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A New Approach for Defining a Fuzzy Color Space

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***Abstract*— In this paper we introduce formal definitions of the concepts of fuzzy color and fuzzy color space. We present an approach to the automatic design of customized fuzzy color spaces on the basis of a collection of crisp colors, each crisp color being fully representative of a certain color term. The approach works on any euclidean crisp space and is based on obtaining a Voronoi diagram having the aforementioned representative crisp colors as centroids. The proposal will be illustrated building fuzzy color spaces on RGB colors on the basis of the ISCC-NBS color naming system.**

I. Introduction

Color is a very important visual feature used in computer vision and image processing. In computers, color is represented as a triplet of real values in different ways, each one with different domains and semantics for the real values. Each such systems is called a *color space*. A well known example is the RGB color space, where the semantics of the three values defining a color in this case is the amount of red, green, and blue necessary to provide the color.

We humans are able to use a very small amount of colors in comparison with the expressive power of color spaces, and we use to express them by means of linguistic terms. For example, we do not employ the numerical triplet $[255, 0, 0]$ in our discourse, but we say *red*; furthermore, there is no biunivocal link between linguistic terms and colors in a color space, but each linguistic term corresponds to a subset of colors. Unfortunately, the boundaries of such set representations are imprecise, subjective, and depend on the application domain and cultural issues.

The lack of a clear correspondence between color spaces and linguistic terms is a clear example of what is known as the "semantic gap", and constitutes an important problem for applications required to support natural language, such as querying for image retrieval [5], [16], [17] or human-machine interaction systems [11]. Color descriptions can be used for recognizing objects by color, describing an image using linguistic terms, and for generating semantic annotations. Just to give a few examples, regions labeled as *light blue* and *strong green* may represent "sky" and "grass" respectively; vivid colors are typically found in man-made objects; and modifiers such as *brownish*, *grayish* and *dark* convey the impression of the atmosphere in the scene.

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In order to fill the gap, automatic color naming models have been proposed in the literature. Although some models based on a pure tessellation of a color space have been proposed [13], [15], human behavior in color naming is not well-modeled with these systems. As already mentioned, the color name provided by a human for a color stimuli has an imprecise representation, and hence many authors consider color naming as a fuzzy process [2], [6], [9], [10], i.e., colors have been interpreted as linguistic labels represented by fuzzy subsets of triplets of a certain color space [14], [19].

However, in most of these fuzzy models, membership functions are defined on the basis of perceptual experiments, so the representativity of the resulting color naming model is limited to these experiments, being not able to capture the influence of subjectivity, culture, and application domain.

Besides, in most of these approaches, colors are defined by combining membership functions defined over each color component. For example, [1], [4], [18] define (usually equidistributed) trapezoidal membership functions for saturation, lightness, and hue, or some combination of them. These approaches impose very strong restrictions on the membership functions that may be obtained, that do not necessarily match human perception. Last but not least, a formal definition of the notion of *fuzzy color*, i.e., linguistic terms represented by fuzzy subsets of a certain color space, and the corresponding extension of color spaces to *fuzzy color space*, together with a deep study of the properties they should verify, are lacking in the literature.

In this paper we introduce formal definitions of the concepts of fuzzy color and fuzzy color space. In addition, we present an approach for designing customized fuzzy color spaces on the basis of a collection of crisp colors, each crisp color being fully representative of a certain color term. The properties that such construction should verify in order to meet the human intuition about color are studied and employed in our approach. Particularly interesting is the possibility to employ existing color naming systems in the literature, providing a crisp representative color for each color term, for building fuzzy color spaces automatically. The approach works on any euclidean color space and is based on obtaining a Voronoi diagram having the aforementioned representative crisp colors as centroids, from which fuzzy membership functions are then obtained.

The rest of the paper is organized as follows. In section II, the notion of fuzzy color is presented. Section III formalizes the concept of fuzzy color space and our approach for building fuzzy color spaces is proposed. Some examples are showed in section IV and, finally, the main conclusions and future works are summarized in section V.

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II. Fuzzy colors

For representing colors, several color spaces can be used. In essence, a color space is a specification of a coordinate system and a subspace within that system where each color is represented by a single point. The most commonly used color space in practice is RGB because is the one employed in hardware devices (like monitors and digital cameras). It is based on a cartesian coordinate system, where each color consists of three components corresponding to the primary colors red, green, and blue. Other color spaces are also popular in the image processing field: linear combination of RGB (like CMY, YCbCr, or YUV), color spaces based on human color terms like hue or saturation (HSI, HSV or HSL), or perceptually uniform color spaces (like CIELa*b*, CIELuv, etc.).

