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# An approach for Fuzzy Dominant Color Descriptor

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**Abstract:** In this paper, a new Dominant Color Descriptor is proposed. This descriptor is defined as a fuzzy set over a finite universe of fuzzy colors, in which membership degrees represent the dominance of each color. The fuzzy colors employed are fuzzy sets defined on an ordinary color space, filling the semantic gap between the color representation in computers and its human perception. The dominance of each fuzzy color is calculated on the basis of a fuzzy quantifier representing the notion of dominance, and a fuzzy histogram representing as a fuzzy quantity the percentage of pixels that match each fuzzy color. The obtained descriptor can be employed in a large amount of applications. We illustrate the usefulness of the descriptor by a particular application in image retrieval.

## 1 INTRODUCTION

Nowadays, the amount of visual information available in digital format is increasing considerably. Traditional and most common methods for describing this visual information are based on attaching keywords to the images. Although this approach has proved to be useful, it is time-consuming, laborious, expensive, and subjective due to a person is required for making the description. In addition, it is almost impossible for a person to label an image with every possible keyword that may be relevant. To overcome this limitation, the use of visual descriptors has been suggested [1, 2]. They describe elementary characteristics such as color, texture and shape, which are automatically extracted from images [3, 4].

Among these characteristics, color plays an important role because of its robustness and independence from image size and orientation [5, 6, 7]. In this sense, several proposals are formulated for describing color properties in images. For example, the well-known MPEG-7 standard [8] proposes color descriptors such as the Color Structure Descriptor, that tries to identify color distributions in an image, and the Scalable Color Descriptor, that deals with a scalable representation of the color.

In this paper we focus on the dominant color descriptor, one of the most important descriptors in MPEG-7. A dominant color descriptor must provide an effective, compact, and intuitive representation of the most representative colors presented in an image. In this context, many approaches to dominant color extraction have been proposed in the literature [9, 10]. Most of them perform the extraction process based on histogram analysis [11, 12] or clustering techniques [13] in color domain. Nevertheless, these approaches consider a crisp notion of dominance, when in fact for human's perception there are degrees of dominance, that is, colors can be clearly dominant, clearly not dominant, or can be dominant to a certain degree. In addition, most of the times they do not consider subsets of crisp colors, as represented in computers, that fully match human perception as expressed by linguistic color terms.

In this paper, we provide a solution to the previous problems by introducing a fuzzy descriptor for dominant colors as a level-two fuzzy sets on fuzzy colors. To the best of our knowledge, this is a completely new approach for the definition of dominant color descriptor. As a basis for the descriptor we rely on the definition of fuzzy colors as fuzzy subsets of a crisp color space (RGB for instance), introduced in [14]. Concretely, a color will be modeled by means of a fuzzy set (a fuzzy color) and a fuzzy partition will be defined in the color feature domain (a fuzzy color space). In this paper we propose to define this partition on the basis of the ISCC-NBS color naming system [15, 16], that is based on the human perception of color. In order to obtain the descriptor we use a histogram of fuzzy colors, as the dominance is related with the frequency of the colors in the image. A fuzzy quantifier will be employed in order to represent the semantics of *dominant* on the basis of the amount of pixels having a certain color, in a natural way. The counting will be performed by using the scalar sigma-count (sum of membership degrees), and the evaluation of the dominance will be finally the compatibility between the quantifier defining the semantics of dominance, and the sigma-count. We use this fast calculation since it is well known to be completely equivalent to other quantification models for evaluating type I sentences with non-decreasing quantifiers, like in this case. On the basis of this dominance, a new descriptor "*Fuzzy Dominant Color Descriptor*" is proposed in this paper. This descriptor will be defined as a fuzzy set over the finite universe of color fuzzy sets (with membership degrees according to its dominance degrees).

The rest of the paper is organized as follows. As a basis for our descriptor, in section 2 we recall fuzzy colors as defined and calculated in [14]. The dominance-based color fuzzy descriptor which is our main contribution here, is defined in section 3. Since in practice it is frequently necessary to match descriptors, we propose fuzzy inclusion and resemblance operators between dominant color descriptors in section 4. In section 5 we show some results of calculating color descriptors for real images; we also show the result of some image retrieval experiments for illustrative purposes. Finally, conclusions and future work are summarized in section 6.

