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JFCS Tool: A Java software tool to design Fuzzy Color Spaces

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***Abstract*—This paper introduces a software tool for designing customized fuzzy color spaces able to fill the semantic gap between the color representation in computers and the subjective human perception. Fuzzy colors allow introducing semantics in the description of color by using linguistic labels, taking into account the fuzzy boundaries between the representation of color terms. *JFCS Tool* is based on an approach, proposed by the authors in previous works, for developing fuzzy color spaces on the basis of a collection of color names and corresponding color crisp representatives. The software is implemented in Java and includes several graphical tools to build fuzzy color spaces, allowing to obtain membership degrees of pixels taken from images to each fuzzy color in a certain fuzzy color space.**

I. Introduction

WITHIN cognitive science, vision science is concerned with the study of processes linked to perception from a computational perspective, with multiple practical and theoretical implications. Color vision is the branch of vision science devoted to the study of color perception [15], addressing problems like color naming and modelling. This is a fundamental issue since color is a very important visual feature used in computer vision and image processing.

In computers, colors are represented in a coordinate system as triplets of real values in several ways, with different domains and semantics for the real values. Each such system is called a *color space*. A well known example is the RGB color space, where the semantics of the three values defining a color is the amount of red, green, and blue necessary to provide the color, respectively. In this sense, color spaces can represent more colors than humans do, in addition to humans do not describe colors by means of of numerical triplets like $[255, 0, 0]$, but using linguistic terms like *red*.

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], [24], [25] or human-machine interaction systems [16]. It is clear that each linguistic term used by humans corresponds to a subset of color triplets as represented in computers. However, finding the set of triplets corresponding to a certain linguistic term is a very complex problem. The collection of employed color terms depends on the application domain and cultural issues, and also on the individual’s subjectivity. Finally, it is well known that the boundaries between sets of triplets representing different linguistic terms are fuzzy [18], [10].

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 in [19], [23], 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 have fuzzy representations, and hence many authors consider color naming as a fuzzy process [2], [13], [14], i.e., colors have been interpreted as linguistic labels represented by fuzzy subsets of triplets of a certain color space [21], [27].

However, in most of these fuzzy models, membership functions are defined on the basis of perceptual experiments, so the representativeness of the resulting color naming model is limited to these experiments, being not able to capture the influence of subjectivity, culture, and application domain. Colors in these proposals are usually defined by combining membership functions built over each color component. For example, the approaches in [1], [4], [26] introduce (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.

Furthermore, these proposals have no software available for use. In addition, even if software tools were provided, laborious experiments and expert skills would be required for defining a fuzzy color space, that would anyway suffer from the theoretical drawbacks already mentioned.

The aim of this paper is to introduce a non-commercial Java software tool, named *JFCS Tool*, that provides a suitable solution to the problem of defining appropriate computational models of linguistic color terms, consisting in fuzzy subsets of triplets in a color space. The main features of *JFCS Tool* are:

- It provides an easy framework to design customized fuzzy color spaces in order to meet the human intuition about color without tedious experiments. The user has to provide just the desired collection of linguistic color terms and a single crisp color that he/she considers as a good representative prototype for each color term, so it can be used by any non-expert user.
- The fuzzy color space is calculated automatically on the basis of the information provided by the user in a transparent way to the user. Also, the fuzzy colors correspond to a formal model based on the paradigm of conceptual spaces [7] including fuzzy boundaries, as proposed in [20].
- The possibility to employ existing color naming systems

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in the literature, providing a crisp representative color for each color term, for building fuzzy color spaces automatically, without previous knowledge.
- The fuzzy color space can be visualized and explored. In addition, the user can load any image and ask the system for the correspondence (membership degree) of crisp colors coming from pixels in the image, and the fuzzy colors in the fuzzy color space.
- It is portable and can be used on any machine with Java, independently of the operating system.

The rest of the paper is organized as follows. In section II, the fuzzy color modelling proposed in [20] is summarized. Section III presents *JFCS Tool*, its main features and modules. Some examples are showed in section IV. Finally, the main conclusions and future works are pointed out in section V.