In order to manage the imprecision in color description, we introduce the following definition of fuzzy color:

Definition 2.1: A fuzzy color $\widetilde{C}$ is a normalized fuzzy subset of colors.

As previously explained, colors can be represented as a triplet of real numbers corresponding to coordinates in a color space. Hence, a fuzzy color can be defined as a normalized fuzzy subset of points of a color space. From now on, we shall note XYZ a generic color space with components X, Y and Z[1], and we shall assume that a color space XYZ, with domains D_X, D_Y and D_Z of the corresponding color components is employed. This leads to the following more specific definition:

Definition 2.2: A fuzzy color $\widetilde{C}$ is a linguistic label whose semantics is represented in a color space XYZ by a normalized fuzzy subset of $D_X \times D_Y \times D_Z$.

Notice that the above definition implies that for each fuzzy color $\widetilde{C}$ there is at least one crisp color $\mathbf{r}$ such that $\widetilde{C}(\mathbf{r}) = 1$.

In this paper we will define the membership function of $\widetilde{C}$ as

$$\widetilde{C}(\mathbf{c}; \mathbf{r}, \mathcal{S}, \Omega) = f\left(\left|\overrightarrow{\mathbf{rc}}\right|; t_1^c, \ldots, t_n^c\right) \tag{1}$$

depending on three parameters: $\mathcal{S} = \{S_1, \ldots, S_n\}$ a set of bounded surfaces in XYZ verifying $S_i \cap S_j = \emptyset \ \forall i, j$ (i.e.,they are pairwise disjoint) and such that $Volume(S_i) \subset Volume(S_{i+1}) \ \forall i = 1 \ldots (n-1)$; $\Omega = \{\alpha_1, \ldots, \alpha_n\} \subseteq (0, 1]$, with $1 = \alpha_1 > \alpha_2 > \cdots > \alpha_n = 0$, the membership degrees associated to $\mathcal{S}$ verifying $\widetilde{C}(\mathbf{s}; \mathbf{r}, \mathcal{S}, \Omega) = \alpha_i \ \forall \mathbf{s} \in S_i$; and $\mathbf{r}$ a point inside $Volume(S_1)$ that is assumed to be a crisp color representative of $\widetilde{C}$.

In Eq.1, $f : \mathbb{R} \to [0, 1]$ is a piecewise function with knots $\{t_1^c, \ldots, t_n^c\}$ verifying $f(t_i^c) = \alpha_i \in \Omega$, where these knots are calculated from the parameters $\mathbf{r}$, $\mathcal{S}$ and Ω as follows: $t_i^c = \left|\overrightarrow{\mathbf{rp}_i}\right|$ with $\mathbf{p}_i = S_i \cap \overline{\mathbf{rc}}$ being the intersection between the line $\overline{\mathbf{rc}}$ (straight line containing the points $\mathbf{r}$ and $\mathbf{c}$) and the surface S_i, and $\left|\overrightarrow{\mathbf{rp}_i}\right|$ being the length of the vector $\overrightarrow{\mathbf{rp}_i}$.

[1]Although we are assuming a three dimensional color space, the proposal can be easily extended to color spaces with more components.

III. Fuzzy color space

For extending the concept of color space to the case of fuzzy colors, and assuming a fixed color space XYZ, with D_X, D_Y and D_Z being the domains of the corresponding color components, the following definition is introduced:

Definition 3.1: A fuzzy color space $\widetilde{XYZ}$ is a set of fuzzy colors that define a partition of $D_X \times D_Y \times D_Z$.

