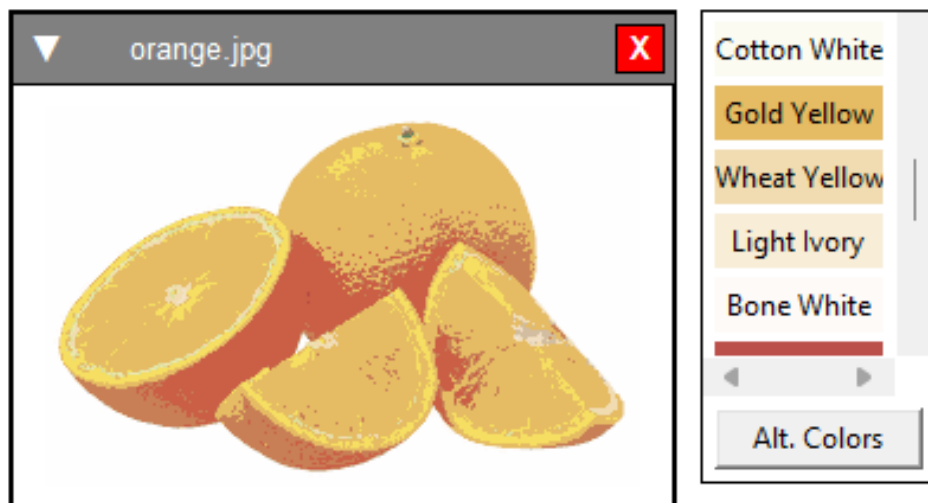
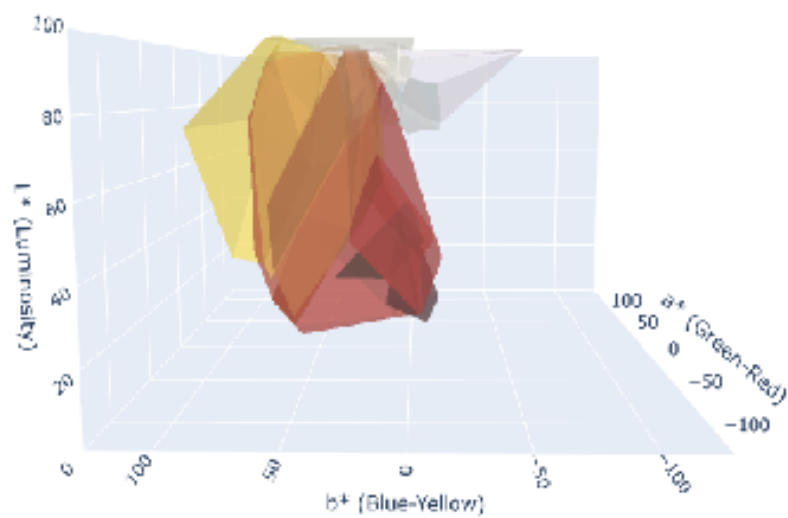


PyFCS GUI: User Manual and Technical Guide

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1 Introduction

PyFCS GUI is a graphical user interface developed as an extension of the open-source PyFCS library, designed for the creation and analysis of fuzzy color spaces. This GUI enhances usability and accessibility, enabling the generation of fuzzy color spaces from palettes or images, along with interactive 3D visualization and advanced color mapping tools.

