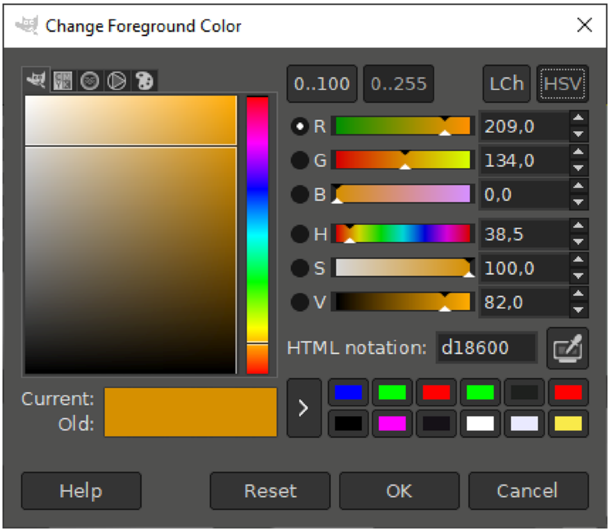
Figure 5 – Diagram of hue or color wheel



Source: Adapted from Rhyne (2017, p. 61).

Furthermore, the FG/BG Color tool allows us to visualize and edit these data (Table 7).

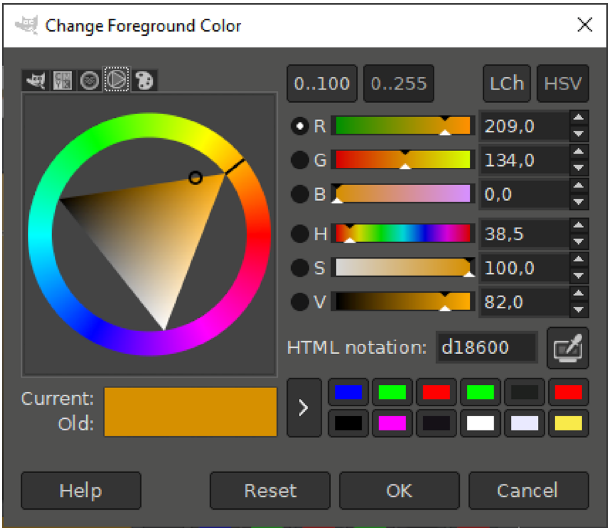
Table 7 — FG/BG Color



The FG/BG Color menu contains several relevant data points. By default, on the right side, we can check the RGB and HSV values of the color, both on a scale from 0 to 100 and on a scale from 0 to 255. The "HTML Notation" refers to the HEX triplet of the color. Note that it has no hashtag (#) at the beginning.

On the left, GIMP displays a visual representation of the image's Saturation by default. The Hue scale is in the thinner colored column, while the Saturation and Value scale is shown in the rectangle right next to it. The value increases on the Y-axis, while the Saturation increases on the X-axis. For example, in the upper left corner (in white) is 0 for Saturation and 100 for Value, while in the lower right corner is 100 for Saturation and 0 for Value.

The currently displayed color is the Orange from Figure 2, indicated by the crosshairs on the rectangle and the line on the thinner column.



GIMP presents four other visual representations: CYMK, Watercolors, Wheel, and Palette. In this article, we will focus on the wheel representation.

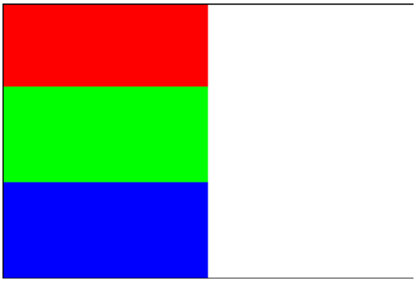
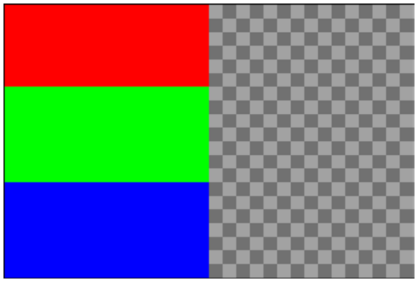
The outer ring represents Hues that vary on a 360-degree scale. The inner triangle, in turn, represents Saturation and Value. Saturation scales vertically, while Value scales horizontally.

This visual representation is particularly useful for determining color harmonies.

Source: Created by the authors.

One last parameter that the color picker tool of GIMP displays is the Alpha channels. For some images, it is possible to display a range from transparency (0%) to total opacity (100%). For example, images in jpg (Joint Photographic Experts Group) format do not support transparency and instead show a color, often white, in the background, while images in png (Portable Network Graphic) format can (Table 8).

Table 8 – jpg vs. png

	
Saved in the jpg. format, the image displays the missing part as white.	Saved in the png. format (and with the alpha channels enabled), the image displays the missing part as transparency (shown as a gray pattern).

Source: Created by the authors.

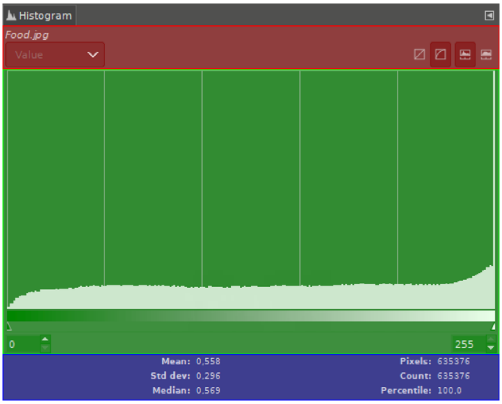
Transparency is not limited to alpha channels, but it is important to note that we can analyze it via GIMP just as we can the other color features.

For a more comprehensive color analysis, we can use the histogram from GIMP. A histogram is a graphical representation of the distribution of data for a given variable. The Histogram (found in Windows → Dockable dialogues[12]) represents "the statistical distribution of color values" (GIMP Documentation Team, 2023, s.p.) and provides options for Value (brightness distribution), Red, Green, and Blue (intensity distribution per RGB channel), and alpha (opacity distribution). In Table 9 we discuss the histogram based on a stock image.

[12] Whenever we show a tool's path, we will highlight it in gray. The path will start from the menu bar on GIMP's upper part. We will also highlight options present in GIMP.

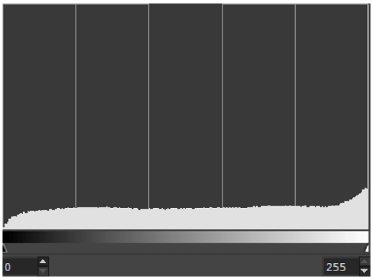
Table 9 — Histogram in GIMP

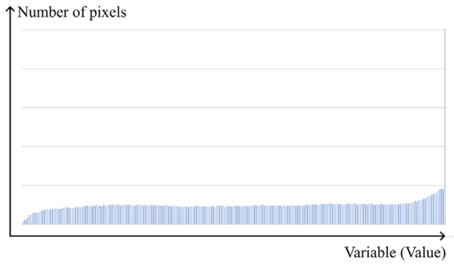
We will use an image from the Microsoft 365 library. The image shows a colorful arrangement of fruits and vegetables.