In this paper we will focus on fuzzy color spaces $\widetilde{XYZ} = \{\widetilde{C}_1, \ldots, \widetilde{C}_m\}$ verifying the following properties:

1) $\bigcup_{\{1,\ldots,m\}} support(\widetilde{C}_i) = XYZ$, i.e., the union of all the supports covers the whole space.
2) $kernel(\widetilde{C}_i) \cap kernel(\widetilde{C}_j) = \emptyset \ \forall i \neq j$, i.e., the kernels are pairwise disjoint.
3) $\forall i \in \{1, \ldots, m\} \ \exists \mathbf{c} \in XYZ$ such that $\widetilde{C}_i(\mathbf{c}) = 1$, i.e., there is at least one color fully representative of the fuzzy color $\widetilde{C}_i$.
4) If $\widetilde{C}_i(\mathbf{c}) = 1$ then $\widetilde{C}_j(\mathbf{c}) = 0 \ \forall j \neq i$, i.e., if a color is fully representative of the fuzzy color $\widetilde{C}_i$, its membership degree to others fuzzy colors is 0

Condition 3 is always verified by definition of fuzzy color. Condition 1 implies $\forall \mathbf{c} \in XYZ \ \exists i \in \{1, \ldots, m\}$ such that $\widetilde{C}_i(\mathbf{c}) > 0$. Conditions 2 and 3 imply $\widetilde{C}_i \not\subseteq \widetilde{C}_j \ \forall i \neq j$.

As we introduced in the previous section (see Eq.1), each fuzzy color $\widetilde{C}_i \in \widetilde{XYZ}$ will have associated a representative crisp color $\mathbf{r}_i$. Therefore, for defining our fuzzy color space, a set of representative crisp colors $R = \{\mathbf{r}_1, \ldots, \mathbf{r}_m\}$ is needed. In this paper we propose to use the color names (and color points) provided by the ISCC-NBS system [7], [8], which is based on human tests about color perception (Fig.1).

For defining each fuzzy color $\widetilde{C}_i \in \widetilde{XYZ}$, we also need to fix the set of surfaces $\mathcal{S}_i$ and the associated memberships degrees Ω_i (see Eq.1). In this paper, we have focused on the case of convex surfaces defined as a polyhedrons. Concretely, three surfaces $\mathcal{S}_i = \{S_1^i, S_2^i, S_3^i\}$ have been used for each fuzzy color $\widetilde{C}_i$ with $\Omega_i = \{1, 0.5, 0\} \forall i$. Note that, using the previous values, $Volume(S_1^i)$ (resp. $Volume(S_2^i)$, $Volume(S_3^i)$) will correspond to the kernel (resp. 0.5-cut, support) of the fuzzy color $\widetilde{C}_i$, In the following subsections, the methodology used to calculate $S_1^i, S_2^i, S_3^i \in \mathcal{S}_i$ is explained.

A. Obtaining the surfaces S_2^i

To obtain $S_2^i \in \mathcal{S}_i \ \forall i$, a Voronoi diagram has been calculated [12] with R as centroid points. A Voronoi diagram is a special kind of partition of a metric space Q (in our case, a three-dimensional space) determined by distances to a specified discrete set of points $H = \{p_1, \ldots, p_m\} \subset Q$ (in our case, $H = R \subset XYZ$). As result, a set of clusters, called "Voronoi cells", are obtained, one per each $p_i \in H$, verifying that $\forall p_i \in H$, the associated Voronoi cell is compounded by the set of points that are closer to p_i than to other points of Q (in our case, the Voronoi cells forms volumes in the three-dimensional space). The boundary of each Voronoi cell form a convex polytope (polyhedron in the three-dimensional case), verifying that a point in the boundary is equidistant from, at least, two points in H.

In our approach, a Voronoi diagram is calculated with $H = R \subset XYZ$ as centroid points, obtaining as result a crisp partition of the color domain (each Voronoi cell will define a convex volume). Then, the boundaries (polyhedrons) of the Voronoi cells will define the surfaces[2] $S_2^i \in \mathcal{S}_i \; \forall i$. Let's remark that all the points in a Voronoi cell boundary are equidistant from, at least, two representative color points in R, so it seems natural to assign a membership degree 0.5 to this points (as Ω_i pointed).

Figure 2(a) shows the surfaces S_2^{yellow}, S_2^{blue}, S_2^{green} and S_2^{gray} (i.e., the Voronoi cell boundaries), corresponding to color names of the ISCC-NBS basic set.