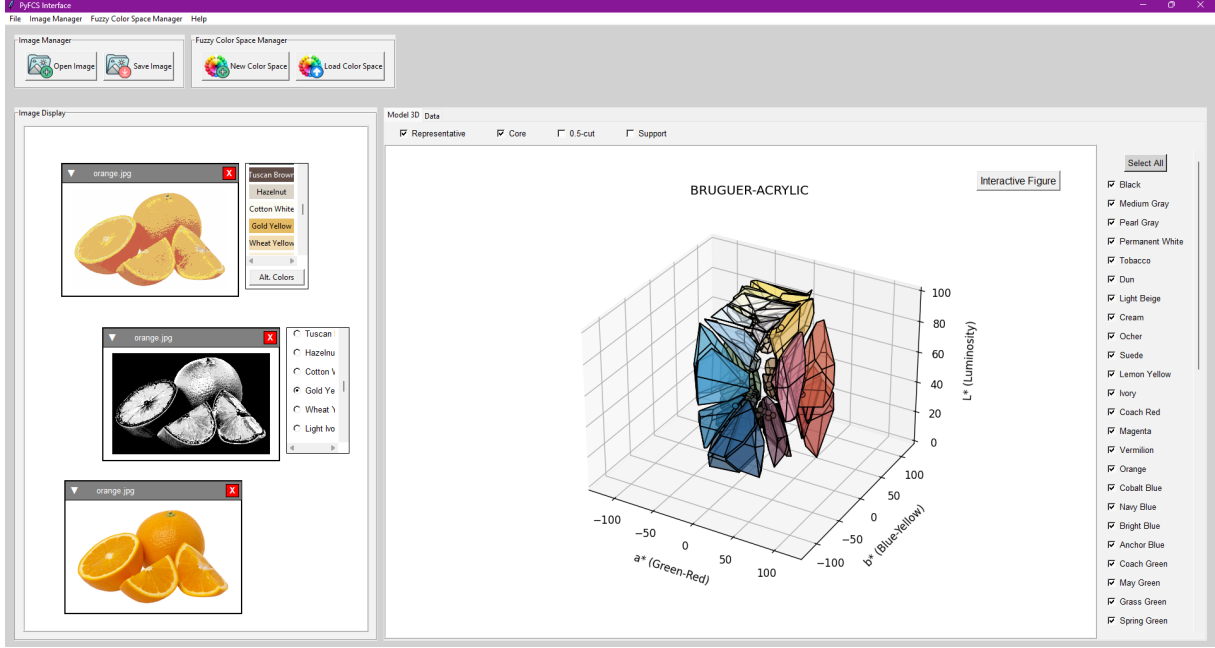


Figure 1: Main interface of PyFCS GUI.

Through parametric controls, it is possible to explore various levels of generalization and specificity in color representation. The generated color spaces can be exported in reusable formats to support reproducibility.

This extension facilitates the practical application of fuzzy color models, providing a versatile tool suitable for scientific research as well as artistic or perceptual analysis.

1.1 System Requirements

The following requirements must be met to ensure proper operation of the application:

- A runtime environment for executing Python scripts.
- Python version 3.9 or higher (version 3.10 recommended).
- The `pip` package manager installed and accessible from the command line.
- Operating system: currently available for Windows only.

2 Installation

The project is publicly available on GitHub at:

<https://github.com/RafaelConejo/PyFCS>

2.1 Installation Steps by Operating System

Before proceeding, ensure that a Python environment is properly configured. Python 3.9 or higher is required (Python 3.10 is recommended). You can use a standard installation or a virtual environment manager like Anaconda.

Important: The commands `python` and `pip` must be accessible from the command line. If not, make sure Python is added to your system's PATH.

Note: If the `pip` command is not recognized, it may not be installed or may not be in the PATH. Install it using:

```
python -m ensurepip --upgrade
```

More details: <https://pip.pypa.io/en/stable/installation/>

Windows

1. Download the project from GitHub using the "**Clone or Download**" option, or download the `.zip` file from the releases section.
2. Extract the `.zip` file to your preferred location.
3. Open CMD or PowerShell, navigate to the project's root directory, and install the dependencies:

```
pip install -r PyFCS\external\requirements.txt
```

4. Launch the interface by executing:

```
python PyFCS\visualization\basic_structure.py
```

Linux

1. Download and extract the project as described above.
2. Open a terminal and navigate to the project's root directory.
3. Make the setup script executable (only required once):

```
chmod +x ./PyFCS/external/setup_pyfcs_linux.sh
```

4. Run the setup script:

```
./PyFCS/external/setup_pyfcs_linux.sh
```

Note: The script automatically creates and activates a virtual environment, installs Python dependencies, and checks/install system-level dependencies like Tkinter. Make sure you have necessary permissions (e.g., `sudo`) if system-level installs are needed.

macOS

1. Download and extract the project from GitHub.
2. Open the Terminal and navigate to the project's root directory.
3. Make the setup script executable (only required once):

```
chmod +x ./PyFCS/external/setup_pyfcs_mac.sh
```

4. Run the setup script and launch the interface:

```
./PyFCS/external/setup_pyfcs_mac.sh
```

Note: The script automatically installs Python (via Homebrew), sets up the virtual environment, installs dependencies, and verifies Tkinter. Ensure you have **Homebrew** and the **Xcode Command Line Tools** installed.