II. Fuzzy Modeling of Colors

In this section, the notions of fuzzy color (Section II-A) and fuzzy color space (Section II-B) introduced in [20] are summarized.

A. Fuzzy color

For representing crisp 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 crisp color is represented by a single point. The most commonly used color space in practice is RGB, because it 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 combinations 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.).

We introduce the following definition of fuzzy color:

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

Hence, a fuzzy color can be defined as a normal fuzzy subset of points of a color space. As usual, "normal" means that for each fuzzy color $\widetilde{C}$ there is at least one crisp color $\mathbf{r}$ such that $\widetilde{C}(\mathbf{r}) = 1$.

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 $D_X \times D_Y \times D_Z$.

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

In this paper, and following the conceptual space approach in [20], we will define the membership function of $\widetilde{C}$ as

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

depending on three parameters: $S = \{S_1, \dots, S_n\}$ a set of bounded surfaces in XYZ verifying $S_i \cap S_j = \emptyset$ $\forall i, j$ (i.e., pairwise disjoint) and such that $Volume(S_i) \subset Volume(S_{i+1})$; $\Omega = \{\alpha_1, \dots, \alpha_n\} \subseteq (0, 1]$, 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 $\{t_1^c, \dots, t_n^c\}$ verifying $f(t_i^c) = \alpha_i \in \Omega$, where these knots are calculated from the parameters $\mathbf{r}$, 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 $\left|\overrightarrow{\mathbf{rp}_i}\right|$ the length of the vector $\overrightarrow{\mathbf{rp}_i}$.

B. 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 $\widetilde{C}_i \in \widetilde{XYZ}$ is associated to a representative crisp color $\mathbf{r}_i$. Therefore, for defining our fuzzy color space, a set of representative crisp colors $R = \{\mathbf{r}_1, \dots, \mathbf{r}_n\}$ is needed.

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 Ω_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. The result is a crisp partition of the color domain given by convex volumes, each volume being 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 [20].

III. JFCS: Java Fuzzy Color Space Tool

JFCS Tool is a Java software that provides an easy framework to design customized fuzzy color spaces. The obtained fuzzy color spaces meet the human intuition about color without tedious visual experiments.

The last available version of *JFCS Tool*, installation instructions can be downloaded from http://www.uco.es/~el1sohij/JFCSTool. A demonstration video the use of *JFCS Tool* can also be visualized on the website.