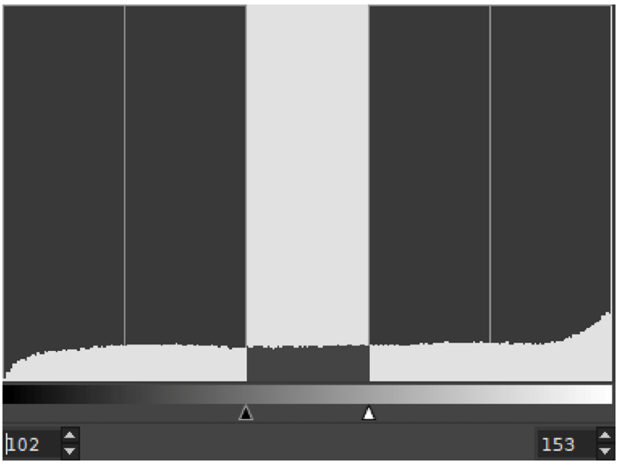
We can see the full histogram in the figure above. For simplicity, we divided the window into three parts, described as follows.

In the upper area (red) we can change which channels the histogram displays (Value, Red, Green, Blue) and the display mode: linear, which is useful for photos, or logarithmic, which is useful for images that "contain substantial areas of constant color" (GIMP Documentation Team, 2023, s.p.). We can also change the histogram display from linear to perceptual space. Here we will use the perceptual space and the linear display.

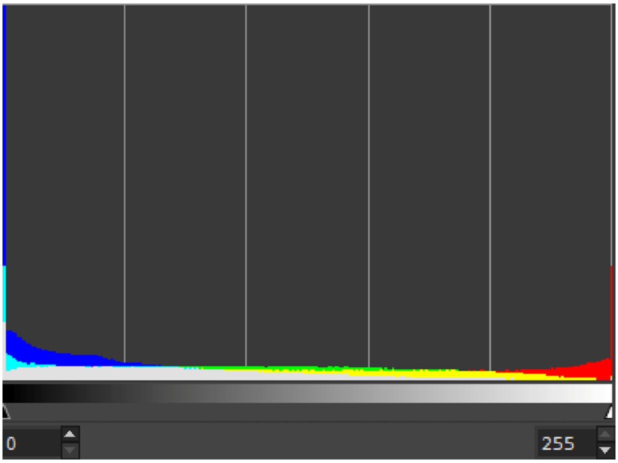




In the middle (Green) we see the actual histogram. On the left, we show how it appears on GIMP, while on the right we show the same data as a graph. The horizontal axis (X) scales from 0 (black) to 255 (white). In this example, we used “value” as the variable. This means that we have a scale from the lowest to the highest Value (“brightness”). The vertical axis (Y) shows the number of pixels for a given value. For example, 4% of the pixels of the image have a Value of 255, which means they have the maximum brightness.



If we need to check how many pixels are in the range of a value, we can select a section of the histogram. In the example above, we select the range from 102 to 153 of Value. The range is highlighted in white and below it the exact selection is displayed numerically.

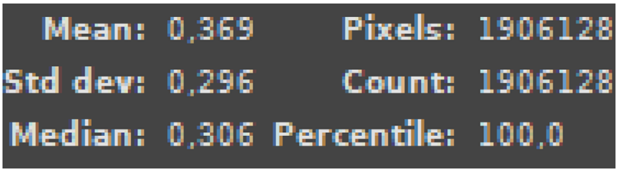


If we select the RGB option, GIMP shows the Red, Green, and Blue channels and how they overlap. White are the areas where all three overlap, while the Red, Green, and Blue areas show where these colors do not overlap. GIMP also shows the overlap of two colors:

Red + Blue = Magenta
Red + Green = Yellow
Blue + Green = Cyan

It is worth mentioning that these values are not the colors themselves, but their respective parameters of Red, Green, and Blue individually. This means that, for example, for a color composed of (100, 0, 255), each parameter is plotted in the histogram.

In the case of the image, Red is particularly present at the upper end of the scale, while Blue is most present at the lower end of the scale. Green accents can also be seen in the middle of the scale. Thus, we can see that Red and hues close to it (yellow, orange etc.) are substantially more saturated than other hues. This is due to the fact that, overall, red composition (closer to 255) is more prevalent than Green or Blue, a fact that may not be easily discernible with mere perception.



Finally, in the lower area, we will find various statistics and other information. In Pixels, GIMP shows the number of pixels in the image, while Count shows how many pixels are in the selected area. Percentile refers to the percentage of pixels in the selected range.

Median refers to the middle value in the selected range, while mean indicates the average value. Finally, Std dev refers to the standard deviation of the selected range or how homogeneous the distribution of values in the selected range is (GIMP Documentation Team, 2023, s.p.), which can be used in research as an indicator of the color purity of the composition.

GIMP automatically converts its values to a number from 0 to 1, to the thousandth digit. These values represent the scale from 0 to 255 — the scale visually represented by the histogram. For example, 0.369 corresponds to 94.095 on a scale of 255, which means that the RGB value of the image averages 94 (out of 255).

The standard deviation, simply put, indicates how much is the average dispersion from the mean. In our case, it is 0.296. If we were to plot the data on a graph, for example, we could calculate one standard deviation below the mean (0.369 - 0.296 = 0.073) and one standard deviation above the mean (0.369 + 0.296 = 0.665), which would give us an interval of $0.073 \leq x \leq 0.665$.

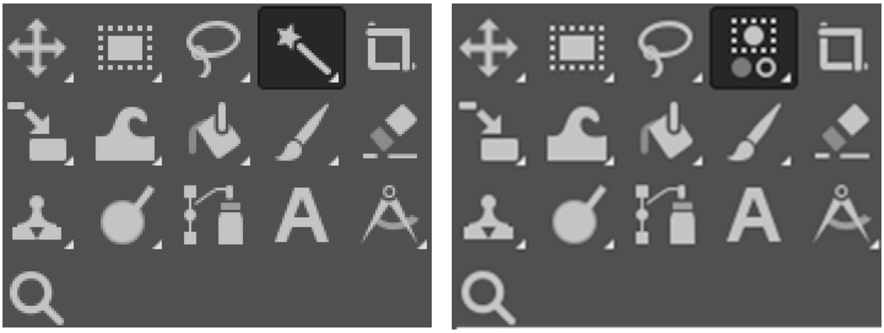
Thus, the higher the standard deviation, the higher the hybridity of the colors, whether from the total set (RGB) or for each channel individually.