## 2 FUZZY MODELING OF COLORS

In this section, the notions of fuzzy color (section 2.1) and fuzzy color space (section 2.2) we presented in a previous work [14] are summarized. Based on it, a fuzzy partition will be defined in the color feature domain (our fuzzy color space) according to the ISCC-NBS color naming system [16].

### 2.1 Fuzzy color

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, and following [14], we will define the membership function of $\widetilde{C}$ as

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

depending on three parameters: $S = \{S_1, \ldots, S_n\}$ a set of bounded surfaces in XYZ verifying $S_i \cap S_j = \emptyset$ $\forall i, j$ (i.e., pairwise disjoint) and such that $Volume(S_i) \subset Volume(S_{i+1})$; $\Omega = \{\alpha_1, \ldots, \alpha_n\} \subseteq (0, 1]$, with $1 = \alpha_1 > \alpha_2 > \cdots > \alpha_n = 0$, the membership degrees associated to $S$ verifying $\widetilde{C}(\mathbf{s}; \mathbf{r}, S, \Omega) = \alpha_i$ $\forall \mathbf{s} \in S_i$; 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 $\mathbf{r}$, $S$ and $\Omega$ 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 $\left|\overrightarrow{\mathbf{rp}_i}\right|$ 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.

### 2.2 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 2.3** *A fuzzy color space $\widetilde{XYZ}$ is a set of fuzzy colors that define a partition of $D_X \times D_Y \times D_Z$.*

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 $R = \{\mathbf{r}_1, \ldots, \mathbf{r}_n\}$ is needed. In this paper we propose to use the color names (and color points) provided by the ISCC-NBS system [15, 16], witch is based on human tests about color perception. ISCC-NBS system defines a set of valid colors terms. In this paper, the basic set formed by 13 color names (10 hues -pink, red, orange, yellow, brown, olive, green, blue, violet, purple- and 3 achromatic colors -white, grey and black-) will be used (i.e, $R = \{\mathbf{r}_1, \ldots, \mathbf{r}_{13}\}$ with $\mathbf{r}_i$ a RGB color).

For defining each fuzzy color $\widetilde{C}_i \in \widetilde{XYZ}$, we also need to fix the set of surfaces $S_i$ and the associated memberships degrees $\Omega_i$ (see Eq.1). In this paper, we have focused on the case of convex surfaces defined as a polyhedra (i.e, a set of faces). Concretely, three surfaces $S_i = \{S_1^i, S_2^i, S_3^i\}$ have been used for each fuzzy color $\widetilde{C}_i$ with $\Omega_i = \{1, 0.5, 0\} \forall i$.

To obtain $S_2^i \in S_i$ $\forall i$, a Voronoi diagram has been calculated [17] with $R$ as centroid points . As results, a crisp partition of the color domain given by convex volumes is obtained (each volume will define a Voronoi cell). The surfaces of the Voronoi cells will define the surfaces $S_2^i \in S_i$ $\forall i$. Once $S_2^i$ is obtained, the surface $S_1^i$ (resp. $S_3^i$) is calculated as a scaled surface of $S_2^i$ with scale factor of $0.5$ (resp. $1.5$). For more details about the parameter values which define each polyhedra, see [14].

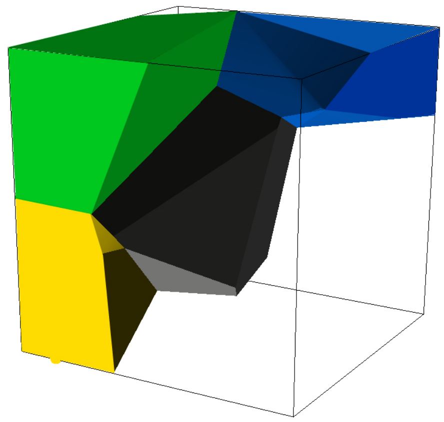
Figure 1 shows the surfaces $S_2^{yellow}$, $S_2^{blue}$, $S_2^{green}$ and $S_2^{grey}$ (on the left), and $S_1^{yellow}$, $S_1^{blue}$, $S_1^{green}$ and $S_1^{grey}$ (on the rigth). The representative crisp values are $\mathbf{r}_{yellow} = [254, 220, 1]$, $\mathbf{r}_{blue} = [1, 90, 200]$, $\mathbf{r}_{green} = [1, 220, 30]$ and $\mathbf{r}_{gray} = [132, 132, 132]$.