B. Obtaining the surfaces S_1^i

Once $S_2^i \in \mathcal{S}_i$ is obtained, the surfaces $S_1^i, S_3^i \in \mathcal{S}_i$ are calculated as scaled surfaces of S_2^i. Let P be a polyhedron and let $\hat{P} = \Lambda^{\mathbf{o},\mathbf{k}}(P)$ be an scaled version of P with respect to the point $\mathbf{o} = [o_1, o_2, o_3]$ and scale factor $\mathbf{k} = [k_1, k_2, k_3]$, where, for each vertex $\mathbf{v} \in P$, the corresponding vertex $\hat{\mathbf{v}} \in \hat{P}$ is calculated as $[\hat{\mathbf{v}}, 1] = [\mathbf{v}, 1] \cdot \mathbf{K}$, with

$$\mathbf{K} = \begin{bmatrix} k_1 & 0 & 0 & 0 \\ 0 & k_2 & 0 & 0 \\ 0 & 0 & k_3 & 0 \\ (1-k_1)o_1 & (1-k_2)o_2 & (1-k_3)o_3 & 1 \end{bmatrix} \quad (2)$$

To obtain S_1^i (let's remind that $Volume(S_1^i)$ corresponds to the kernel of the fuzzy color $\widetilde{C}_i$), the surface S_2^i is "reduced" by means of the uniform scaling $S_1^i = \Lambda^{\mathbf{r_i},\mathbf{k}_\lambda}(S_2^i)$, where $\mathbf{k}_\lambda = [\lambda, \lambda, \lambda]$ with $\lambda \in [0, 1)$, and $r_i \in R$ is the centroid of S_2^i. Following the previous procedure, it is clear that $Volume(S_1^i) \subset Volume(S_2^i)$ and $Volume(S_1^i) \cap Volume(S_2^j) = \emptyset \; \forall j \neq i$.

Figure 2(b) shows the surfaces S_1^{yellow}, S_1^{blue}, S_1^{green} and S_1^{gray} obtained by scaling (reducing) the corresponding S_2^i surfaces (Figure 2(a)).

C. Obtaining the surfaces S_3^i

To obtain S_3^i (let's remind that $Volume(S_3^i)$ corresponds to the support of the fuzzy color $\widetilde{C}_i$), the surface S_2^i is "enlarged" by means of the uniform scaling $S_3^i = \Lambda^{\mathbf{r_i},\mathbf{k}_{\lambda'}}(S_2^i)$, where $\mathbf{k}_{\lambda'} = [\lambda', \lambda', \lambda']$ with $\lambda' \in (1, 2)$, and $r_i \in R$ is the centroid of S_2^i.

In order to verify the fuzzy color space properties, we have to take into account that S_3^i cannot intersect with the kernels of other fuzzy colors (i.e, $Volume(S_3^i) \cap Volume(S_1^j) = \emptyset$ $\forall j \neq i$). In our case, and due to the polyhedrons $S_2^i \; \forall i$ are Voronoi cell boundaries, this property is verified if $\lambda + (\lambda' - 1) \leq 1$. In the particular case of $\lambda + (\lambda' - 1) = 1$, the boundary of the support of a given fuzzy color will limit with the boundaries of the adjacent fuzzy color kernels. In this paper, the values $\lambda = 0.5$ and $\lambda' = 1.5$ have been used.

[2]For more details about the parameter values which define each polyhedron, see http://www.uco.es/∼el1sohij/ColorWCCI2010

D. Defining the function f

Finally, as function f in Eq.1, a spline function of order 1 (linear spline) is used:

$$f\left(x; t_1^c, t_2^c, t_3^c\right) = \begin{cases} 1 & x \leq t_1^c \\ \frac{(t_2^c - x) + (t_2^c - t_1^c)}{2(t_2^c - t_1^c)} & t_1^c < x \leq t_2^c \\ \frac{t_3^c - x}{2(t_3^c - t_2^c)} & t_2^c < x \leq t_3^c \\ 0 & x \geq t_3^c \end{cases} \quad (3)$$

where t_i^c, with $i = 1, 2, 3$, is calculated for each $\mathbf{c}$ as was explained in section II.