To visualize how each channel affects the image, we can use the Hue-Saturation tool (Colors → Hue-Saturation...). The GIMP tool lets you edit the Hue, Lightness, and Saturation of the primary RGB colors and the complementary colors (Cyan, Magenta, and Yellow). This allows us to locate areas of interest for each color. It should be noted, however, that depending on the colors used, we may also select colors that fall between a primary and a complementary color. In the image to the left, we desaturated all colors except for the Yellow hue, whose Saturation was set to maximum. This highlights the Yellow areas and some colors between Green and Yellow, and between Yellow and Red. If we do the same process but saturate Red and Green to the maximum, we can see how they relate to Yellow.

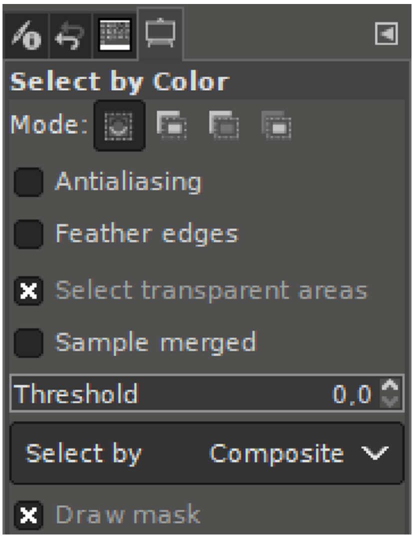
Source: Created by the authors.

The histogram can give us a quick overview of the image and its dominant channels. It can also be used in conjunction with the Select by color and the Fuzzy selection tools, both of which are included in the Toolbox. These tools allow us to select a specific color in the image: The first tool selects all instances of a particular color, while the second selects a delimited area where the color occurs. In the histogram, GIMP shows how many pixels (both in *count* and *percentile*) are allotted to the selected color. These tools also have a threshold option. By default, this is set to 0, which means the tool will only select the exact color we clicked on. If we increase the threshold, GIMP will average and select colors similar to the selected one, as shown in Table 10.

Table 10 – Select by color tool



We have highlighted both tools in the figure above with a dark box. We can change them by right-clicking on their icons. The magic wand icon points to the Fuzzy selection tool, while the square icon points to the Select by Color tool.



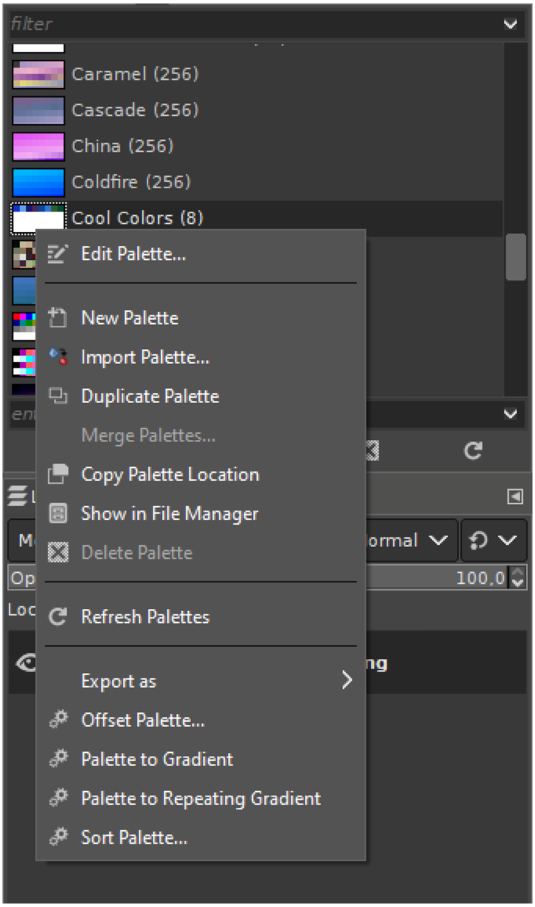
Both tools offer almost identical options. Relevant to this article is the threshold scale mentioned earlier and the drop-down menu directly below it. In it, the researcher can choose which parameter GIMP should use to select colors, such as Red, Green, and Blue values. By default, the “Composite” parameter is used, which takes into account the overall composition of the color.

When the Histogram tab is open, we can right-click on the image and go to Select → All (Select all), which will select all pixels in the image. In our example, the image has 1,906,128 pixels.
We then use the Select by Color tool (with a threshold of 75) and click on a Yellow pixel in the image. The selected area is outlined with dashed lines. The histogram (in *pixels*) shows how many pixels we have selected. In our case, it is 193,011 pixels, or about 10% of the entire image.

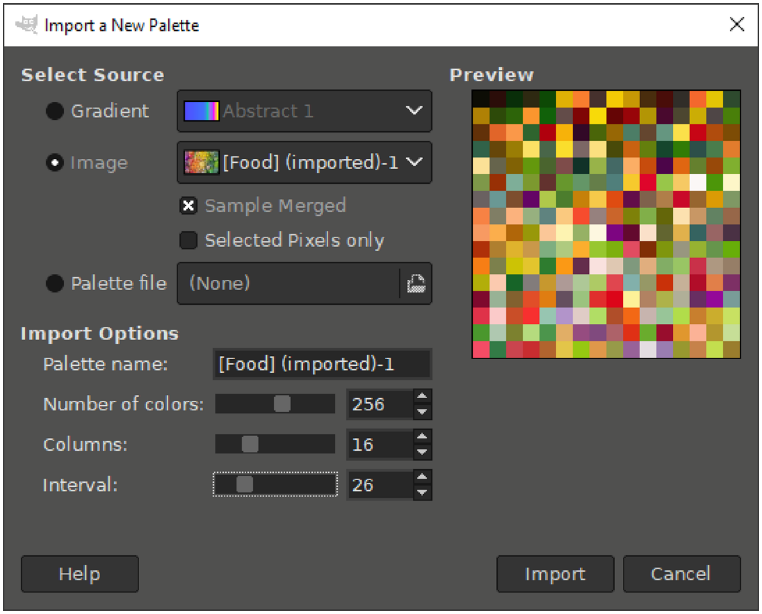
Source: Created by the authors.

Another important tool for color analysis is the Palette Import and Editor (Windows → Palettes). GIMP allows the researcher to import colors from any image and in this way create a palette based on the imported colors. In Table 11 we briefly describe the process.

Table 11 — Importing palettes in GIMP



If we right-click on one of the palettes preloaded with GIMP, the Import Palette... option is displayed.