3 Theoretical Foundations

3.1 Fuzzy Colors and Fuzzy Color Spaces

A *fuzzy color* is a flexible categorization of color that captures the subjective and imprecise nature of human color perception. Mathematically, a fuzzy color is defined within a color space (such as RGB or CIELAB [1]) where each color is associated with a membership degree that quantifies how representative it is of a particular fuzzy category.

Formally, given a color space C , a fuzzy color \tilde{C} is defined by a membership function $\mu_{\tilde{C}} : C \rightarrow [0, 1]$. A value close to 1 indicates a strong representation of the fuzzy color, while a value near 0 implies low representativeness.

A *fuzzy color space* is a collection of such fuzzy colors, each represented by its own membership function [2]. It provides a conceptual framework where color categories can have overlapping boundaries, reflecting the way humans perceive color. Formally, we define a fuzzy color space as $\tilde{\Gamma} = \{\tilde{C}_1, \dots, \tilde{C}_m\}$, where each fuzzy color \tilde{C}_i is defined on a crisp color space Γ .

3.2 Methodology for Developing Fuzzy Color Spaces

This subsection presents the methodology used for representing color terms as fuzzy colors. It combines the theory of conceptual spaces [2, 3] with specialized fuzzification techniques as described in [4]. While the approach can construct a complete fuzzy color space $\tilde{\Gamma} = \{\tilde{C}_1, \dots, \tilde{C}_m\}$, it does so by modeling each fuzzy color \tilde{C}_i individually.

Conceptual spaces typically define distinct, crisp categories. However, due to the fuzzy nature of color language, this methodology defines fuzzy boundaries by determining multiple α -cuts through a sequence of increasingly inclusive volumes $\mathcal{V}_{\tilde{C}_i}$ in the color space. These volumes are derived by scaling a central volume, representing the crisp category, to generate different levels of inclusion. According to the fuzzy set representation theorem, a fuzzy set can be reconstructed from its α -cuts. However, it is not practical to define all $\alpha \in (0, 1]$, so our approach defines key cuts (e.g., core and support) and interpolates the remaining membership values.

The fuzzification methodology from [4] follows these steps:

- **Prototype selection:** Identify a representative crisp color \mathbf{r}^i (positive prototype) for the color term C_i , and a set R_i^- of negative prototypes that are distinct from C_i .
- **Voronoi tessellation:** Apply a Voronoi partition on the crisp color space Γ using \mathbf{r}^i and the negative prototypes. The Voronoi cell V^i associated with \mathbf{r}^i represents the 0.5-cut of the fuzzy color \tilde{C}_i .
- **Core and support scaling:** Create the core volume V_1^i and support volume V_q^i by scaling V^i around \mathbf{r}^i using two scale factors: $\lambda \in [0, 1]$ to shrink for the core, and $\lambda' \in [1, 2]$ to expand for the support. These ensure separation from the cores of negative prototypes.
- **Membership interpolation:** Construct the membership function of \tilde{C}_i by linearly interpolating between the boundary surfaces of V_1^i , V^i , and V_q^i .

This method enables the software to represent human-like color categories with fuzzy boundaries and is used internally to classify, visualize, and interpret fuzzy color inputs.

4 PyFCS: Design and Features

Developed in Python, **PyFCS** is an open-source library available on GitHub¹. It provides a versatile and user-friendly framework for constructing and manipulating fuzzy color spaces. Its modular architecture, designed with Python’s broad adoption and scientific ecosystem in mind, ensures high accessibility and seamless integration with tools for scientific computing and image processing.