IV. RESULTS

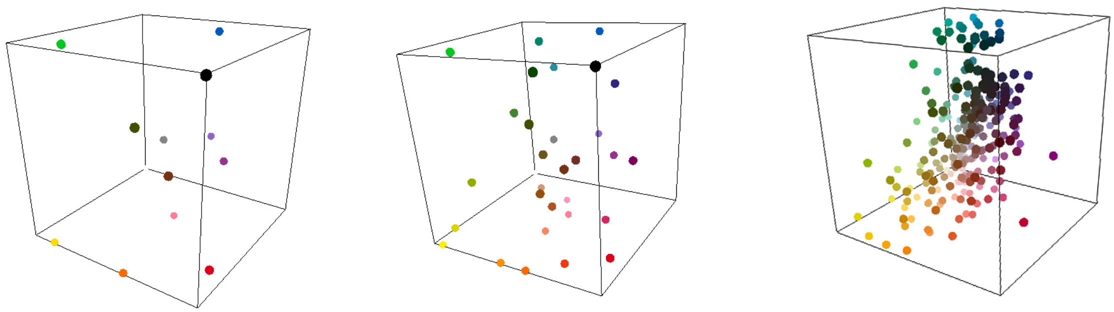
In this section we illustrate our proposal by defining several fuzzy color spaces using color names provided by the well-known ISCC-NBS system [7], [8]. This system is based on the pioneering work of Berlin and Kay [3] about color naming and has been tested with humans on a task of color description. ISCC-NBS provides several color sets in the form of sets of pairs (linguistic term, crisp color). Using the method introduced in the previous section, we shall obtain fuzzy representations for the colors of a certain set starting from the set of crisp representatives for that set.

In our experiments, we have used the following sets of color names:

- Basic Set: 13 color names corresponding to ten basic color terms (pink, red, orange, yellow, brown, olive, green, blue, violet, purple), and 3 achromatic ones (white, gray, and black).
- Extended Set: 31 color names corresponding to those of the basic set and some combination of them formed by adding the $-ish$ suffix (Brownish Orange, Purplish Blue among others).
- Complete Set: 267 color names obtained from the extended set by adding five tone modifiers for lightness (very light, light, medium, dark and very dark) and four adjectives for saturation (grayish, moderate, strong and vivid). Also, three additional terms substitute certain lightness-saturation combination (pale for light grayish, brilliant for light strong and deep for dark strong). Theses color names are represented by the Universal Color Language, Level 3 in the ISCC-NBS system.

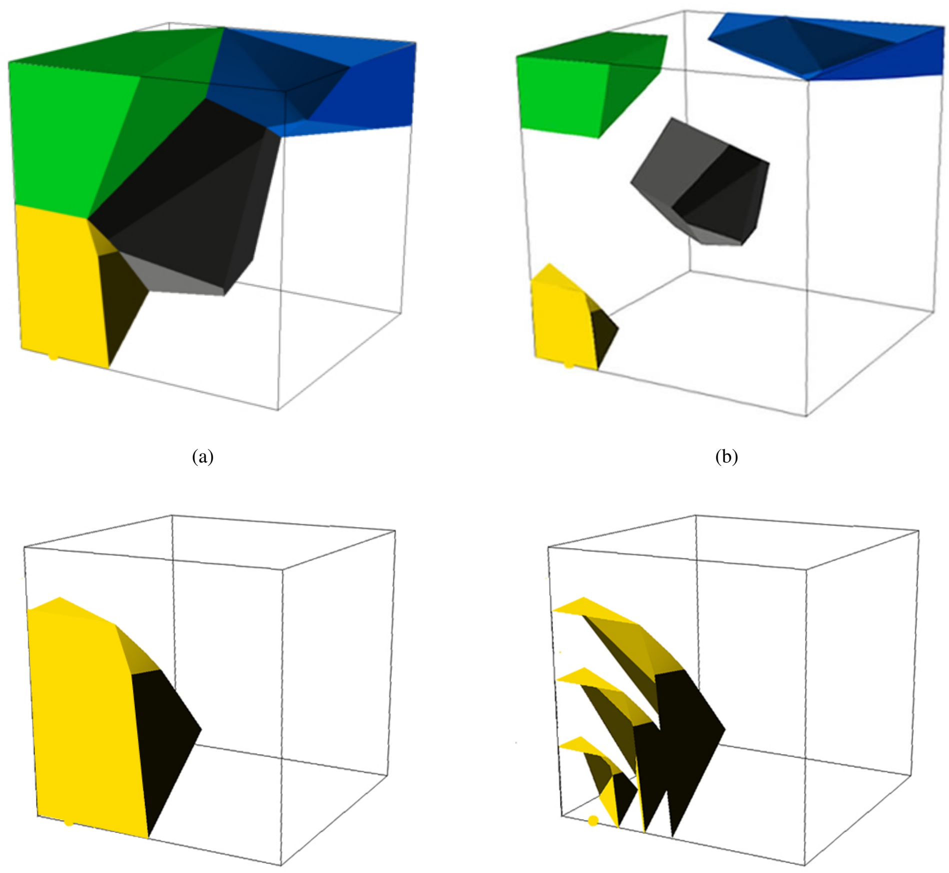
Figure 1 shows the representative color points from the ISCC-NBS color sets. On the basis of these color sets we have obtained three fuzzy color spaces, named FCS_{Basic}, $FCS_{Extended}$, and $FCS_{Complete}$, respectively.