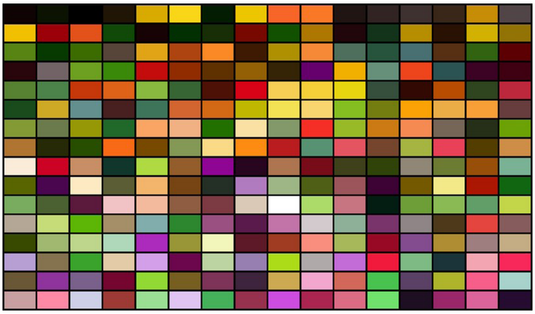
In the Import New Palette menu, we can import from an already created palette or from an image (second option).

In the import options we can choose how many colors the palette should contain (up to 10,000), how many columns the palette should display, and finally we can group colors with the Interval option. Although the limit is 10,000, it may not be possible to load all colors. Since a small change in the parameters will change the color, the image may contain several similar colors, which GIMP will add to the palette individually. Therefore, increasing the interval value will display an average color generated from a set of similar colors (GIMP Documentation Team, 2023, s.p.).

In the Colorcube Analysis (Colors → Info → Colorcube Analysis), GIMP shows how many unique colors are present in the image. The software detects 388,632 unique colors in our image, which far exceeds the maximum capacity of the palette.

Therefore, we can convert the image — most likely in RGB format — to index colors (Image → Mode → Indexed...), which limits the colors to a maximum of 256.

Since GIMP tries to calculate an average value for the color of the image, it may change significantly. It is also important to note that due to the averaging of the image, the colors displayed may not exactly match the original colors, so it is not an accurate representation, but an overall view of the colors in the image.

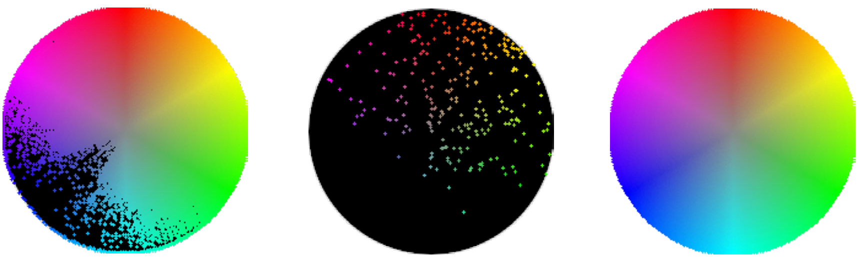


In our example, we converted the image to 256-indexed colors and then back to RGB. We then created a 256-color palette. If we double-click on the created palette, the palette editor window will open. In it, we can change the number of columns displayed and, most importantly, check the data of each color. If we double-click on one of the colors, the Edit Palette window will open, which looks exactly like the FG/BG Color window. Note that changes made in the Edit Palette Color will affect the created palette.

Source: Created by the authors.

Depending on the quality and/or complexity of the image, the palette may be more or less indicative of the overall color composition of the image. Another option is the Colour wheel analysis plugin by Rebecca (username rbreu), who also provides instructions for installing and using the plugin. We used this tool to create Figure 6 based on our example:

Figure 6 – Color wheel of the image

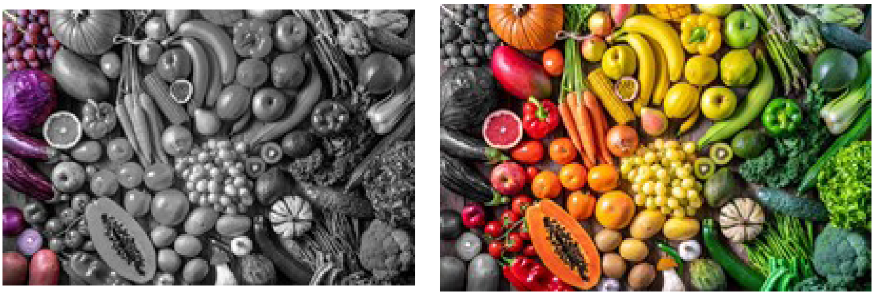


RGB | Index color | Full-color wheel

Source: Created by the authors.

The plugin maps the colors on a color wheel, which allows us to determine the color harmonies present in the image. As we can see, the image uses colors from almost all hues except Blue and its adjacent hues. It is worth mentioning that this refers to the image as a whole, so all the elements depicted are taken into account. GIMP allows us to delete parts of the image, which can be productive for color analysis (Figure 7). There are several ways to achieve this, for example, using Fuzzy Selection and Select by Color tools or the Paths and Free Selection tools.

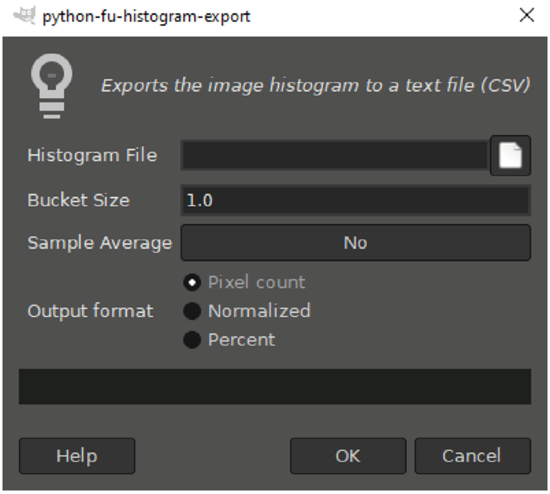
Figure 7 — Purple areas vs non-Purple areas



Source: Created by the authors.

For a quantitative approach to color, GIMP offers the possibility to export a text file of the generated histogram. Under Color → Info → Export Histogram... there are several options for displaying the information in a comma separated values (CSV) file. Table 12 describes the Export Histogram option and its output file.

Table 12 – Export histogram in GIMP



In histogram file, the user can select the location of the file.
"Bucket Size" "lets you control the number of values considered as similar and counted in the same 'bucket'. A higher bucket size will produce fewer buckets, and thus fewer rows in the exported file" (GIMP Documentation Team, 2023, s.p.).
Sample Average produces either a histogram of all image layers ("yes") or only the current layer ("no").
There are three options for the output format: Pixel *count* (pixels per bucket), *normalized* (pixels per bucket divided by the pixel count of the image), and *percent*, which does the same as normalized but displays the values as percentages (GIMP Documentation Team, 2023, s.p.).

