A Model for Qualitative Colour Description and Comparison

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Abstract

A model for Qualitative Colour Description and Comparison (QCDC) is presented in this paper. Using Hue Saturation and Lightness colour space, qualitative colours are defined in general distinguishing *rainbow* colours, *pale*, *light*, *dark* colours and colours in the *grey* scale. The relational structure or the conceptual neighbourhood of our qualitative colour model is analysed and used to formulate a measure of similarity between colour names. This measure of similarity is proved to solve absolute and relative comparison of qualitative colours. Finally the cognitive adequacy of the QCDC model is analysed.

1 Introduction

Human beings have three types of cone cells or photoreceptors in the eyes that are often referred to as blue, green, and red, but that can be more specifically described as: short wavelength (S), medium wavelength (M), and long wavelength (L). Humans are trichromats and mixing these three colour wavelengths can distinguish a palette of around 1,000,000 colours [King, 2005].

However, a real fact in human cognition is that people go beyond the purely perceptual experience to classify things as members of categories and attach linguistic labels to them, and colour is not an exception: fresh blood and ripe tomatoes are all classified as *red*, even though they produce their own particular wavelengths [Palmer, 1999]. Humans also attach colours to objects and think about them qualitatively and as a constant: *white* wine, *blue* sea, etc. Even knowing that *white* wine is exactly *yellowish* or *golden* and that the sea is sometimes *grey* or *turquoise*. Moreover, as demonstrated by Conway [1992] in his research about colour naming in natural language: the basic colours that can be named by human beings are limited to about 10-20.

Therefore, although the physiology of the human eye can remind the RGB colour space, human beings are not aware of how wavelengths are perceived by the photoreceptors of their eyes, what they are conscious of is that they describe and compare colours by its name, that is, qualitatively. Furthermore, human beings have a relational structure of colours in the mind. As Palmer [1999] mentions: '*Without relational structure we would not experience different colours as being more closely related to each other (...) Nor would we experience grey as being intermediate between white and black; we would experience them only as different*'. Therefore, qualitative colours must be organized in a colour space for their comparison. And, according to Clark [1999]: '*To capture the entire gamut of colours that humans can perceive, one must construct hue circles of different lightness levels, from white to black, and then stack them one on top of the other. Each hue circle is two-dimensional with hue as the angular coordinate, saturation as the radius. The entire order is hence three-dimensional, with dimensions of hue, saturation and lightness.*' Therefore, the more suitable colour space to organize qualitative colour is Hue Saturation and Lightness (HSL).

A qualitative colour description can be easily understood and interpreted by human-users. Therefore, by using it, the user-machine communication in many applications could be enhanced. For example, a qualitative colour description can be used as part of a key search in image retrieval from data bases, and it can also be included in a user-interface both written and read aloud by a speech synthetizer application for blind and deaf users to understand. Moreover, a qualitative colour description can be assigned a meaning by relating it to an ontology and, in this way, it could be interpretable by intelligent web agents and also by robotic agents. However, how things are labelled is important because, as previously mentioned, sometimes naming can involve meaning. Therefore, how colours can be properly labelled in a general and adaptive way?

Comparing qualitative colours also allow intelligent agents to simplify colour similarity calculus because different hue, illumination and saturation values are assigned the same name, and two equal colour names are always considered as similar. Another problem appears when trying to compare two colour names. How can be defined how similar are *blue* and *purple* colours? Or which colour is darker, *grey* or *dark-blue*? Or which colour is yellowish, *orange* or *pink*? A solution to these questions is given in this paper by defining a model for Qualitative Colour Description and Comparison (QCDC) based on HSL colour space.

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The rest of the paper is organized as follows. Section 2 presents related work on colour naming and Section 3 explains related work on colour comparing. The model for Qualitative Colour Description (QCD) is presented in Section 4 and parameterized in Section 5. Then, Section 6 explains the relational structure of our QCD using a conceptual neighbourhood diagram that is used in Section 7 to define a similarity measure between qualitative colours. Section 8 uses the similarity measure defined to solve absolute and relative qualitative colour comparisons. Section 9 outlines the cognitive adequacy of the QCDC model and finally, in Section 10, conclusions are explained.

2 Related Work on Colour Naming

Colour naming models intend to relate a numerical colour space with semantic colour names used in natural language. Therefore, they are an effective and widely used way to support semantic-based image retrieval [Liu *et al.*, 2007].

In literature, different colour spaces have been used for colour organization: RGB (red, green and blue), HSL (hue, saturation and lightness), HSV/HSB (hue, saturation and value or brightness), HSI (hue, saturation and intensity), CIE (*Commission Internationale de l'Eclairage*) L*ab* or L*uv* (luminance L and chrominance *uv* or *ab*), L*C*H* (lightness, chroma and hue) or Munsell colour space [Nickerson, 1976], CIECAM02 (*CIE colour appearance model*) [Moroney *et al.*, 2002], HCL (hue, chroma and luminance) inspired from HSL and L*ab* [Sarifuddin and Missaoui, 2005].