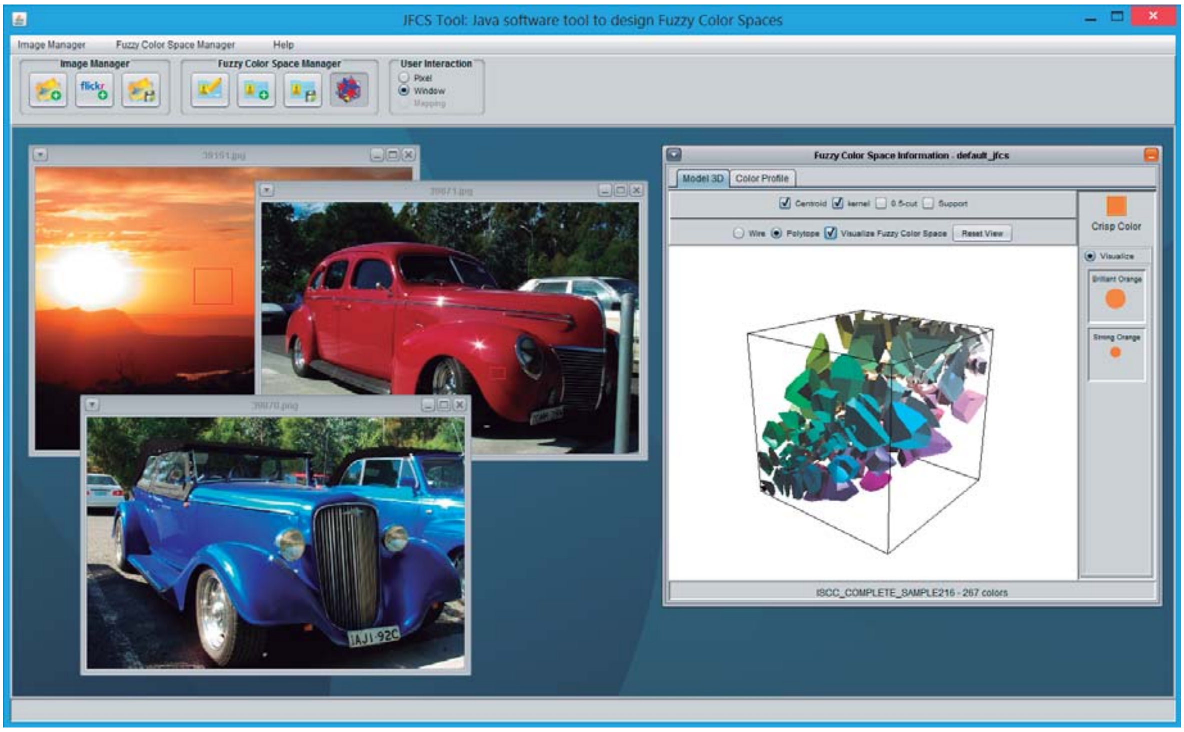


Fig. 1. An example of the main view of *JFCS Tool*

In the following subsections we describe the main characteristics and modules of *JFCS Tool*. In Section III-A the most relevant characteristics of *JFCS Tool* are explained in detail. The *Image Manager* module, responsible for managing images in *JFCS Tool*, is explained in Section III-B1. The *Fuzzy Color Space Manager* module, which is detailed in Section III-B2, handles the management of fuzzy color spaces, such as creating, editing, storing, etc. The *Fuzzy Color Space Information Display* module, in charge of showing information about fuzzy color spaces, is detailed in section III-B3. Finally, the *User Interaction* module is described in Section III-B4.

A. Characteristics

JFCS Tool is a non-commercial Java software tool which main contribution is to design customized fuzzy color spaces on the basis of a collection of crisp colors. In this sense, *JFCS Tool* allows to employ existing color naming systems in the literature for building fuzzy color spaces automatically. For this purpose, a crisp representative color and a label for each color term are provided with color naming systems. It is important to remark that *JFCS Tool* provides a very easy way to design fuzzy color spaces and it can be used by any non expert user.

Additionally, once a fuzzy color space is built, *JFCS Tool* allows to describe, in a simple way, the colors present on a given image.

Figure 1 shows an example of the main view of *JFCS Tool*.

B. Modules

The presently available version of *JFCS Tool* consists of the following functional modules:

1) ***Image Manager Module****:* This module is tasked with the management of images in *JFCS Tool*. Images can be saved in the computer or loaded to the main desktop framework of *JFCS Tool* from a local drive or from the *Flickr* online image database [6] by means of this module.

2) ***Fuzzy Color Space Manager Module****:* This module is made up of a set of tools that can be used to create, load, and save fuzzy color spaces. The module has three options, each of which is accessible through the menu or the buttons under *Fuzzy Color Space manager*. In the following, we will briefly describe them:

- *New Fuzzy Color Space*. This option permits to select a collection of crisp colors from a color palette or from images and to assign them labels. The selected crisp colors can be deleted or edited in a easy way. In addition, through the button *ADD (Images)* this module can select automatically the most fundamental crisp colors in images (by means of dominant color extraction process) and incorporate them into the selected crisp colors.

  Finally, the button *Create* builds a Fuzzy Color Space with the selected crisp color representatives and labels mentioned before and stores it in a file in the computer with a specific format.
- *Save Fuzzy Color Space*. This option saves the fuzzy color space as a file with a specific format designed

for storing the collection of fuzzy colors, labels, representatives and surface equations, among other key data. The files, with extension *.fcs*, are text files that can be open and read using any text editor. Example files can be also found in the web page http://www.uco.es/~el1sohij/JFCSTool.