## 3 DOMINANCE-BASED COLOR FUZZY DESCRIPTOR

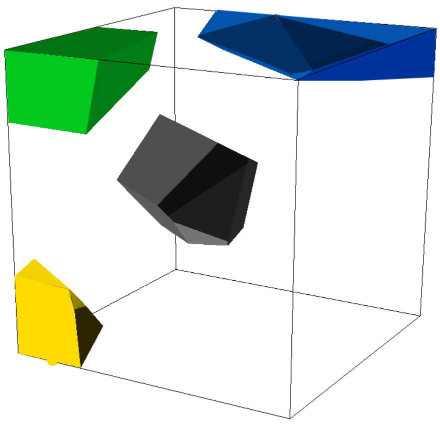
For describing semantically an image, the dominant colors will be used. In this section, Fuzzy Descriptors for dominant colors are proposed (section 3.2) on the basis of the dominance degree of a given color (section 3.1).

### 3.1 Dominant Fuzzy Colors

Intuitively, a color is dominant to the extend it appears frequently in a given image. As it is well known in the computer vision field, the histogram is a powerful tool for measuring the frequency in which a property appears in an image. The histogram is a function $h(x) = n_x$ where $x$ is a pixel property



(a)



(b)

Fig. 1: Some surfaces associated to the fuzzy color space. (a) $S_2^i$ (b) $S_1^i$ for $i = \{yellow, blue, green, grey\}$

(grey level, color, texture value, etc.) and $n_x$ is the number of pixels in the image having the property $x$. It is common to normalize a histogram by dividing each of its values by the total number of pixels, obtaining an estimate of the probability of occurrence of $x$.

Working with fuzzy properties suggests to extend the notion of histogram to "fuzzy histogram". In this sense, a fuzzy histogram will give us information about the frequency of each fuzzy color. In this paper, the counting will be performed by using the scalar sigma-count (i.e., the sum of membership degrees). Thus, for any fuzzy set $F$ with membership function $F : X \to [0, 1]$, the fuzzy histogram is defined as

$$h(F) = \frac{1}{NP} \sum_{x \in X} F(x) \tag{2}$$

with $NP$ being the number of pixels.

Using the information given by the histogram, we will measure the "dominance" of a color fuzzy set. Dominance is an imprecise concept, i.e., it is possible in general to find colors that are clearly dominant, colors that are clearly not dominant, and colors that are dominant to a certain degree, that depends on the percentage of pixels where the color appears.

It seems natural to model the idea of dominance by means of a fuzzy set over the percentages given by $h(F)$, i.e., a fuzzy quantifier defined by a non-decreasing subset of the real interval $[0, 1]$. Hence, we define the fuzzy subset "Dominant", noted as $Dom$, as follows:

$$Dom(F) = \begin{cases} 0 & h(F) \le u_1 \\ \frac{h(F)-u_1}{u_2-u_1} & u_1 \le h(F) \le u_2 \\ 1 & h(F) \ge u_2 \end{cases} \tag{3}$$

where $u_1$ and $u_2$ are two parameters such that $0 \le u_1 < u_2 \le 1$, and $h(F)$ is calculated by means of Eq. 2.

### 3.2 Dominance-based fuzzy descriptors

On the basis of the dominance of colors, a new image descriptor is proposed in this section. For a generic image property, we introduce de following definition of fuzzy descriptor:

**Definition 3.1** *Let $\mathscr{P}$ be a finite universe of fuzzy sets associated to a given image property*[2]*. A fuzzy descriptor is defined as a fuzzy set over the reference universe $\mathscr{P}$*

In the case of the "Color" property, we define the following fuzzy descriptor for dominant colors:

**Definition 3.2** *Let $\mathscr{C}$ a finite reference universe of color fuzzy sets. We define the* Fuzzy Dominant Color Descriptor *as the fuzzy set*

$$FDCD = \sum_{C \in \mathscr{C}} Dom(C)/C \tag{4}$$

*with $Dom(C)$ being the dominance degree of $C$ given by Eq. 3.*

## 4 Matching operators

Fuzzy operators over fuzzy descriptors are needed in many practical applications. In this section, a "Fuzzy inclusion operator" (section 4.1) and a "Fuzzy resemblance operator" (section 4.2) are proposed.