Range Start	Value	Red	Green	Blue
0	9336	36513	84317	216677
16	39960	46834	52292	94719
32	37441	50903	43448	63539
48	41285	48659	41558	67666
64	36605	32875	53648	35025
240	90709	90030	3251	2502

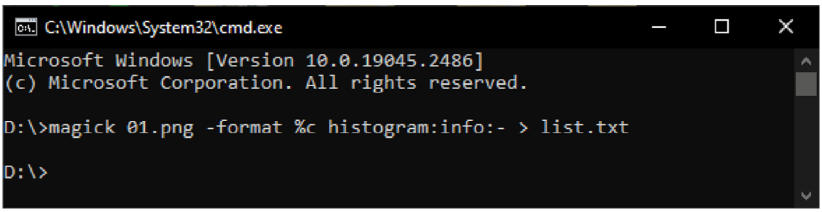
We can access the output file with programs like Microsoft Notepad or Notepad++, which is open source and free, but also with spreadsheet programs like Microsoft Excel. In the example on the right, we created the file with a bucket size of 16 and a Percent output. “Range start” refers to the value from 0 to 255 for each of the parameters. For example, the penultimate row with a “Range Start” value of 48 refers to the 49th bucket and includes all pixels between the values 48 and 63. Therefore, the last four numbers in row 48 in order mean that “41,285 pixels have a value between 48 and 63,” “48,659 pixels have a Red value from 48 to 63,” “41,558 pixels have a Green value from 48 to 63,” and “67,666 pixels have a Blue value from 48 to 63” (GIMP Documentation Team, 2023, s.p.). The last row ranges from 240-255, the most saturated colors. As can be seen, Red is the representative channel in this range.

Source: Created by the authors.

Depending on the resolution of the image, trying to determine the colors individually may be overwhelming with this tool. Alternatively, ImageMagick can be used to determine exactly what colors are present in an image and how pronounced they are, allowing the user to determine which colors are dominant.

Table 13 shows how to list the color composition of an image.

Table 13 – Color composition using ImageMagick



In Microsoft Windows, we can access the folder of the image. In the top bar Windows shows the path of the folder/file. On the left side, there is an icon for the folder. When we click on it, we can type "cmd" and press Enter. A window with a command prompt will open.

It lists the path to the folder of the image. We can then type: magick *image.ext* -format %c histogram:info:- > list.txt[13]. image.ext refers to the file name and extension of the image (png., jpg., webM., etc.), while list.txt refers to a plain text file containing the color information.

The filename in our example is 01, and its extension is .png. So the string becomes magick 01.png -format %c histogram:info:- > list.txt. After a few seconds, a file named "list.txt" appears in the image's folder.

127: (0,0,0) #000000 black
30: (0,0,2) #000002 srgb(0,0,2)
14: (0,0,4) #000004 srgb(0,0,4)
13: (0,0,5) #000005 srgb(0,0,5)
5: (0,0,7) #000007 srgb(0,0,7)
2: (0,0,8) #000008 srgb(0,0,8)
4: (0,0,9) #000009 srgb(0,0,9)
243: (0,1,0) #000100 srgb(0,1,0)
11: (0,1,2) #000102 srgb(0,1,2)
6: (0,1,3) #000103 srgb(0,1,3)
6: (0,1,4) #000104 srgb(0,1,4)
9: (0,1,5) #000105 srgb(0,1,5)

We can open the file with the standard Windows software Notepad or other text editors like Notepad++.

In the file, each line corresponds to a color in the following format: first, how many pixels correspond to the color; its RGB parameters; its HEX triplet value; and finally, its srgba value[14].

As it is, ImageMagick has mapped 388,577 colors. Most of them contribute little to the overall image, corresponding to less than 100 pixels out of 1,906,128. This is because, for example, a color characterized in RGB parameters as (224, 111, 232) is different from (224, 108, 232). Although they are hardly noticeable, ImageMagick considers them as different and therefore counts them as separate entries.

13 Code presented by user chas_prinz on Reddit https://www.reddit.com/r/GIMP/comments/rn8fyn/getting_colour_percentages_for_a_colour_indexed/

14 sRGB, or standard RGB, is a color space created in 1996 by Microsoft and Hewlett-Packard Company (RHYNE, 2017, p. 40).

Pixel count	RGB	HEX triplet	sRGB
9336	(0,0,0)	#000000	black
4434	(4,49,5)	#043105	srgb(4,49,5)
1770	(5,30,21)	#051E15	srgb(5,30,21)
6108	(6,30,4)	#061E04	srgb(6,30,4)
3847	(9,58,0)	#093A00	srgb(9,58,0)
11018	(14,20,4)	#0E1404	srgb(14,20,4)
16536	(16,7,5)	#100705	srgb(16,7,5)
1903	(18,104,18)	#126812	srgb(18,104,18)
2125	(19,55,45)	#13372D	srgb(19,55,45)

So we can use index colors to Reduce the number of colors and group these similar colors. We will now use 256 colors. Although the document is clearer this way, it can still be cumbersome to read.

To better analyze and organize the data, both on an RGB and index color basis, we can use Microsoft Excel. First, we can open the file in a text editor, use the *Find and Replace* function (Ctrl+F), go to the Replace tab, and replace all ":" (colon) with nothing (leave "*Replace* with" blank[15]). When we copy and paste the text lines, Excel will automatically divide them into different rows. We recommend leaving the first row blank. If the pasted data is in a single column, we can select all the rows and go to Data → Text to Columns. We first select *Delimited*, then click *Next*. Select "*Space*" from the *Delimiters* menu and then click *Next* and *Finish*. Excel will automatically split the data into columns. In the first row, we can now label each column (e.g. "Number of Pixels", "RGB", "HEX", etc.). Select the labels and go to Data → Filter. Excel now allows the researcher to filter the data, for example, by highest to lowest pixel count. This allows the researcher to determine, for example, which colors are dominant in the composition and better analyze the use of color in the image.

[15] We can also use the *find* and *replace* function on Microsoft Excel. However, Excel can incorrectly interpret the colon due to how to software reads data. It will then change the data shown.

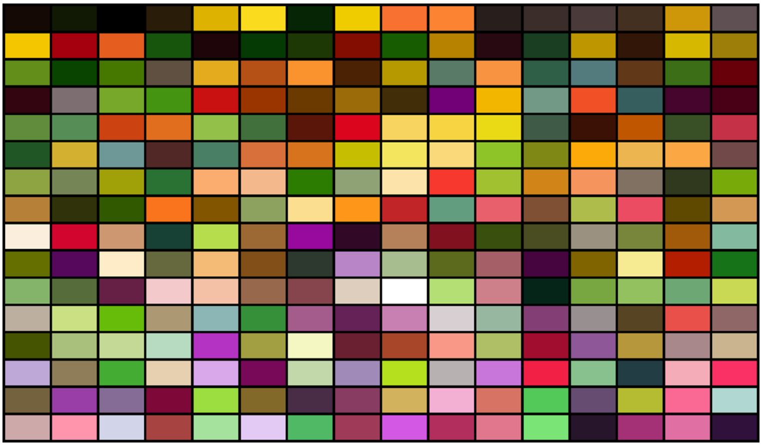
Pixel count	RGB	HEX triplet	sRGB
16536	(16,7,5)	#100705	srgb(16,7,5)
11018	(14,20,4)	#0E1404	srgb(14,20,4)
9336	(0,0,0)	#000000	black
6878	(34,22,8)	#221608	srgb(34,22,8)
6664	(217,170,0)	#D9AA00	srgb(217,170,0)
6433	(249,215,24)	#F9D718	srgb(249,215,24)
6108	(6,30,4)	#061E04	srgb(6,30,4)
6000	(236,198,0)	#ECC600	srgb(236,198,0)
5808	(247,102,40)	#F76628	srgb(247,102,40)

In our example, we can see that in the index colors, the following are the five most common colors in the image: (16,7,5), (14,20,4), (0,0,0), (34,22,8), (217,170,0). Excel can automatically sum the selected values. If we select the number of pixel values for these five colors, Excel will show in the lower right corner that they total 50,432 pixels. If we then select the entire column, Excel displays 1,906,128, the same number shown by GIMP. Using these values, we can see that the five predominant colors account for about 2.6% of the entire image.