Different colour naming models have been defined using these colour spaces. Menegaz *et al.* [2007] present a model for computational colour categorization and naming based on CIE L*ab* colour space and fuzzy partitioning. Van De Weijer and Schmid [2007] presented a colour name descriptor based on CIE L*ab* colour space. Mojsilovic [2005] presented a computational model for colour categorization and naming and extraction of colour composition based on CIE L*ab* and HSL colour spaces. Seaborn *et al.* [2005] defined fuzzy colour categories based on Musell colour space (L*C*H). Liu *et al.* [2004] converted the dominant colour of a region (in HSV space) to a set of 35 semantic colour names some of them related to natural scene images like *sky blue* or *grass green*. Stanchev *et al.* [2003] defined 12 fundamental colours based on the L*uv* colour space and used Johannes Itten theory of colour to define light-dark contrast, warm-cold contrast, etc. Corridoni *et al.* [1998] presented a model for colour naming based on the HSL colour space and also introduce some semantic connotations as *warm/cold* or *light/dark* colours. Lammens [1994] presented a computational model for colour perception and colour naming based on CIE XYZ, CIE L*ab* and NPP colour spaces. Berk *et al.* [1982] defined the well-known Colour Naming System (CNS) that quantizes HSL space into 627 distinct colours: the hue (H) value is quantized into 10 basic colours and saturation (S) and lightness (L) are adjectives signifying the richness and brightness of the colour.

All these studies have inspired our model for qualitative colour description which has been defined in a general way on a HSL colour space and can be adapted to the requirements of any application.

3 Related Work on Colour Similarity

Different colour pixel similarity measures have been defined, each one related to a different colour space (see Section 2). Euclidean distance is frequently used in cubic representation spaces as RGB or CIE L*ab* and occasionally in cylindric spaces like L*C*H [Sarifuddin and Missaoui, 2005]. Another Euclidean-like distance was proposed for L*C*H in the work by Vik [2004]. Moreover, Plataniotis and Venetsanopoulos [2000] use a cylindric distance for obtaining colour similarity defined on cylindric and conic spaces like HSL, HSV and L*C*H. Another formulae for computing colour difference in colour spaces as L*C*H and CIECAM02 was also proposed by Luo *et al.* [2001]. Similarity and dissimilarity values based on the Fuzzy C-Means were defined to compare fuzzy colour categories based on Musell colour space in the work by Seaborn *et al.* [2005]. A similarity measure for comparing colours defined in the HCL colour space was defined by Sarifuddin and Missaoui [2005]. All these similarity measures are obtained from numerical values which define colours.

However, there are less studies that calculate a similarity measure between colour names. To the best of our knowledge, only psychological studies try to obtain a similarity relation between colour names based on surveys made to people. For example, in the work by Griffin [2001, 2006] people were asked about *'which is the most similar colour pair: A and B or C and D?'* from which diagrams of the psychological colour structure were obtained and used to study colour symmetries and oppositions.

4 The Qualitative Colour Description (QCD) Model

Our approach translates the Red, Green and Blue (RGB) colour channels of each segmented object in a digital image into coordinates of Hue, Saturation and Lightness (HSL) colour space in order to give a name to the perceptual colour of the object.

In contrast to the RGB model, HSL is considered a more natural colour representation model as it is broken down according to physiological criteria: hue refers to the pure spectrum colours and corresponds to dominant colour as perceived by a human and takes values between 0 and 360; saturation corresponds to the relative purity or the quantity of white light that is mixed with hue and takes values between 0 and 100; and luminance refers to the amount of light in a colour and takes values between 0 and 100. Furthermore, as W3C mentions[1], additional advantages of HSL are that it is symmetrical to lightness and darkness (which is not the case with HSV, for example). This means that: (i) in HSV, considering the value colour coordinate (V) at the maximum, it goes from saturated colour to white, which is not intuitive, whereas in HSL, the saturation colour coordinate (S) takes values from fully saturated colour to the equi-

[1] See the CSS3 specification from the W3C (http://www.w3.org/TR/css3-color/#hsl-color)

valent grey; and (ii) in HSV, the value colour coordinate (V) only goes from black to the chosen hue, while in HSL, the lightness colour coordinate (L) always spans the entire range from black through the chosen hue to white. Therefore, HSL

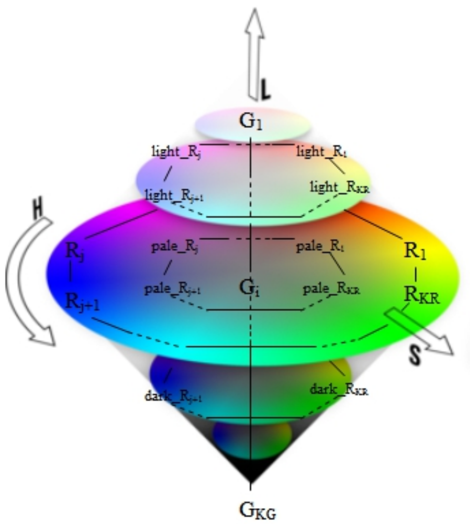

Figure 1: The QCD model on the HSL colour space.

colour space is suitable for dividing into intervals of values corresponding to colour names and also intuitive for adding semantic labels to these names in order to refer to the richness (saturation) or the brightness of the colour (lightness) [Sarifuddin and Missaoui, 2005].