4.1 General Design and Modules

The architecture of PyFCS is carefully modular, with key components working together to support the construction and analysis of fuzzy color spaces. The main modules include:

- **Color Space Module:** Handles different color representations and conversions, essential for ensuring accurate processing across RGB, HSV, LAB, and other standards.
- **Geometry Module:** Manages geometric constructs such as points, vectors, planes, and faces. These are foundational for building and manipulating volumes in color modeling.
- **Fuzzy Logic Module:** Contains core fuzzy logic operations and algorithms for handling fuzzy color modeling and membership function computation.
- **Visualization Module:** Provides visualization tools for fuzzy colors and spaces, including support, core, and α -cut boundaries, improving interpretability.
- **Input/Output Module:** Supports file import/export in various formats to facilitate interoperability and persistence.
- **External Libraries Module:** Integrates external packages such as `skimage.color` and `scipy.spatial.Voronoi`, extending PyFCS capabilities.
- **Test Module:** Includes example scripts and test cases for validating and demonstrating the functionality of each module.

4.2 Core Classes and Responsibilities

PyFCS defines several key classes, each implementing specific functionality within the fuzzy color modeling pipeline:

- **ColorSpace.py:** Manages color space conversions (e.g., RGB, HSV, CIELAB), ensuring consistent and accurate color representation.
- **Point.py:** Represents points in a multidimensional color space; the fundamental building block for all geometric entities.
- **Vector.py:** Builds on **Point.py** to define vectors, providing direction and magnitude for geometric operations.

¹<https://www.github.com/RafaelConejo/PyFCS>

- **Plane.py:** Constructs planes from vectors to represent boundaries and spatial partitions in color space.
- **Face.py:** Assembles faces from planes, forming surface elements of volumes used in fuzzy color definitions.
- **Volume.py:** Manages the definition and manipulation of volumes (core, support, α -cuts), integrating with `scipy.spatial.Voronoi` for region generation.
- **FuzzyColor.py:** Defines fuzzy colors via their volume representations. Includes a label and membership function for proximity-based membership computation.
- **FuzzyColorSpace.py:** Orchestrates multiple **FuzzyColor** instances to construct and manage a full fuzzy color space.
- **Prototype.py:** Stores and manages color prototypes (positive and negative), critical for Voronoi-based fuzzification.
- **MembershipFunction.py:** Performs interpolation between α -cut surfaces to compute fuzzy membership degrees based on spatial relationships.
- **Input.py:** Facilitates parsing and adapting input data formats (e.g., `.fcs`, `.cns`) into PyFCS-compatible objects.

4.3 External Integration and Extensibility

PyFCS is built to integrate with well-established libraries like `skimage.color`, which ensures accurate color transformations, and `scipy.spatial`, which powers robust Voronoi tessellation and geometric computation. This enables a reliable and extensible platform suitable for both academic research and practical applications in fuzzy logic, color science, and human-centered computing.

4.4 Connection to PyFCS GUI

The **PyFCS GUI** is a graphical interface built on top of this library. All GUI functionalities—such as defining prototypes, visualizing color categories, and exporting fuzzy color spaces—are powered directly by PyFCS. Understanding the core PyFCS design is essential for developers or advanced users who wish to extend, debug, or interact with the system beyond the graphical layer.

5 User Guide

Upon launching the application, three main modules are available to create, visualize, and apply fuzzy color spaces. Their key functionalities are outlined below:

5.1 Fuzzy Color Space Manager

This module allows for the creation, loading, and management of fuzzy color spaces using two primary methods:

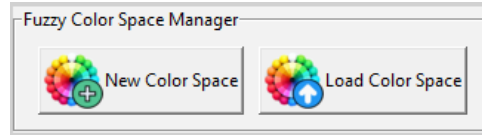


Figure 2: Fuzzy Color Space Manager module interface, showing available actions for creating and loading color spaces.

5.1.1 Creating New Color Spaces

The **New Color Space** button initiates the construction of a new fuzzy color space, which can be done through two main approaches:

- **Palette-based creation:** Colors can be entered in CIELAB space, labeled with linguistic tags, and used to automatically generate the corresponding fuzzy sets (Figure 3).