- *Load Fuzzy Color Space*. This option allows to load an existing fuzzy color space from a stored file. For this purpose, a file browser is used and a preview of the fuzzy color space is showed before loading a Fuzzy Color Space in *JFCS Tool*.

*3) **Fuzzy Color Space Information Display Module**:* This module is used to represent, show and visualize information about the current fuzzy color space. It is accessible through the menu or the button on the right of *Fuzzy Color Space manager*.

This module has two sections, *Model 3D* and *Color profile*:

- *Model 3D*. This section displays a 3D visualization of a fuzzy color space within the RGB cube. Figure 3(b) shows a 3D visualization example of the kernel surfaces. Centroid, kernel, 0.5 alpha-cut, and support of fuzzy colors can be displayed by selecting the corresponding checkboxes. In addition, a navigation into the RGB cube can be done by clicking and dragging with the mouse in the RGB cube.
- *Color Profile*. This section shows information about the collection of representative crisp colors and color names of fuzzy color spaces. All the information can be edited and can be used to create a new fuzzy color space or modify an existing one.

*4) **User Interaction Module**:* The objective of this module is to show the membership of a crisp color to each fuzzy color in the current fuzzy color space. The crisp color is taken from a previously loaded image using one of two user interaction modes. *Pixel mode* allows to select one pixel and *Windows mode* allows to select a rectangular window. If pixel mode is activated, the crisp color of the selected pixel in the image is used as crisp color in *Model 3D* module. However, if windows mode is activated, the most representative color of the window (calculated as a median) is used. The membership degrees (only those greater than 0 are shown) of the selected crisp color to the fuzzy colors in the current fuzzy color space are shown in a visual way. For example, the memberships $0.57/Yellow$, $0.42/Orange$ are represented in the Figure 2, where each term is modeled by a color ball where the thickness corresponds with the membership degree and the background color with the representative crisp color of the fuzzy colors.

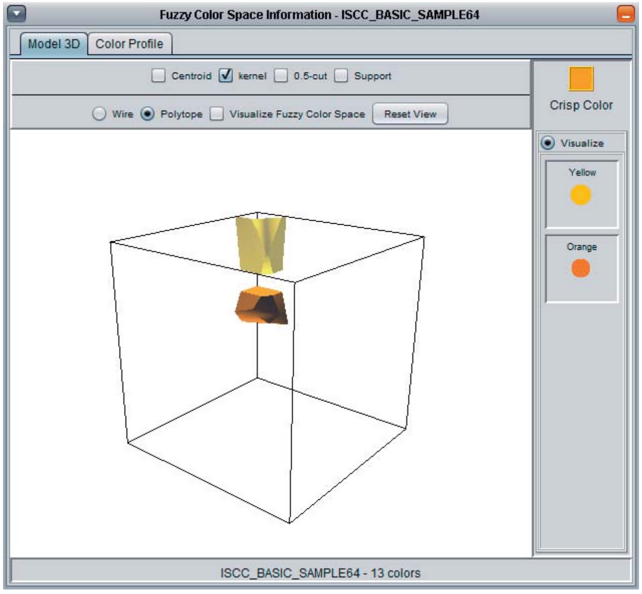


Fig. 2. An example of visual representation of the memberships $0.57/Yellow$, $0.42/Orange$