From the HSL colour coordinates obtained, a reference system for qualitative colour description is defined as: QCRS = {UH, US, UL, $QC_{LAB1..M}$, $QC_{INT1..M}$} where UH is the Unit of Hue; US is the Unit of Saturation; UL is the Unit of Lightness; $QC_{LAB1..M}$ refers to the qualitative labels related to colour distributed in M colour sets; and $QC_{INT1..M}$ refers to the three intervals of Hue, Saturation and Lightness colour coordinates associated with each colour label of the M colour sets.

HSL colour space distributes colours in the following way (see Figure 1). The *rainbow colours* are located in the horizontal central circle. The colour lightness changes in the vertical direction, therefore *light rainbow colours* are located above, while *dark rainbow colours* are located below. The colour saturation changes from the boundary of the two cone bases to the axis of the cone bases, therefore, *pale rainbow colours* are located inside the horizontal central circle. As a consequence of the changing colour saturation and lightness, the vertical axis locates the qualitative colours corresponding to the *grey scale*. According to this, our model for QCD considers $M = 5$ colour sets: (1) grey colours, (2) rainbow colours, (3) pale rainbow colours, (4) light rainbow colours and (5) dark rainbow colours, where the QC_{LAB_M} and QC_{INT_M} are:

$QC_{LAB_1} = \{G_1, G_2, G_3, ..., G_{KG}\}$

$QC_{INT_1} = \{[0, g_{ul_1}], (g_{ul_1}, g_{ul_2}], (g_{ul_2}, g_{ul_3}], ..., (g_{ul_{KG-1}}, 100] \in UL \,/\, \forall\, UH \in [0, 360] \wedge \forall\, US \in [0, g_{us_{MAX}}]\ \}$

where KG colour names are defined for the grey scale in QC_{LAB_1} whose corresponding intervals of values in HSL are determined in QC_{INT_1}. All the colours in this set can take any value of hue, values of saturation between 0 and $g_{us_{MAX}}$ and values of lightness ($g_{ul_{KG}}$) between 0 and 100, which determine the different colour names defined. Note that the saturation coordinate of the HSL colour space (US) determines if the colour corresponds to the grey scale or to the rainbow scale.

$QC_{LAB_2} = \{R_1, R_2, R_3, ..., R_{KR}\}$
$QC_{INT_2} = \{(r_{uh_{KR-1}}, 360] \wedge [0, r_{uh_1}], (r_{uh_1}, r_{uh_2}], (r_{uh_2}, r_{uh_3}], ...\ ,(r_{uh_{KR-2}}, r_{uh_{KR-1}}] \in UH \,/\, \forall\, UL \in (r_{ul_{MIN}}, r_{ul_{MAX}}] \wedge \forall\, US \in (r_{us_{MIN}}, 100]\ \}$

where KR colour names are defined for the rainbow scale in QC_{LAB_2} and considered the more saturated ones or the strong ones. In QC_{INT_2}, their saturation can take values between $r_{us_{MIN}}$ and 100, whereas their lightness can take values between $r_{ul_{MIN}}$ and $r_{ul_{MAX}}$. Here, the different values of hue ($r_{uh_{KR}}$) can take values between 0 and 360 and determine the colour names defined for this set.

$QC_{LAB_3} = \{pale\_ + QC_{LAB_2}\}$
$QC_{INT_3} = \{(r_{uh_{KR-1}}, 360] \wedge [0, r_{uh_1}], (r_{uh_1}, r_{uh_2}], (r_{uh_2}, r_{uh_3}], ...\ ,(r_{uh_{KR-2}}, r_{uh_{KR-1}}] \in UH \,/\, \forall\, UL \in (r_{ul_{MIN}}, r_{ul_{MAX}}] \wedge \forall\, US \in (g_{us_{MAX}}, r_{us_{MIN}}]\ \}$

where KR pale colour names are defined in QC_{LAB_3} by adding the prefix *pale_* to the colours defined for the rainbow scale (QC_{LAB_2}). These colour names are defined in QC_{INT_3} by the same hue and lightness intervals and they differ from rainbow colours by their saturation, which can take values between $g_{us_{MAX}}$ and $r_{us_{MIN}}$.