### 4.1 Fuzzy inclusion operator

Given two Fuzzy Dominant Color Descriptors, $FDCD^i$ and $FDCD^j$, the operator presented in this section calculates the inclusion degree of $FDCD^i$ in $FDCD^j$. The calculus is done using the *Resemblance Driven Inclusion Degree* introduced in [18], which computes the inclusion degree of two fuzzy sets whose elements are imprecise.

**Definition 4.1** *Let $FDCD^i$ and $FDCD^j$ be two Fuzzy Dominant Color Descriptors defined over a finite reference universe of fuzzy sets $\mathscr{P}$, $FDCD^i(x)$ and $FDCD^j(x)$ the membership functions of these fuzzy sets, $S$ the resemblance relation defined over the elements of $\mathscr{P}$, $\otimes$ be a t-norm, and $I$ an implication operator. The inclusion degree of $FDCD^i$ in $FDCD^j$ driven by the resemblance relation $S$ is calculated as follows:*

$$\Theta_S(FDCD^j|FDCD^i) = \min_{x \in \mathscr{P}} \max_{y \in \mathscr{P}} \theta_{i,j,S}(x, y) \tag{5}$$

[2]For example, the property "Color" with $\mathscr{P}$ being a set of fuzzy colors.

*where*

$$\theta_{i,j,S}(x,y) = \otimes(I(FDCD^i(x), FDCD^j(y)), S(x,y)) \quad (6)$$

In this paper we use the minimum as t-norm, the compatibility as the resemblance relation $S$, and as implication operator the one defined in equation 7.

$$I(x,y) = \begin{cases} 1 & \text{if } x \leq y \\ y/x & \text{otherwise} \end{cases} \quad (7)$$

### 4.2 Fuzzy resemblance operator

The operator presented in this section calculates the resemblance degree between two Fuzzy Dominant Color Descriptors, $FDCD^i$ and $FDCD^j$. This resemblance degree is calculated by means of the *Generalized Resemblance between Fuzzy Sets* proposed in [18], which is based on the concept of double inclusion.

**Definition 4.2** *Let $FDCD^i$ and $FDCD^j$ be two Fuzzy Dominant Color Descriptors defined over a finite reference universe of fuzzy sets $\mathscr{P}$, over which a resemblance relation S is defined, and $\otimes$ be a t-norm. The generalized resemblance degree between $FDCD^i$ and $FDCD^j$ restricted by $\otimes$ is calculated by means of Equation (8).*

$$\Lambda_{S,\otimes}(FDCD^i, FDCD^j) =$$

$$= \otimes(\Theta_S(FDCD^j|FDCD^i), \Theta_S(FDCD^i|FDCD^j)) \quad (8)$$

## 5 RESULTS

In this section, we will use the proposed Fuzzy Dominant Color Descriptor (FDCD) in order to obtain the dominant colors present in an image. In addition, the fuzzy operators over the FDCD will be used to define conditions in image retrieval queries.

In this paper, we have used the fuzzy color space defined in section 2 which is designed on the basis of a collection of crisp colors and color names. The color names (and color points) provided by the ISCC-NBS system [15, 16], based on human tests about color perception, have been used. Specifically, we have used the set formed by 13 color names (10 hues -pink, red, orange, yellow, brown, olive, green, blue, violet, purple- and 3 achromatic colors -white, grey and black-).

In our experiments we have empirically fixed the parameters $u_1$ and $u_2$ in equation 3 to 0.05 and 0.25 respectively.

### 5.1 Fuzzy Dominant Color Descriptor examples

In order to show the suitability of the Fuzzy Dominant Color Descriptor (FDCD) for describing the dominant colors in an image, we have calculated it in real images with a large variety of colors. This way, we get a description of the dominant colors present in an image in terms of fuzzy colors and the corresponding dominance degrees.

Figure 2 shows a graphical representation of the FDCD obtained from two color images. For the *parrot* image (Figure 2(a)), the Fuzzy Dominant Color Descriptor (Figure 2(c)) corresponding to fuzzy colors and its dominance degree (ordered in decreasing order of dominance degree) is $FDCD^{parrot} = 1/Black + 0.95/Green + 0.58/Orange + 0.39/Yellow + 0.29/Red + 0.22/Brown + 0.08/Blue + 0.03/Gray$.