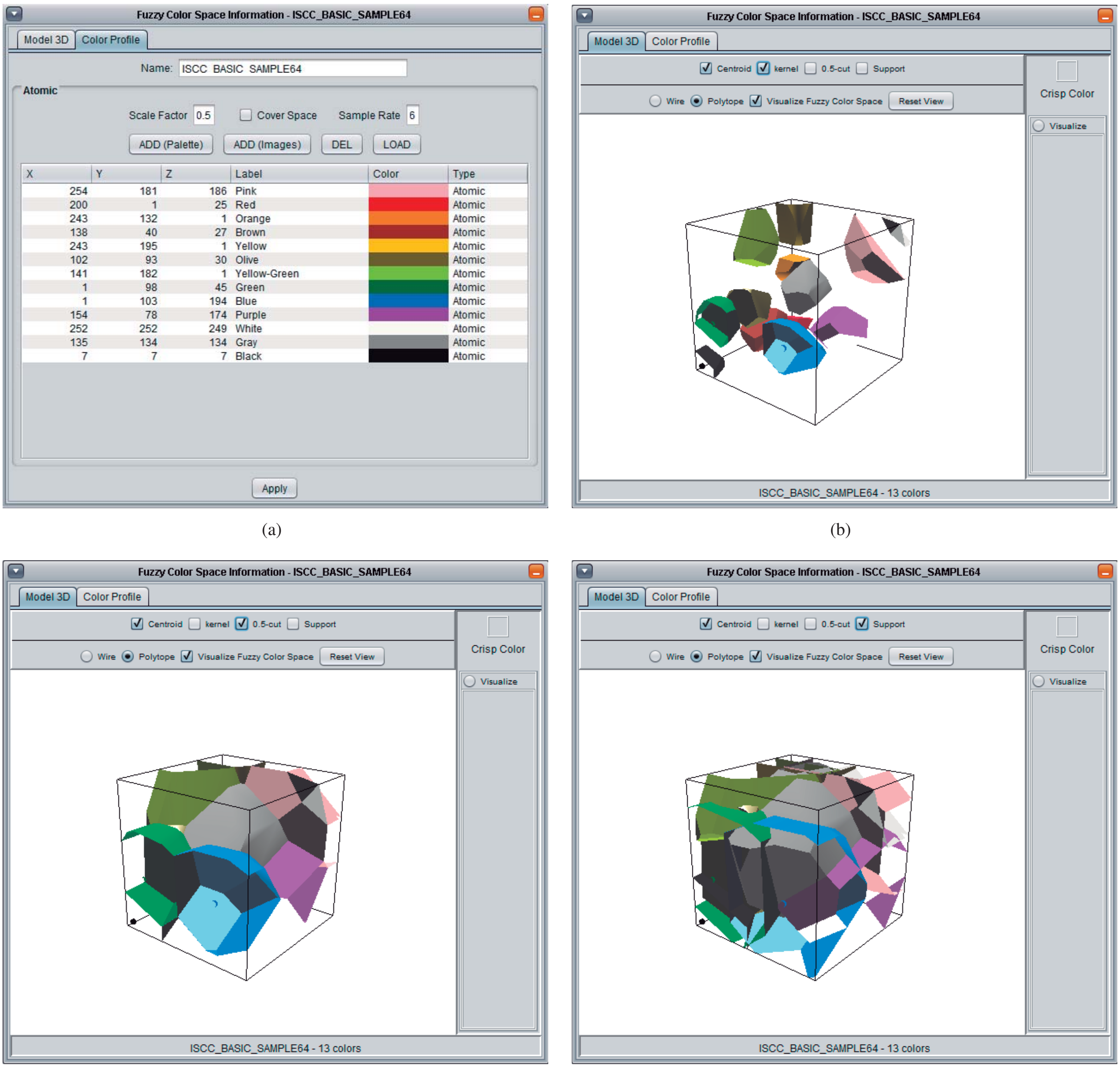
IV. Illustrative example

In this section we illustrate *JFCS Tool* by defining several fuzzy color spaces and obtaining descriptions of colors present in images in terms of fuzzy colors and the corresponding membership degrees.

We define several fuzzy color spaces using color names provided by the well-known ISCC-NBS system [12], [11]. 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)[2]. Specifically, three sets of color names: Basic Set (13 color names), Extended Set (31 color names) and Complete Set (267 color names), have been employed. On the basis of these color sets and using the *Fuzzy Color Space Manager* module (section III-B2) we have obtained three fuzzy color spaces, named $ISCC_{Basic}$, $ISCC_{Extended}$, and $ISCC_{Complete}$, respectively. Figure 3 shows an example of the creation of $ISCC_{Basic}$ and fuzzy representations for the colors provided by the basic set of ISCC-NBS using *JFCS Tool*.