We can then import this data into GIMP and create a palette for the dominant colors. Here we will select the 24 dominant colors from the image. First, we write a header in software like Notepad++ as follows:

GIMP Palette
#

After the hashtag, we need to insert the RGB values of the colors. These values must not be between parentheses and must be separated by a comma and a space. To speed up the process, we can use *Find and* R*eplace* to remove the parentheses and replace the commas (,) with a comma + space (,).
We can then import this file into GIMP using the Import palette... menu but instead of choosing an image as the source, we choose a palette file.



By default, GIMP arranges the colors from left to right according to their order in the txt. file. In this way, we get a visual representation of the colors by which occur most often.

Source: Created by the authors.

Color theory and software such as GIMP and ImageMagick can greatly enhance color analysis from a social-semiotic perspective. The categories presented here are consistent with Kress and van Leeuwen's approach, both in their names and in their descriptions. Thus, rather than creating new categories from scratch, we will use Rhyne's contributions to better adapt the features for digital color analysis in Table 14:

Table 14 – Color distinctive features revised

Distinctive feature	Description
Value	Refers to the scale from pure black (0% in HSV color space) to pure light (100% in HSV color space) (Rhyne, 2017, p. 62, Kress; Van Leeuwen, 2021, p. 245).
Saturation	Refers to the scale from pure colors (our hues) to neutral gray. On the color wheel, the most saturated colors are in the outer region. It is one of the parameters in both HSV and HSL color spaces and scales from 0% (no dominance) to 100% (pure color) (Rhyne, 2017, p. 61, Kress; Van Leeuwen, 2021, p. 245).

Distinctive feature	Description
Purity	Refers to a scale between the use of a single color and its hues, tints, tones, and shades (purity or monochromaticity) and a variety of analogous colors (hybridity) (Rhyne, 2017, p. 86, Kress; Van Leeuwen, 2021, p. 245).
Modulation	Refers to the degree of monochromatic modulation, i.e., the use of a register within a color or its variety of hues, tints, tones, and shades (Rhyne, 2017, p. 86, Kress; Van Leeuwen, 2021, p. 245).
Transparency	Refers to the scale from transparency to opacity. For some image extensions (e.g., png.), transparency can be quantified by *alpha levels*. For others, we detect it by color overlap (Kress; Van Leeuwen, 2021, p. 246).
Luminosity (or Lightness)	Refers to the degree of brightness of a color. In HSL color space, Lightness varies with Saturation from 0% (pure black) to 100% (presence of color) (Rhyne, 2017, p. 62, Kress; Van Leeuwen, 2021, p. 246-7).
Differentiation	Refers to the scale from monochrome registers to a full range of colors and harmonies (Rhyne, 2017, p. 86, Kress; Van Leeuwen, 2021, p. 247).
Hue	Hue in HSV and HSL color spaces varies in a 360-degree wheel, with 0/360 being Red. Hue can also be represented by its RGB configuration, i.e., how much Red, Green, and Blue are in the color. Finally, it can also be represented as a HEX triplet, which represents the RGB values in a hexadecimal format (Rhyne, 2017, p. 61, 66).

Source: Created by the authors.

5 Case study: color analysis of two stock images

We will comparatively analyze two images to demonstrate the methods presented here and discuss the potential for meaning in colors. We will again draw on the Microsoft 365 image database. We searched for the keywords "Europe" and "Africa" and obtained the results in Figure 8:

Figure 8 – Stock image for “Europe” and “Africa”

Source: Microsoft (2023).

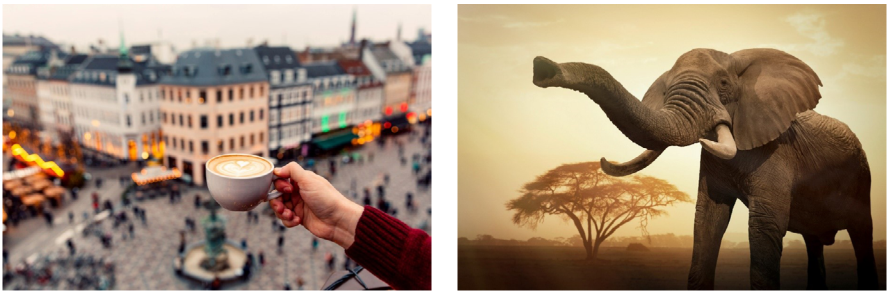
Searching for “Europe” yields 11 images, while searching for “Africa” yields eight images. An important difference between the results is the nature of the participants (Kress; Van Leeuwen, 2021, p. 45, p. 113-5): Europe is represented by people, cityscapes, natural landscapes, and animals, while Africa is represented mainly by animals and natural landscapes.

Although the sample size is small, this difference could be relevant in terms of how Europe and Africa are culturally defined and semiotically realized. For example, one of the “Europe” images depicts the Eiffel Tower, which references the image to France, while one of the “Africa” images depicts the Pyramids of Giza in Egypt. Both are recognizable images for their respective countries, but in the context of the stock images presented, they have different meanings. If we place the Eiffel Tower in a series with other landscapes, we can consider it as one representative of European architecture among others. Conversely, the pyramids are the only man-made structure in Africa, which, in addition to emphasizing natural landscapes, can create an associative meaning of Europe as a metropolitan, modern place, and Africa as a natural, ancient place.

In addition, we can determine the location of the 'Europe" results with relative precision, which means that we can more easily distinguish and recognize different parts of Europe. In the "Africa" results, on the other hand, the landscapes, apart from the pyramids, can only be identified as savannah. This represents Africa as a single landscape that is culturally recognized as a stereotypical image of "Africa," which in turn reproduces an ideological notion of the African continent, devoid of its many cultures and biomes.

This is significant in that while stock images are intended to be inherently neutral so that they are suitable for a variety of contexts and uses, there are nevertheless discourses that inform the semiotic choices employed, not necessarily from image to image, but based on the images chosen to represent a participant. Therefore, we will focus on two images (Figure 9), one for each set, and analyze how the colors used in both relate to discursive constructions of Europe and Africa.