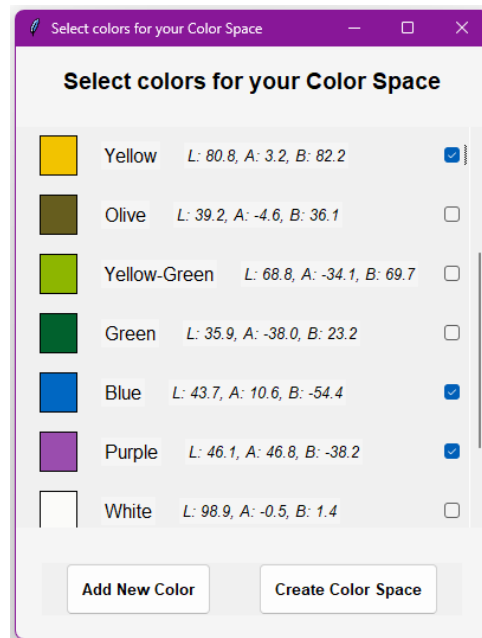


Figure 3: Palette-based creation interface.

Colors can be added using the **Add New Color** button. LAB values can be entered manually or selected visually using the **Browse Color** option, which opens a color

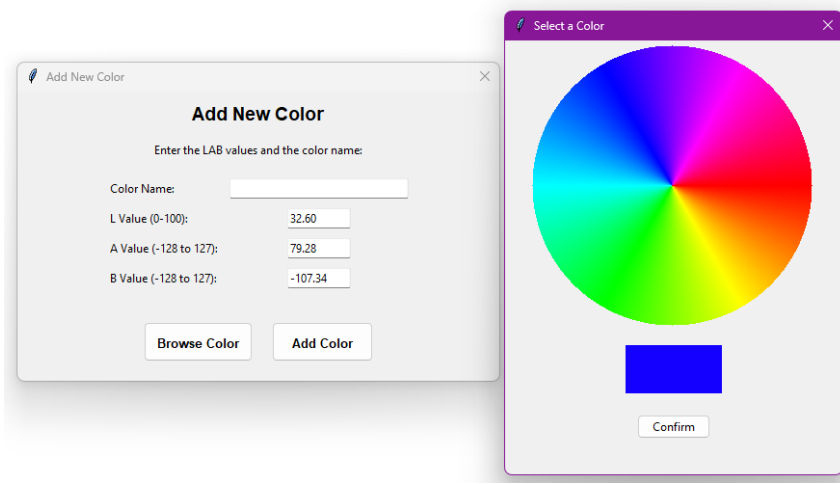


Figure 4: Color input interface showing the fields to define new color and linguistic label.

wheel (Figure 4). Each color must be named and confirmed using the **Add Color** button.

After adding at least two colors (minimum required to create a space), a dialog appears to name the fuzzy color space. The space is saved in the `PYFCS/fuzzy_color_spaces` directory with a `.fcs` extension.

- **Image-based creation:** A fuzzy color space can also be generated from dominant colors extracted from one or more images using the DBSCAN clustering algorithm [5] (Figure 5).

The threshold parameter (between 0 and 1) controls the generalization level. Lower values result in fewer, more generalized colors, while higher values yield more detailed segmentation. The **Recalculate** button must be pressed after modifying the threshold.