Notice that the FDCD provides a full description of the perceived dominant colors present in Figure 2(a). As it is shown in this image, the background color ($Black$) is clearly dominant, which match with the $FDCD^{parrot}$ ($1/Black$). In addition, the colors present in the wings of the parrot ($Green$, $Orange$, $Yellow$ and $Red$) are less dominant than the background, as well as the colors of the trunk ($Brown$) and the head ($Blue$) are less dominant than the colors of the wings. It can be seen that our fuzzy descriptor captures the dominance degree of the wings colors ($0.95/Green$, $0.58/Orange$, $0.39/Yellow$, $0.29/Red$) and the trunk and the head colors ($0.22/Brown$ and $0.08/Blue$), respectively.

Similarly, in Figure 2(d) we can see the Fuzzy Dominant Color Descriptor obtained from the *flower* image (Figure 2(b)). In this case, $FDCD^{flower} = 1/Red + 1/Green + 0.89/Yellow + 0.73/Olive + 0.22/Gray + 0.06/Orange + 0.02/Brown$. Thus, the color of the petals and the leaves are clearly dominant ($1/Red$ and $1/Green$ respectively) and the colors of the stamen and pistil area dominate with less degree ($0.89/Yellow$). Finally, we can see that the color of the shadow in the petals is dominant to an insignificant degree ($0.02/Brown$).

Unlike existing techniques that consider *dominant* as a crisp concept, the FDCD describes dominance degrees to the fuzzy colors considered.

### 5.2 Retrieval examples

In this illustrative application, the *Flickr* online image database and the fuzzy inclusion and resemblance operators have been used for retrieving images. Flickr [19] is an image hosting which has increasingly been adopted by many web users to share and embed personal photographs. Nowadays, there are more than 5 billion images hosted in *Flickr*. We have used a collection of 10000 images provided by *Flickr* API [20] as the most interesting photos for a certain month.

Two retrieval examples will be shown in order to illustrate the performance of the FDCD for retrieving images. In the first example, linguistic labels will be used as query, whereas in the other example the query is specified as an image. Notice that our approach to dominant color descriptor allows us to perform both kind of queries with a single representation.

Figure 3 shows the retrieval results for the query *images where red and green are dominant*, using the color-based linguistic labels *Red* and *Green* as dominant colors. This query can be solved by considering the query descriptor will be $FDCD^{query} = 1/Red + 1/Green$, and determining its degree of inclusion in the dominant color description of each image. Retrieved images are shown in decreasing order of resemblance degree, that is shown below each image. Notice that images containing similar dominant colors can be found in these results. Furthermore, the most representative colors in these images match human perception of the color-based linguistic labels *Red* and *Green*.

Also, we may be interested in getting images with similar dominant colors to a sample image. This condition can be defined by using the fuzzy resemblance operator to compute the resemblance degrees between the fuzzy descriptor $FDCD$ and the corresponding $FDCD$ of each image in the collection.

We have used the $FDCD$ calculated for the previous image (Figures 2(b) ) for retrieving images with similar domi-