$QC_{LAB_4} = \{light\_ + QC_{LAB_2}\}$
$QC_{INT_4} = \{(r_{uh_{KR-1}}, 360] \wedge [0, r_{uh_1}], (r_{uh_1}, r_{uh_2}], (r_{uh_2}, r_{uh_3}], ... ,(r_{uh_{KR-2}}, r_{uh_{KR-1}}] \in UH \,/\, \forall\, UL \in (r_{ul_{MAX}}, 100] \wedge \forall\, US \in (r_{us_{MIN}}, 100]\ \}$

$QC_{LAB_5} = \{dark\_ + QC_{LAB_2}\}$
$QC_{INT_5} = \{(r_{uh_{KR-1}}, 360] \wedge [0, r_{uh_1}], (r_{uh_1}, r_{uh_2}], (r_{uh_2}, r_{uh_3}], ... ,(r_{uh_{KR-2}}, r_{uh_{KR-1}}] \in UH \,/\, \forall\, UL \in (rd_{ul}, r_{ul_{MIN}}] \wedge \forall\, US \in (r_{us_{MIN}}, 100]\ \}$

where KR light and dark colour names are defined in QC_{LAB_4} and QC_{LAB_5}, respectively, by adding the prefixes *dark_* and *light_* to the colour names in the rainbow scale (QC_{LAB_2}). The intervals of values for dark and light colour sets (QC_{INT_4} and QC_{INT_5}, respectively) take the same values of hue and saturation as those taken by the rainbow colours in QC_{INT_2}. Here, the lightness coordinate (UL) determines the luminosity of the colour, dark or light, and it takes values between $r_{ul_{MAX}}$ and 100 for light colours and between r_{ul} and $r_{ul_{MIN}}$ for dark colours.

Let us indicate that the parameters depend on the granularity given by the researcher in each situation.

As an example, according to the previous definitions, if the colour of the object has the HSL colour coordinates [0, 0, 0], the colour name assigned to it is G_1 in the grey scale (QC_{LAB_1}).

5 Parameterizing the QCD Model

In order to determine the interval of values associated to the Qualitative Colour Reference System or QCRS = {UH, US, UL, $QC_{LAB_{1..5}}$, $QC_{INT_{1..5}}$}, some experts in the implementation area (image processing) have been asked. The values extracted from them for parameterizing our model are the following:

QC_{LAB_1} = {*black, dark_grey, grey, light_grey, white*}
QC_{INT_1} = {[0, 20), [20, 30), [30, 40), [40, 80), [80, 100) ∈ UL / ∀ UH ∈ [0, 360] ∧ ∀ US ∈ [0, 20] }

QC_{LAB_2} = {*red, yellow, green, turquoise, blue, purple, pink*}
QC_{INT_2} = {(335, 360] ∧ [0, 40], (40, 80], (80, 160], (160, 200], (200, 260], (260, 297], (297, 335] ∈ UH / ∀ US ∈ (50, 100] ∧ ∀ UL ∈ (40, 55] }

QC_{LAB_3} = {*pale_* + QC_{LAB_2}}
QC_{INT_3} = {(335, 360] ∧ [0, 40], (40, 80], (80, 160], (160, 200], (200, 260], (260, 297], (297, 335] ∈ UH / ∀ US ∈ (20, 50] ∧ ∀ UL ∈ (40, 55] }

QC_{LAB_4} = {*light_* + QC_{LAB_2}}
QC_{INT_4} = {(335, 360] ∧ [0, 40], (40, 80], (80, 160], (160, 200], (200, 260], (260, 297], (297, 335] ∈ UH / ∀ US ∈ (50, 100] ∧ ∀ UL ∈ (55, 100] }

QC_{LAB_5} = {*dark_* + QC_{LAB_2}}
QC_{INT_5} = {(335, 360] ∧ [0, 40], (40, 80], (80, 160], (160, 200], (200, 260], (260, 297], (297, 335] ∈ UH / ∀ US ∈ (50, 100] ∧ ∀ UL ∈ (20, 40]}

For the grey scale, QC_{LAB_1}, the chosen granularity was 5, while for the rainbow scale, $QC_{LAB_{2..5}}$, the chosen granularity was 7. Therefore, in the final QCRS, 10 basic colours are defined (*black, grey, white, red, yellow, green, turquoise, blue, purple, pink*) and adding the semantic descriptors *pale_*, *light_* and *dark_*, a total of 5 + 7 × 4 = 33 colour names are obtained.

Finally, Figures 2 and 3 show the colour values assigned to each colour name corresponding to the central value of each interval in HSL.

Figure 2: Colour values and names in the grey scale for the QCD model.

Figure 3: Colour values and names in the rainbow scale for the QCD model.

6 Analysing the Relational Structure of the QCD Model

The relational structure of our QCD model can be studied by analysing the conceptual neighbourhood of the qualitative concepts defined.

Freksa [1991] determined that two qualitative terms are conceptual neighbours if *'one can be directly transformed into another by continuous deformation'*. Therefore, colours *grey* and *dark_grey* are conceptual neighbours since a decrease of lightness cause a direct transition from *grey* to *dark_grey*.