As example, Figure 2 shows the surfaces $\mathcal{S}_i$ associated to the fuzzy colors *yellow*, *blue*, *green* and *gray* from the FCS_{Basic} (for the sake of clarity, not all the fuzzy colors in FCS_{Basic} have been shown). The representatives crisp colors are $\mathbf{r}_{yellow} = [254, 220, 1]$, $\mathbf{r}_{blue} = [1, 90, 200]$, $\mathbf{r}_{green} = [1, 220, 30]$, and $\mathbf{r}_{gray} = [132, 132, 132]$, respectively. Figure 2(a) shows the surfaces S_2^i, i.e., the Voronoi cell boundaries, associated to these colors. From S_2^i, the kernel boundaries, i.e., S_1^i, are obtained by means of an uniform scaling with scale factor 0.5 (Figure 2(b)). In the same way,



(a) (b) (c)

Fig. 1. Representative points provided by the ISCC-NBS system. (a) Basic set (b) Extended set (c) Complete set



(a) (b)

(c) (d)

Fig. 2. Surfaces associated to the fuzzy colors $yellow$, $blue$, $green$ and $gray$ from the fuzzy color space FCS_{Basic}. (a) Voronoi cell boundaries: S_2^i (b) Kernel boundaries : S_1^i (c) Support boundary only for the fuzzy color $yellow$: S_3^i (d) Superimposed views of a "truncated" version of the surfaces S_1^i, S_2^i, S_3^i for the fuzzy color $yellow$

the support boundaries, i.e., S_3^i, are obtained by means of an uniform scaling with scale factor 1.5. In this case, only the for the fuzzy color *yellow* is shown in Figure 2(b)). In addition, for this last color, a view of a "truncated" version of the surfaces is shown in Figure 2(d), where the faces in the sides of the RGB-cube has been eliminated to highlight how the surfaces are scaled version of the Voronoi cell boundary.

In order to show the suitability of the fuzzy color spaces obtained and validate our methodology, we have obtained the description in terms of fuzzy colors and the corresponding membership degrees, of colors present in several regions of a real image (Figure 3) with a large variety of colors. We have selected regions that contain the most fundamental colors in the image and we have checked if the semantic description of the representative color of the regions are in accordance with human description using our fuzzy color spaces. Figure 3 shows the eight regions of our choice and the corresponding representative color (calculated as the mean in this paper).

The degree of correspondence of each color with the fuzzy colors for the three fuzzy color spaces we have defined is shown in Table I. In our opinion, the linguistic terms that appear and the corresponding degrees are not conflicting with human intuition. It is interesting to remark how in the description of color (E) using the fuzzy color space FCS_{Basic}, membership degrees are obtained to the fuzzy colors *yellow* and *green* separately, when the color is a kind of combination of both, (more specifically the description obtained is *yellow* with 0.64 and *green* with 0.35 and *gray* tone description but with a very small membership degree). This is because FCS_{Basic} does not include a definition for a fuzzy color called *yellow-green*. However, using both $FCS_{Extended}$ and $FCS_{Complete}$, we obtain high degrees for *yellow-green* and *greenish yellow* in the color description region (E); specifically, the description is $0.7/yellow\ - green + 0.3/greenish\ yellow$ in $FCS_{Extended}$, and $0.19/vivid\ yellow - green + 0.81/strong\ greenish\ yellow$ in $FCS_{Complete}$.

Notice as well that colors (B), (C), (D), (F), (G) and (H) are recognized as pertaining to the kernel of fuzzy colors using FCS_{Basic}, and hence they are described by a single linguistic label; however, this description is refined by the much more specific spaces $FCS_{Extended}$ and $FCS_{Complete}$ in most of the cases. For example, in the case of color (B), all the spaces agree that the linguistic label that best matches the color is *red* (though they define *red* in different ways); however, $FCS_{Extended}$ adds a degree 0.2 to *reddish orange* (degree for *red* is 0.8), whilst $FCS_{Complete}$, in addition to a degree 0.6 for *red*, refines the description given by $FCS_{Extended}$ and gives degrees 0.39 to *deep reddish orange* and 0.1 to *vivid reddish orange*.