In order to show the suitability of the fuzzy color spaces created, we have obtained the description in terms of fuzzy colors and the corresponding membership degrees, of colors present in several regions in images from the image collection *IAPR TC-12* [22]. This image collection[3] is created for the CLEF cross-language image retrieval track (ImageCLEF) [9] and consists of 20,000 still natural images annotated by users. These annotations contain a semantic description of the image contents [8], or in other words, they describe the images using short sentences and noun phrases. Among these semantic descriptions, basic color attributes based on the work of Berlin and Kay are used. For example, image "39870.jpg" of *IAPR TC-12* (Figure 4) is annotated with the sentence "*two blue and black vintage convertibles are standing on a grey car park with cars behind it and green trees and bushes in the background*".

[2]ISCC-NBS color centroids are available at http://tx4.us/nbs-iscc.htm
[3]*IAPR TC-12* is available at http://www.imageclef.org/photodata



(a) (b) (c) (d)

Fig. 3. An example of the $ISCC_{Basic}$ and fuzzy representations for the colors provided by the basic set of ISCC-NBS using *Fuzzy Color Space Information* module in *JFCS Tool*. (a) Color names and representatives in RGB. (b), (c), (d) 3D visualization of kernel, 0.5 alpha-cut and support surfaces in $ISCC_{Basic}$ respectively.

Figure 4 shows the four main color regions described by the user in the image "39870.jpg" of *IAPR TC-12* and the corresponding representative colors (calculated as the mean in this paper). Figure 5 shows descriptions in terms of fuzzy colors in $FCS_{Extended}$ and $FCS_{Complete}$ of region (C) (Figure 4) using *User Interaction* and *Fuzzy Color Space Information Display* modules.

The degrees of correspondence of the color of the regions (A) to (D) of the image with the fuzzy colors in FCS_{Basic}, $FCS_{Extended}$ and $FCS_{Complete}$ are shown in Table I. In our opinion, the linguistic terms that appear and the corresponding degrees are not conflicting with human intuition and are in accordance with user annotation in *IAPR TC-12* of the image "39870.jpg".

It is interesting to remark that the description of color (C) provided by using FCS_{Basic} is *Olive* whereas the user description of the "trees and bushes" in the image is *Green*. This is because Berlin and Key work consider only 11 basic color terms whilst the basic color set in ISCC-NBS consider 13, where color *Green* in Berlin and Key work corresponds

TABLE I
DESCRIPTION IN TERMS OF FUZZY COLORS IN FIGURE 4(A)-(D) FOR EACH FUZZY COLOR SPACE.

Region in figure 4	**RGB value**	FCS_{Basic} (13 colors)	$FCS_{Extended}$ (31 colors)	$FCS_{Complete}$ (267 colors)
A	[142, 144, 144]	0.71 / Gray	1.0 / Gray	0.72 / Purplish Gray
				0.27 / Pale Green
B	[3, 58, 185]	1.0 / Blue	1.0 / Blue	1.0 / Strong Blue
C	[70, 97, 49]	1.0 / Olive	1.0 / Olive	0.69 / Moderate Olive Green
				0.30 / Grayish Olive Green
				0.13 / Deep Yellow Green
D	[17, 20, 22]	1.0 / Black	1.0 / Black	/ 0.65 Blackish Green
				0.34 / Black

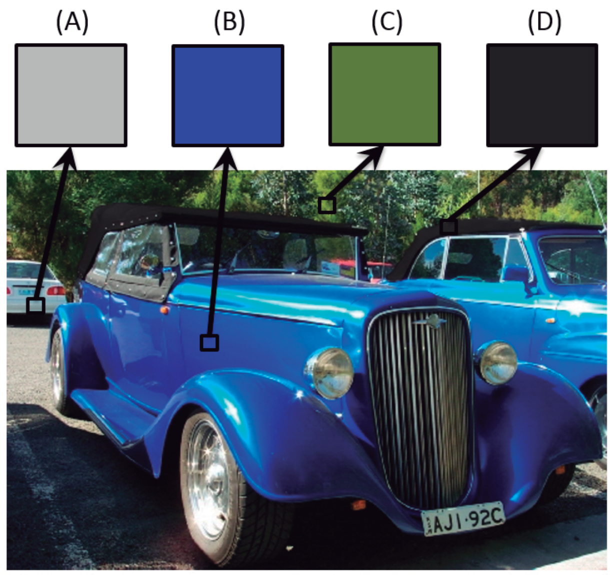


Fig. 4. Representative color (mean) of pixels of regions (A) to (D) in image "39870.jpg" of *IAPR TC-12*.

to colors *Green*, *Olive* and *Yellow-Green* in the basic ISCC-NBS color set.