A Conceptual Neighbourhood Diagram (CND) can be described as graphs containing: (i) nodes that map to a set of individual relations defined on intervals and (ii) paths connecting pairs of adjacent nodes that map to continuous transformations which can have weights assigned in order to establish priorities.

According to the QCD model defined in previous sections, the CND shown in Figure 4 can be built. This CND is tridimensional and it has the shape of a double cone, as HSL colour space (see Figure 1). The *rainbow colours* (*red, yellow, green, turquoise, blue, purple, pink*) are located in the horizontal central circle. The colour lightness changes in the vertical direction, therefore *light rainbow colours* are located above, while *dark rainbow colours* are located below. The colour saturation changes from the boundary of the two cone bases to the axis of the cone bases, therefore, *pale rainbow colours* are located inside the horizontal central circle. As a consequence of the changing colour saturation and lightness, the vertical axis locates the qualitative colours corresponding to the *grey scale* (*black, dark_grey, grey, light_grey, white*).

7 A Similarity Measure for the QCD Model

The dissimilarity between two qualitative colours in our QCD model, denoted by $dsColour(\cdot, \cdot)$, can be calculated as the minimal path between the nodes of the CND in Figure 4. In this CND, the paths connecting pairs of adjacent nodes that

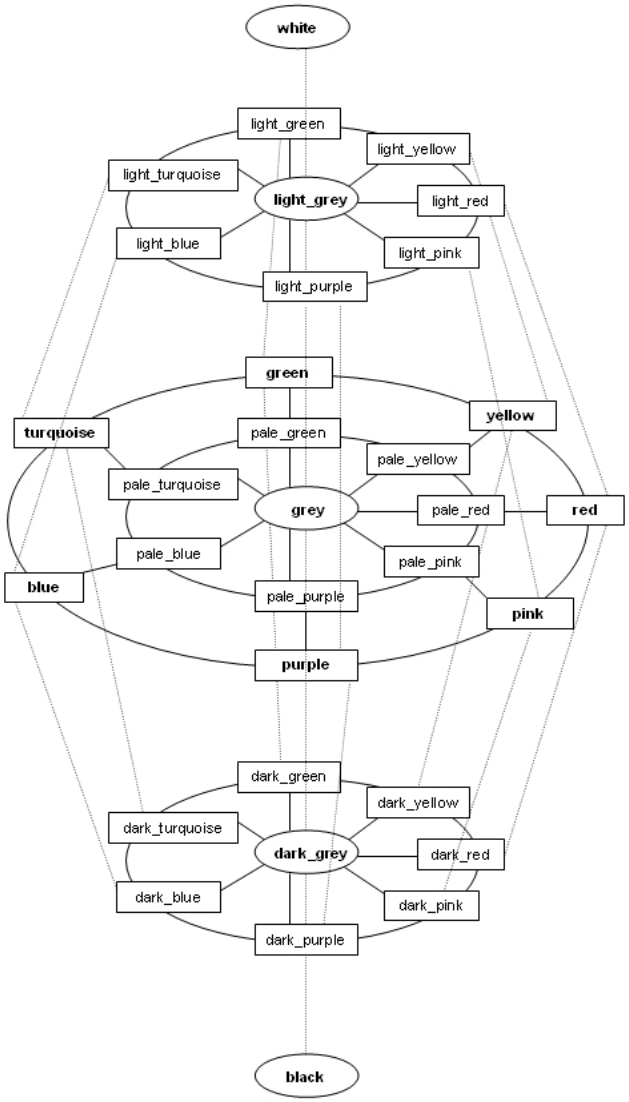

Figure 4: CND for our model for QCD.

map to continuous transformations can be assigned the following weights in order to establish priorities:

- w_1 is the weight assigned to the transition between a colour name and the same colour name with a semantic prefix (*pale_*, *light_*, *dark_*). That is, to transitions that not involve changes in the hue colour coordinate. For example: $dsColour(red, light\_red) = w_1$ and $dsColour(grey, dark\_grey) = w_1$.
- w_2 is the weight assigned to the transitions between colour names in the rainbow scale with or without a semantic prefix (*pale_*, *light_*, *dark_*). For example: $dsColour(pink, red) = w_2$ and, $dsColour(pale\_pink, pale\_red) = w_2$.
- w_3 is the weight assigned in the transition between the colours in the grey scale (located in the vertical axis) and the *light*, *pale* and *dark* colours in the rainbow scale. For example: $dsColour(pale\_red, grey) = w_3$, $dsColour(light\_yellow, light\_grey) = w_3$ and, $dsColour(dark\_blue, dark\_grey) = w_3$.
- w_4 is the weight assigned to the transitions between *black* and *white* colour names and the colours in the grey scale (located in vertical axis). For example: $dsColour(black, dark\_grey) = w_4$, $dsColour(white, light\_grey) = w_4$.