Figure 9 – Selected images from each search result



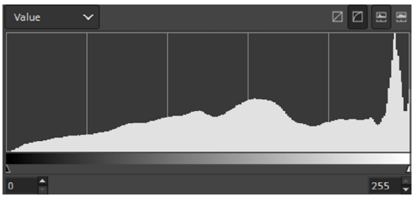
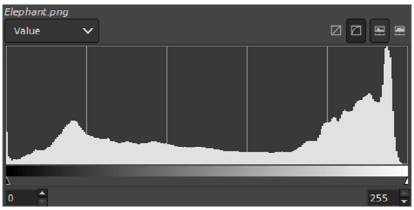
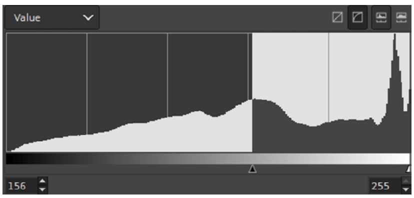
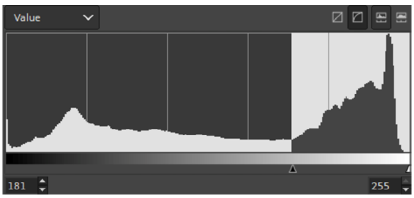
Source: Microsoft (2023).

The European image shows the Amagertorv (Amager Square) in Copenhagen, Denmark. The image depicts a person with a cup of coffee in the foreground and the cityscape in the background displaying several buildings, pedestrians, and the Stork Fountain in the center.

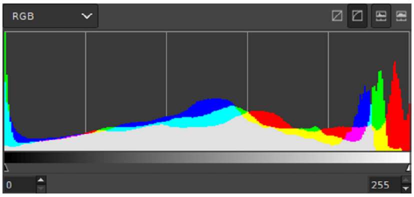
In the African picture, there is an elephant in the foreground. In the background, there is an acacia tree and some undergrowth. Based on these descriptors, we can assign the image to the savannah biome, one of the biomes where elephants live (Kingdon, 1997, p. 305), but we cannot identify a specific country.

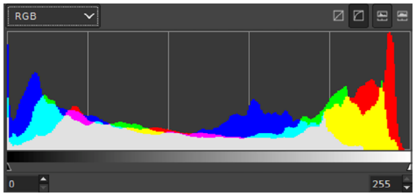
As for the use of colors, we can first analyze the images using the Colorcube analysis to determine the number of colors in each image, and the histogram to quantify the total values and RGB composition of the images (Table 15).

Table 15 — Histogram analysis

Europe	Africa
	
Number of unique colors: 1,040,592	Number of unique colors: 212,041
	
	

The Value ("brightness") - that is, the distinction between black and full color - tends toward the higher scale for both images. We used the scale selection to determine the range that accounts for 50% of the pixels of the images. According to the histograms, the elephant image has relatively more bright pixels than the city image. This means that although the elephant and the ground are darker than the background and make up a significant portion of the image, brightness prevails.





The RGB composition presents peaks for all three colors, as well as some mixtures (such as Yellow and Magenta). To understand how each channel modulates the composition, we can use the Hue-Saturation… tool.

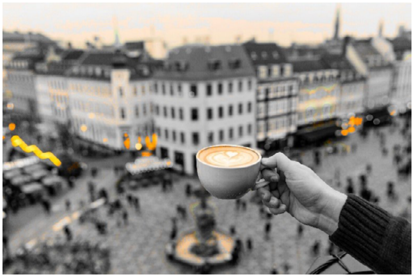
We have lowered the Saturation of all colors except Red and Yellow. To make the contrast between the two colors more visible, we inverted the hues so that Red became Magenta, and Yellow became Blue. As we can see, the image consists mainly of tones between Orange and Yellow. The presence of Green in the histogram represents Yellow, which is a mixture of Green and Red. Blue, on the other hand, is present because the light behind the elephant is almost white, that is, in RGB (255, 255, 255).

Red

Green

Blue

Cyan



Yellow

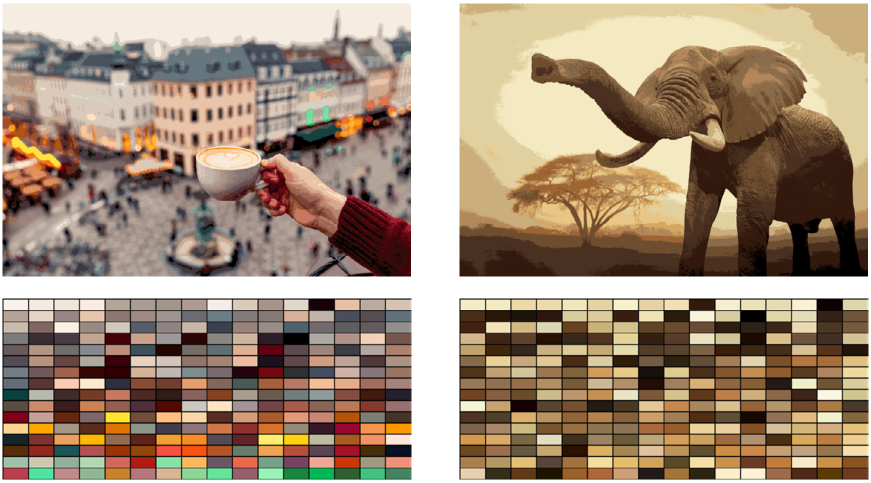
Magenta

In contrast to the elephant image, the city shows several colors. By desaturating all but one of the hues, we can determine where each color appears most strongly. Green and Magenta appear very sparsely; Blue, Cyan, and Yellow appear in specific areas, such as on rooftops. Red covers the entire composition.

Source: Created by the authors.

Furthermore, we can list the colors present on the image with GIMP's Index colors and ImageMagick. These tools yield the results displayed in Table 16.

Table 16 — Color quantification



Source: Created by the authors.

Based on this data, we can propose how color creates meaning in these images. As mentioned earlier, semiotic resources are simultaneously historically situated and motivated by sign makers during the sign-making process. This means that while there are some culturally established uses (e.g., Red as a sign of violence), we often need to consider the resource on its own terms and how it is used in this specific semiotic artifact.

In the case of the elephant image, there are two main hues: Orange and Yellow, as well as some intermediate hues (e.g., Yellowish Orange). Since they form a dividing line between the ground and the sky, we can interpret that this diad harmony (Orange ⇔ Yellow) creates a contrast between these two levels. On the other hand, since Orange and Yellow are close to each other, the meaning could be, conversely, that these two realms are similar and not opposite.