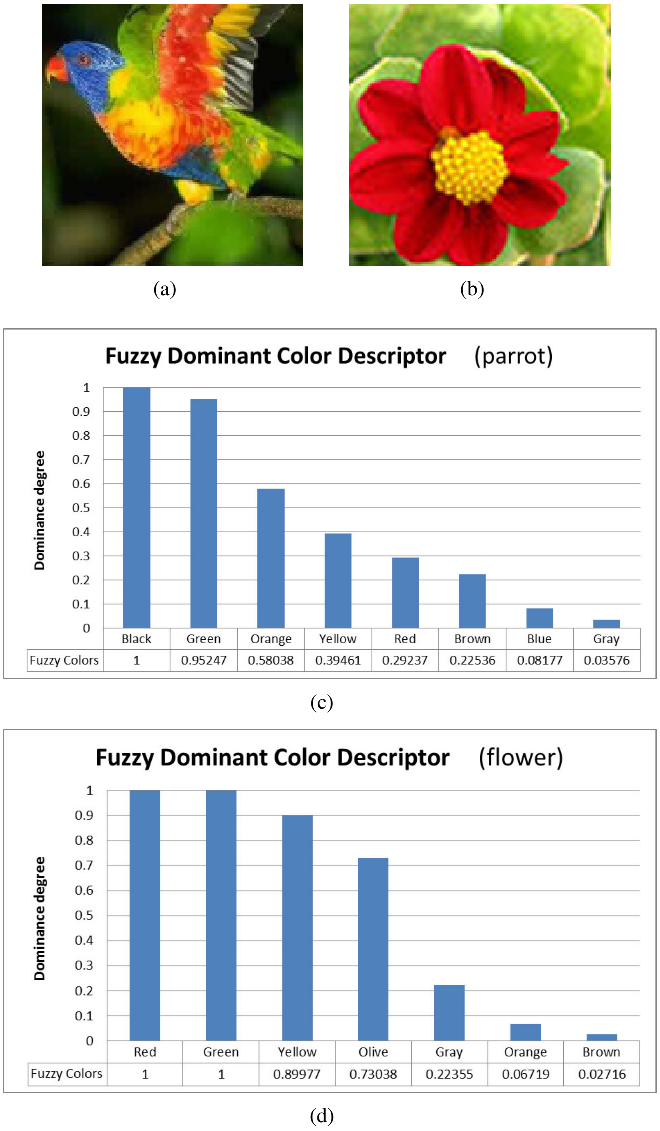



Fig. 2: **(a)** Parrot image. **(b)** Flower image. **(c)(d)** A graphical representation of the $FDCD$ obtained from (a) and (c) images respectively.

nant colors to this. In this case, the retrieval results are shown in Figure 4. These results are ordered by its resemblance degree. It can be shown that images with similar FDCD (similar dominant colors and dominance degree) can be found in these results.

## 6 Conclusions

In this paper, a new Fuzzy Dominant Color Descriptor has been proposed. This descriptor has been defined as a fuzzy set over a finite universe of fuzzy colors, in which membership degrees represent the dominance of each color. The color fuzzy sets have been defined taking into account the relationship between the color representation in computers and its human perception. In addition, fuzzy operators over the new descriptor have been proposed. We have illustrated the usefulness of our proposals with an application in image retrieval.

Several future work related to this will be to apply the descriptor in the linguistic description of images and other interesting applications. We also plan to define other color descriptors on the basis of the fuzzy color spaces we have introduced in previous works.

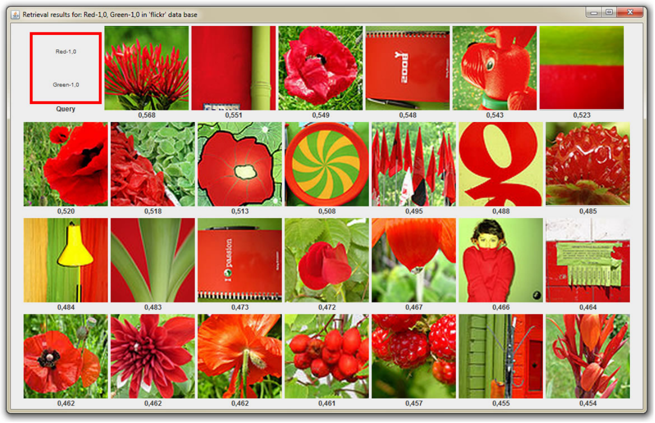
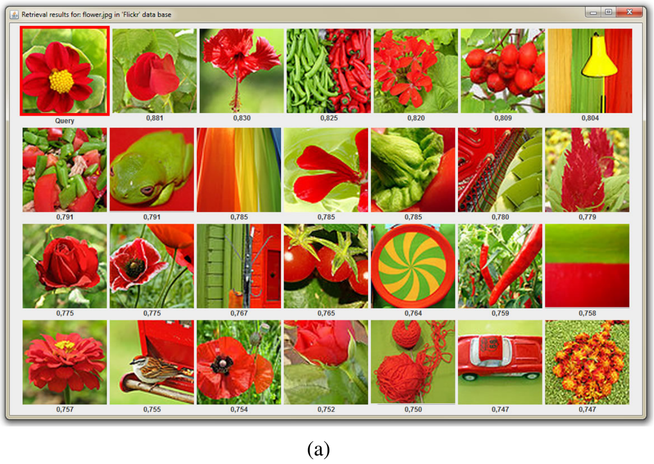


Fig. 3: Retrieval results on Flickr "interestingness" collection for the color inclusion query with the labels *Red* and *Green*



(a)

Fig. 4: Retrieval results on Flickr "interestingness" collection using the previously colorful image (Flower) as query.

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