According to the importance of meaning of these transitions, the priorities established must verify: $w_1 \leq w_2 \leq w_3 \leq w_4$. Hence, the dissimilarity that map the pairs of nodes in the CND to the minimal path distance between them are shown in Tables 1 - 5.

Table 1 shows the dissimilarity for the transformations for the qualitative colours in the *grey scale* which correspond to the vertical central nodes of the CND in Figure 4.

Table 1: Dissimilarity in the *grey scale*.

	black	*dark_ grey*	*grey*	*light_ grey*	*white*
black	0	w_4	$w_4 + w_1$	$w_4 + 2w_1$	$2w_4 + 2w_1$
dark_ grey	w_4	0	w_1	$2w_1$	$2w_1 + w_4$
grey	$w_4 + w_1$	w_1	0	w_1	$w_1 + w_4$
light_ grey	$2w_1 + w_4$	$2w_1$	w_1	0	w_4
white	$2w_4 + 2w_1$	$w_4 + 2w_1$	$w_4 + w_1$	w_4	0

Table 2 shows the matrix containing the dissimilarities between the qualitative colours in the *rainbow scale* without prefix or with the same prefix (denoted as *p-* which refers to *pale_*, *light_* or *dark_*). Note that the resulting dissimilarity is denoted as d and it will be used later on.

Table 3 shows the dissimilarities between qualitative colours in the *rainbow scale* (located in the external central circle) and the *light_/pale_/dark_* qualitative colours in

Table 2: Dissimilarity in the *rainbow scale*.

d	*(p-) red*	*(p-) yellow*	*(p-) green*	*(p-) turq.*	*(p-) blue*	*(p-) purple*	*(p-) pink*
(p-) red	0	w_2	$2w_2$	$3w_2$	$3w_2$	$2w_2$	w_2
(p-) yellow	w_2	0	w_2	$2w_2$	$3w_2$	$3w_2$	$2w_2$
(p-) green	$2w_2$	w_2	0	w_2	$2w_2$	$3w_2$	$3w_2$
(p-) turq.	$3w_2$	$2w_2$	w_2	0	w_2	$2w_2$	$3w_2$
(p-) blue	$3w_2$	$3w_2$	$2w_2$	w_2	0	w_2	$2w_2$
(p-) purple	$2w_2$	$3w_2$	$3w_2$	$2w_2$	w_2	0	w_2
(p-) pink	w_2	$2w_2$	$3w_2$	$3w_2$	$2w_2$	w_2	0

the rainbow scale (located in the three central circles located above/in the middle/below in the CND, respectively). The parameter denoted as rc corresponds to the *rainbow colour* names. The dissimilarity denoted as d is the result of the dissimilarity matrix shown in the Table 2.

Table 3: Dissimilarity in rainbow scale with different prefixes.

	rc	*pale* + rc	*light* + rc	*dark* + rc
rc	d	$d + w_1$	$d + w_1$	$d + w_1$
pale + rc	$d + w_1$	d	$d + 2w_1$	$d + 2w_1$
light + rc	$d + w_1$	$d + 2w_1$	d	$d + 2w_1$
dark + rc	$d + w_1$	$d + 2w_1$	$d + 2w_1$	d

Table 4 shows the dissimilarities between the qualitative colours in the *rainbow scale* (nodes connected to the external central circle) and the qualitative colours in the *grey scale* (nodes connected to the vertical central line).

Finally, Table 5 shows the dissimilarities between the qualitative colours in the *grey scale* (nodes connected to the vertical central line) and the qualitative *light_/pale_/dark_* colours in the *rainbow scale* (nodes connected to the three central circles located above/in the middle/below in the CND, respectively).

Therefore, given two qualitative colours, denoted by QC_A and QC_B, referring to the colours of the objects A and B respectively, a similarity between them, denoted by $SimQCD(QC_A, QC_B)$, is defined as:

$$SimQCD(QC_A, QC_B) = 1 - \frac{dsColour(QC_A, QC_B)}{MaxDsColour}, \quad (1)$$

Table 4: Dissimilarity in *rainbow scale* and *grey scale*.

	black	*dark_grey*	*grey*	*light_grey*	*white*
red	$w_1 + w_3 + w_4$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3 + w_4$
yellow	$w_1 + w_3 + w_4$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3 + w_4$
green	$w_1 + w_3 + w_4$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3 + w_4$
turquoise	$w_1 + w_3 + w_4$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3 + w_4$
blue	$w_1 + w_3 + w_4$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3 + w_4$
purple	$w_1 + w_3 + w_4$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3 + w_4$
pink	$w_1 + w_3 + w_4$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3$	$w_1 + w_3 + w_4$

Table 5: Dissimilarity in the *grey scale* and the qualitative *light_/pale_/dark_* colours in the *rainbow scale*.