Orange, in turn, also covers the cityscape. We can likewise consider Blue and Cyan in the roofs and the stork statue as harmonious. Cyan-Blue is complementary to Orange, while Blue is complementary to Yellow. Thus, they form a double complementary harmony. This has two immediate effects on the image: first, the Cyan on the statue against the background of the overall Orange composition makes the statue stand out more, even though it is very small. Second, it creates layers in the image: The Blue and Cyan roofs separate the square and the buildings from the sky. Since their hues complement each other, a striking but harmonious contour is created for these two areas.

We can make some meaning hypotheses about the harmonies created, but as mentioned earlier, all the distinctive features work together to make a color effective. Therefore, we can analyze more features to make more meaning hypotheses. So far, we have been able to use Hues, Purity (number of colors), and Differentiation (number of harmonies) to establish possible opposing relationships that are likely or unlikely depending on how the other features work. So, we can analyze Saturation, Modulation, and Luminosity to better understand the images.

As for Saturation, we can use the index color to group the colors into a manageable number. We can also use the Color Picker tool to find the average Saturation of an area of the image. In Table 17 we provide the processed images.

Table 17 — Indexed colors

	
By using indexed colors and the Color Picker tool, we can group parts of the image and check Saturation. Saturation leads to different groupings: From the foreground to the background, the image becomes progressively less saturated; there is also an overlap in the middle area between the elephant's saturated head and the less saturated light in the background. Finally, the bottom and the legs of the elephants are also saturated (except for the black areas), which could confirm the dichotomy of the top and bottom areas of the image.	In the case of the cityscape, there are several Saturation spots, of which the Orange-Yellow lights are the most important. The high Saturation of these areas creates points of interest in the overall composition, especially since they contrast with the grayish tones of some of the buildings and the square.

Source: Created by the authors.

Interestingly, the sky in both images is almost white (255, 255, 255), which means that they have almost 100% Lightness. In the case of the elephant image, the sky looks like a light source, while in the case of the city image, it does not. Instead, the artificial lights look like standout lights.

This is due not only to the colors used but also to the composition. For example, the first image frames the skylight in the center, a salient area (Kress; Van Leeuwen 2021, p. 198), while the second image confines the sky to the upper area. In addition, the purity of the white color looks less interesting than the many colors in the lower areas, especially in the center, where the coffee cup, the building in the middle, and the statue directly below are located.

By combining Saturation, Lightness, and image composition, we can create and add to our hypothesis. First, Saturation adds three-dimensionality to the image of the elephant by adding a dichotomy of foreground and background in addition to the dichotomy of top and bottom. In the image of the city, on the other hand, Saturation highlights the artificial lights in different areas of the square. However, one of the effective areas of light in the city image, the sky, is not very noticeable.

We can now analyze the features of these two images comparatively: The modulation of multiple hues can create a "complex" image, as opposed to a "simple" image. In these cases, the contrast can come from the nature of what is being depicted (a city versus an animal), which can make the city be seen as more complex and desirable[13]. This is also supported by the fact that the same colors in the sky do not have the same effect, but an opposite one: The "natural" light of the city is not of interest, while the same light envelops the entire image of the elephant.

Considering this hypothesis, we can interpret that the diadic harmony in the elephant image creates a relationship of similarity, since

[13] We can point to a similar effect in the *Street Fighter II* game (Matumoto, 2022a). Both the Brazil stage ('scenario') and the US stage depict a waterfront location. However, color plays a key role in typifying (Barthes, 1973; 1977; Van Leeuwen, 2001, p. 95) — i.e., using stereotypes to create types rather than individuals — the people and architecture of Brazil, which are constructed as one and the same because both have a similar brown hue. The US stage, on the other hand, uses a variety of colors to individualize the people and separate them from the scenery. This creates a contrast between Brazil, an isolated and homogeneous space, and the US, an open and individualized, diverse space.

they are both natural participants, in contrast to the double complementary harmony in the city image, where the Blue and Cyan hues create a barrier between the city and the sky. This, in turn, is related to the discourses that envelop the stock images of "Europe" and "Africa": While the former is an amalgam of many landscapes while maintaining its metropolitan character, Africa is exclusively a natural or ancient landscape.

As we can see in this case study, colors provide multiple sources of meaning that can be analyzed individually or in combination. However, if we analyze a group of features, we can better determine which hypothesis the semiosis is most likely to point to. In addition, compositional resources can further enhance color analysis and vice versa.

6 Conclusion

In this paper, we have presented both analytical categories and methods for color analysis in digital media within a social-semiotic framework. Our theoretical contribution lies in the dialogue between the social-semiotic framework and color theory, through which we can analyze colors' features as a truly quantitative resource, i.e., we can classify each feature into a comparative scale. Besides, we provide methods that allow reproducible results for color analysis. Among recent works on color, we can cite Johannessen et al.'s (2021) "A Corpus-Based Approach to Color, Shape, and Typography in Logos", in which color analysis is based on Kress and van Leeuwen's distinctive feature approach. The authors also demonstrate their approach using Adobe Photoshop, although a discussion of how to use that tool is not their primary focus. By discussing how to use the free and readily available tools presented here, we hope to have shown how the analysis can be supported by the use of some quantitative approaches that provide a more systematic description of colors and their meaning potential.

As mentioned earlier, color presents a number of challenges for visual analysis. This is primarily because of how we interact with it. This means that designers need to understand both how color works and how audiences will interact with what they produce. Color is currently a sought-after resource outside of professional design as well: from Instagram (www.instagram.com) to Canva (www.canva.com), non-professionals are learning how to work with color in digital media, from photos to presentations.

Back to color deficiencies: Designers need to avoid color schemes that are difficult for some people to read. For example, according to Heron, Crameri, and Shephard (2021), scientific images can be misleading or inaccessible to some of the public because of the colors used, which are difficult for people with color deficiencies to read. This opens up the discussion of how meaningful colors are in different contexts and how we should pay attention to their use and analysis.

The fact that people are increasingly interacting with color, and that this interaction is mediated by digital media, necessitates semiotic methods based on these practices and media. In this sense, this article offers an example and a call for color analysis based on digital *corpora* and methods. In this regard, there are a number of other software besides GIMP and ImageMagick that can support research (e.g., https://inkscape.org/), and as mentioned earlier, we have not discussed all the possibilities of GIMP and ImageMagick. This means that social semiotics can be constantly revitalized and updated in line with its socially grounded approach to help semioticians understand the semiotic process and current trends.

Authorship statement

Both authors contributed extensively to all aspects of this article. André de Oliveira Matumoto was responsible for conceptualizing the study, conducting formal analysis, funding acquisition, performing investigations, developing the methodology, creating visualizations, and drafting the original manuscript. Paulo Roberto Gonçalves Segundo was responsible for conceptualization, funding acquisition, validating the findings, and reviewing and editing the manuscript.

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