Notice as well that colors (A), (B), (C) and (D) 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 space $FCS_{Complete}$ in most of the cases. For example, in the case of color (C), all the spaces agree that the linguistic label that best matches the color is *olive* (though they define *olive* in different ways); however, $FCS_{Complete}$ refines the description given by $FCS_{Extended}$ and FCS_{Basic} and gives degrees 0.69 to *Moderate Olive Green*, 0.30 to *Grayish Olive Green* and 0.13 to *Deep Yellow Green*.

V. CONCLUSIONS

JFCS Tool provides an easy framework to design and automatically obtain customized fuzzy color spaces in order to fill the semantic gap between color terms and crisp colors represented in computers. Fuzzy color spaces can be easily obtained by non-expert users, since the only information required is a representative crisp color for each linguistic color term to be modelled. A fuzzy color (normal fuzzy subset of crisp colors) is obtained which models the semantics of each color term. The fuzzy color space can be visualized and explored, and a matching between colors in images and the fuzzy color space can be obtained. The system is portable as it is based on Java and is available for free at http://www.uco.es/~el1sohij/JFCSTool.

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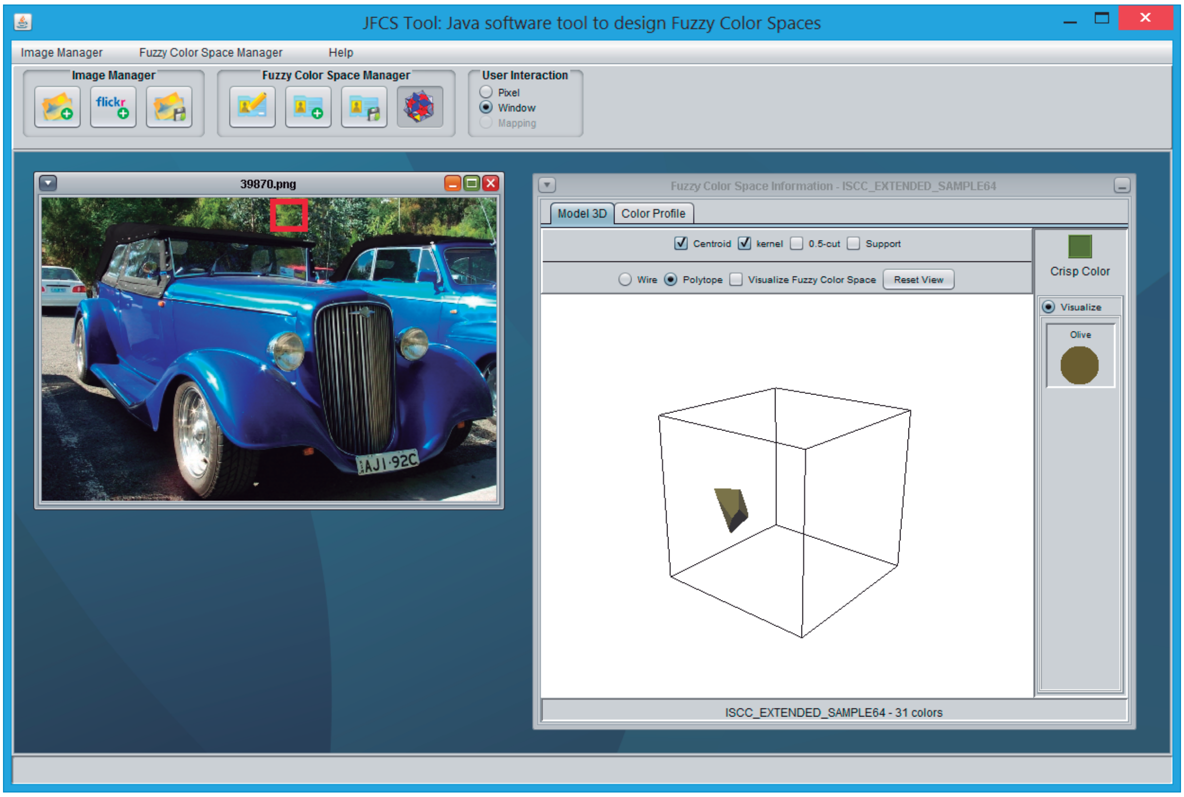
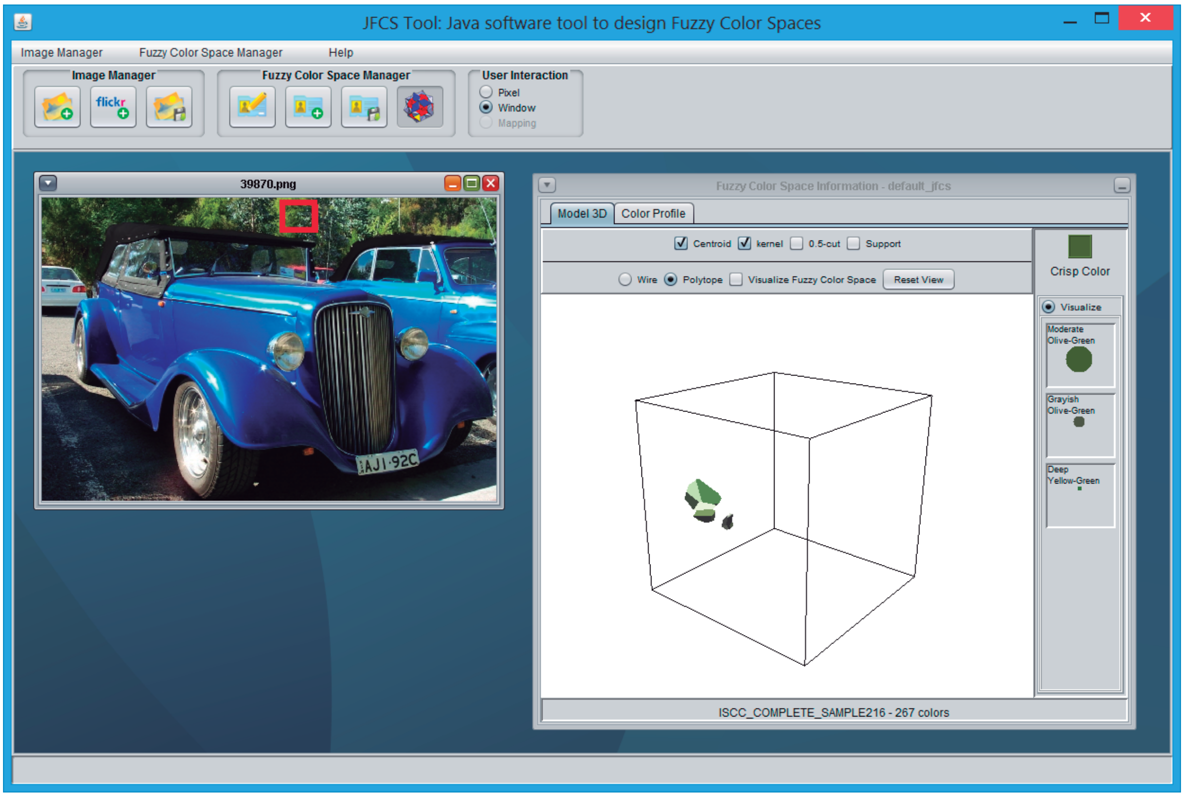


(a)



(b)

Fig. 5. Description in terms of fuzzy colors of region (C) of Figure 4 using *User Interaction* and *Fuzzy Color Space Information Display* modules. (a) $FCS_{Extended}$ (b) $FCS_{Complete}$

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