	black	*dark_grey*	*grey*	*light_grey*	*white*
pale + rc	$w_3 + w_1 + w_4$	$w_3 + w_1$	w_3	$w_3 + w_1$	$w_3 + w_1 + w_4$
light + rc	$w_3 + 2w_1 + w_4$	$w_3 + 2w_1$	$w_3 + w_1$	w_3	$w_3 + w_4$
dark + rc	$w_3 + w_4$	w_3	$w_3 + w_1$	$w_3 + 2w_1$	$w_3 + 2w_1 + w_4$

where $dsColour(QC_A, QC_B)$ denotes the dissimilarity previously defined. $MaxDsColour$ denotes the maximum dissimilarity for all colour names, which is $dsColour(black, white) = 2(w_1 + w_4)$ for our case of study. Hence, by dividing $dsColour(QC_A, QC_B)$ and $MaxDsColour$ the proportion of dissimilarity related to qualitative colours QC_A and QC_B is obtained. Finally, this value is subtracted from 1 with the aim of providing a similarity instead of a dissimilarity.

The main properties of this final similarity measure are:

- Symmetry:
  $SimQCD(QC_A, QC_B) = SimQCD(QC_B, QC_A)$
- Upper and lower bounds:
  $$0 \leq SimQCD(QC_A, QC_B) \leq 1$$
- Intuitive: $SimQCD(QC_A, QC_B) = 0$ means that $dsColour(QC_A, QC_B) = MaxDsColour$, that is, both colours are as different as possible.

Finally, some examples of $SimQCD$ values are shown using as weight values defined by experts: $w_1 = 1$, $w_2 = 3$ and $w_3 = w_4 = 5$. And some intuitive properties (from the point of view of human thinking) of our colour similarity approach are extracted:

- the null similarity is given between *black* and *white* and also between any *light* rainbow colour (rc) and *black* and any *dark* rc and *white*:
  $SimQCD(white, black) = SimQCD(light\ rc, black) = SimQCD(dark\ rc, white) = 0$
- the similarity given between any rc and *black/white* or any *pale* rc and *black/white* is the same:
  $SimQCD(rc, black/white) = 1/12$
  $SimQCD(pale\ rc, black/white) = 1/12$
- the same similarity is given between any *light* rc and *white* and any *dark* rc and *black*:
  $SimQCD(light\ rc, white) = 1/6$
  $SimQCD(dark\ rc, black) = 1/6$
- the similarity given between any rc and the same *dark*, *pale* or *light* rc is the same:
  $SimQCD(pale\ rc, rc) = SimQCD(light\ rc, rc) = SimQCD(dark\ rc, rc) = 11/12$
- the same similarity is given between any *prefix* (*pale*, *dark* or *light*) of the same rc:
  $SimQCD(pale\ rc, dark\ rc) = 10/12$
  $SimQCD(pale\ rc, light\ rc) = 10/12$
  $SimQCD(dark\ rc, light\ rc) = 10/12$
- the similarity given between any *pale* rc and *grey*, and between any *light* rc and *light_grey*, and between any *dark* rc and *dark_grey* is the same:
  $SimQCD(pale\ rc, grey) = 7/12$
  $SimQCD(light\ rc, light\_grey) = 7/12$
  $SimQCD(dark\ rc, dark\_grey) = 7/12$
- any *light* rc is more similar to *white* than any *pale* rc to *white* and, in the same way, any *dark* rc is more similar to *black* than any *pale* rc to *black*:
  $SimQCD(light\ rc, white) > SimQCD(pale\ rc, white)$
  $SimQCD(dark\ rc, black) > SimQCD(pale\ rc, black)$

8 Absolute and Relative QCDC

After defining the model for QCD and a similarity measure between qualitative colours, in this section, it is explained how to use both to solve absolute and relative Qualitative Colour Description Comparisons (QCDC).

Given qualitative colours, denoted by QC_A, QC_B, QC_C and QC_D , our model can calculate:

- absolute comparisons such as: *How similar are QC_A and QC_B?* by calculating: $SimQCD(QC_A, QC_B)$
- absolute comparisons such as: *Is QC_A similar to QC_B?* by defining a similarity threshold ($SimQCD\_Th$) and to see if: $SimQCD(QC_A, QC_B) > SimQCD\_Th$
- relative comparisons such as: *'Which is the most similar pair, QC_A and QC_B or QC_C and QC_D?'* by calculating and proving if:
  $SimQCD(QC_A, QC_B) > SimQCD(QC_C, QC_D)$ or $SimQCD(QC_A, QC_B) < SimQCD(QC_C, QC_D)$
- relative comparisons such as: *'Is QC_A darker than QC_B?'* by calculating and proving if: $SimQCD(QC_A, black) > SimQCD(QC_B, black)$
- relative comparisons such as: *'Is QC_A lighter than QC_B?'* by calculating and proving if: $SimQCD(QC_A, white) > SimQCD(QC_B, white)$
- relative comparisons such as: *'Is QC_A paler than QC_B?'* by calculating and proving if: $SimQCD(QC_A, grey) > SimQCD(QC_B, grey)$
- relative comparisons such as: *'Is QC_A bluer/redder/etc. than QC_B?'* by calculating and proving if: $SimQCD(QC_A, rc) > SimQCD(QC_B, rc)$ where rc = {*blue*/*red*/etc.}

9 How Cognitive is the QCDC Model?

Does our model reflect how human beings perceive and understand colours?