In the case of color (C), both FCS_{Basic} and $FCS_{Extended}$ agree with a description $1/Yellow$, whilst $FCS_{Complete}$ yields $0.54/vivid\ greenish\ yellow + 0.46/vivid\ yellow$. The cases of colors (D), (F), and (G) are similar to those of (B) and (C). Finally, all the color spaces agree to give a description $1/black$ for color (H); however, let us remark again that the fuzzy color $black$ is defined in a different way in the three spaces.

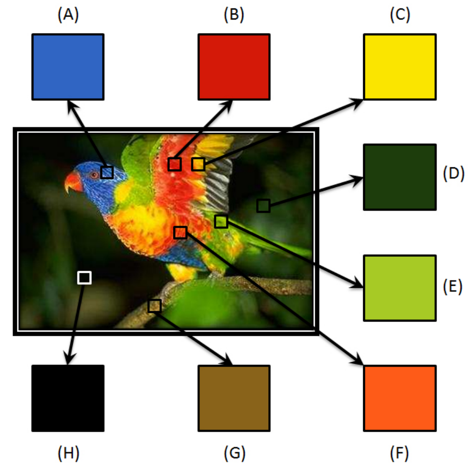


Fig. 3. Color information of a representative pixel of the region (A) to (H) in a real image

V. Conclusions

We have introduced formal definitions and properties for the concepts of fuzzy color and fuzzy color space. We have proposed a methodology to automatically design customized fuzzy color spaces on the basis of a collection of crisp colors, each one assumed to be fully representative of a certain color term. The approach works on any euclidean crisp space, and it has been illustrated by defining three fuzzy color spaces on RGB using as a basis the color sets Basic, Extended, and Complete proposed in the ISCC-NBS color naming system. The results obtained when applying these fuzzy spaces for describing semantically colors in a real image are promising and consistent with the human perception. There are many potential applications of this technology.

As future work, we shall formalize and study properties of similarity measures. This will serve as the basis for many applications, in particular for developing image retrieval systems working with linguistic, flexible queries to image databases. We are also working on the automatic generation of linguistic description of images on the basis of color information.

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Region in figure 3	**RGB value**	FCS_{Basic} (13 colors)	$FCS_{Extended}$ (31 colors)	$FCS_{Complete}$ (267 colors)
A	[49, 102, 194]	0.83 / Blue	0.64 / Blue	0.62 / Strong Purplish Blue
		0.16 / Violet	0.35 / Greenish Blue	0.37 / Strong Blue
		0.02 / Gray	0.06 / Violet	0.30 / Brilliant Greenish Blue
				0.30 / Brilliant Blue
				0.15 / Moderate Blue
B	[211, 27, 6]	1.0 / Red	0.80 / Red	0.60 / Vivid Red
			0.20 / Reddish Orange	0.39 / Deep Reddish Orange
				0.10 / Vivid Reddish Orange
C	[250, 229, 0]	1.0 / Yellow	1.0 / Yellow	0.54 / Vivid Greenish Yellow
				0.46 / Vivid Yellow
D	[32, 61, 13]	1.0 / Olive	0.87 / Olive Green	0.61 / Deep Olive Green
			0.13 / Olive	0.39 / Very Dark Yellowish Green
E	[169, 201, 39]	0.64 / Yellow	0.70 / Yellow Green	0.81 / Strong Greenish Yellow
		0.35 / Green	0.30 / Greenish Yellow	0.19 / Vivid Yellow Green
		0.09 / Gray		
F	[255, 90, 24]	1.0 / Orange	0.74 / Orange	0.93 / Vivid Reddish Orange
			0.26 / Reddish Orange	0.07 / Vivid Orange
G	[141, 99, 28]	1.0 / Brown	1.0 / Yellowish Brown	0.83 / Strong Yellowish Brown
				0.17 / Moderate Olive Brown
				0.10 / Strong Brown
H	[1, 2, 1]	1.0 / Black	1.0 / Black	1.0 / Black

TABLE I

POSSIBILITY DISTRIBUTION FOR PIXELS IN FIGURE 3(A)-(H) FOR EACH FUZZY COLOR SPACE

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