From the point of view of colour naming research, according to the review by Kay and Regier [2006] recent studies have found that: (i) colour categories appear to be organized around universal colour foci, but (ii) naming differences across languages do cause differences in colour cognition because colour categories are determined at their boundaries by language. Without knowing a priori which tendency will be the correct one for cognitive colour naming and perceiving, the QCDC model presented in this paper can be parameterized for communicating an intelligent agent (robot, web searcher, etc.) to a human user in a universal way or in a specific way for a concrete society that understand colour names differently.

Furthermore, the research by Conway [1992] on natural language colour naming showed that, although it may be strictly accurate, people tend not to describe a colour as *dark pale blue* and may even consider this a contradiction, and it recommended that, in order to produce more cognitive colour name descriptions, no more than one adjective should be applied to a basic colour name and also, if a lightness and saturation modifier appear equally applicable to a particular colour, the saturation modifier should be chosen. This aspect is reflected in the QCDC model.

From the point of view of the psychological structure of colours, there are a lot of theories in literature that explain conceptual colour oppositions. For example, Goethe's traditional colour model opposed $white \leftrightarrow black$, $red \leftrightarrow green$, $yellow \leftrightarrow purple$ and $orange \leftrightarrow blue$ (see Figure 5 (a)), whereas traditional Hering's colour model opposed $white \leftrightarrow$

$black$, $red \leftrightarrow green$ (as Goethe's), $yellow \leftrightarrow blue$ and $pink \leftrightarrow brown$ (see Figure 5 (b)). And other more recent studies by Griffin [2001, 2006] show the following oppositions: $white \leftrightarrow black$, $yellow \leftrightarrow purple$ (as Goethe's), $red \leftrightarrow orange$, $blue \leftrightarrow green$, $pink \leftrightarrow brown$ (as Hering's). Finally, as Figure 5 (c) shows, the opposites in HSL colour space to the human-eye are different: $white \leftrightarrow black$, $yellow \leftrightarrow blue$ (as Hering's), $green \leftrightarrow purple$ or $pink$ and $turquoise \leftrightarrow red$. As far as we are concerned, there are no

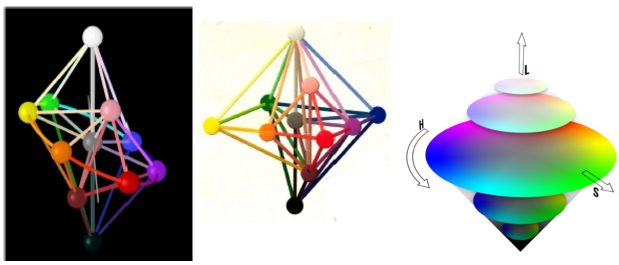

Figure 5: (a) Goethe's and (b) Hering's psychological structure of basic colours terms (obtained from Griffin [2001, 2006]) and (c) HSL colour space.

universal opposites for colours except for $white \leftrightarrow black$. It seems that according to the colour space used or other influences, the results can vary from one study to another. Moreover, the studies found usually are done with at most the 11 Basic Colour Terms (BCT) found by Berlin and Kay [1969]. Possibly, by increasing the variability of colour naming, more opposites could be found.

However, leaving the aspect of colour opposites aside, in general, psychological structures of colours are similar to HSL colour space (as shown in Figure 5) and they are also similar to the CND obtained for the QCDC model. This CND is completely adaptable as it can be assigned different weights to connections in order to represent the desired cognitive colour opposites or even in order to change the elevation of the central colour wheel to reflect the lightness or darkness of the basic colour terms.

10 Conclusions and Future Work

A model for Qualitative Colour Description (QCD) based on the Hue Saturation and Lightness (HSL) colour space is presented in this paper. This colour space has been chosen because of its cognitive properties. The QCD model defines qualitative colours generally by distinguishing *rainbow* colours, *pale*, *light*, *dark* colours and colours in the *grey* scale.

The relational structure of the QCD is analysed using a conceptual neighbourhood diagram that is used to define a measure of similarity between qualitative colour names. This measure of similarity is proved to have interesting and intuitive properties and can be used to solve absolute and relative comparison of qualitative colours.

Finally, the cognitive adequacy of the Qualitative Colour Description and Comparison (QCDC) model is analysed from the point of view of colour naming in natural language and from the point of view of the relational structures of colour perception obtained in psychological studies.

As future work, we intend to: (i) define a new similarity measure between qualitative colours based on interval distances; (ii) design and elaborate a psychological study in order to test our QCDC on people and to analyse its suitability for human machine interaction.

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