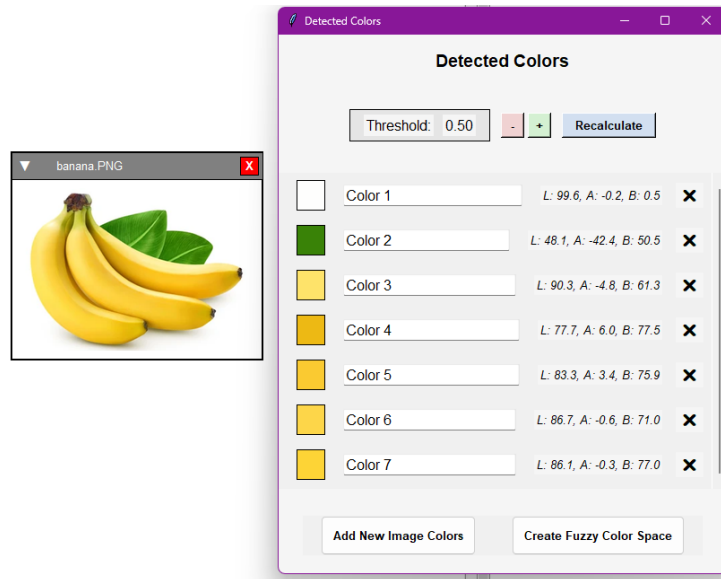


Figure 5: Example of color extraction from an image using DBSCAN.

At least one image must be loaded using the Image Manager Module for this function

to operate. The **Add New Image Colors** button allows the inclusion of additional colors from other loaded images.

Before finalizing the color space, detected color names can be edited, and undesired ones can be removed. The **Create Fuzzy Color Space** button triggers the naming dialog and saves the file in `PYFCS/fuzzy_color_spaces` with a `.fcs` extension.

5.1.2 Loading Color Spaces

The **Load Color Space** button allows for importing previously saved fuzzy color spaces. Files with `.fcs` and `.cns` extensions are supported. By default, the file browser opens in the `PYFCS/fuzzy_color_spaces` directory.

5.2 Fuzzy Color Space Visualization Module

This module offers interactive tools for visually inspecting and editing the structure of fuzzy color spaces:

- **3D Visualization:** Fuzzy colors are displayed in the CIELAB space using a 3D representation, showing crisp representatives, cores, α -cuts (e.g., $\alpha = 0.5$), and support regions (Figure 6).

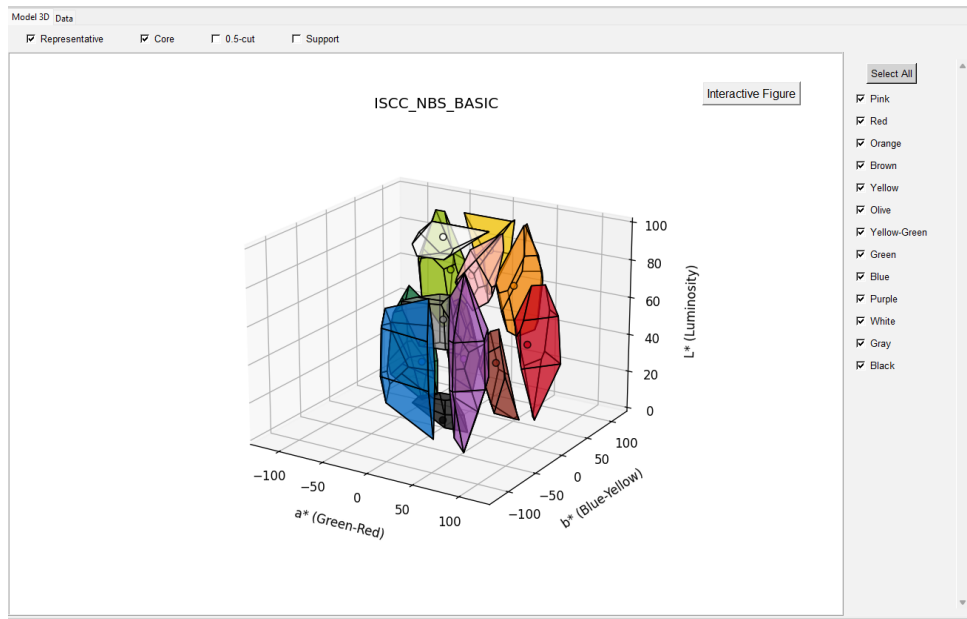


Figure 6: 3D visualization of a Fuzzy Color Space core regions.

Colors can be selected individually or all at once using the **Select All** button. The **Interactive Figure** button opens an auxiliary window with enhanced features such as zoom, pan, screenshot, and free rotation (Figure 7).

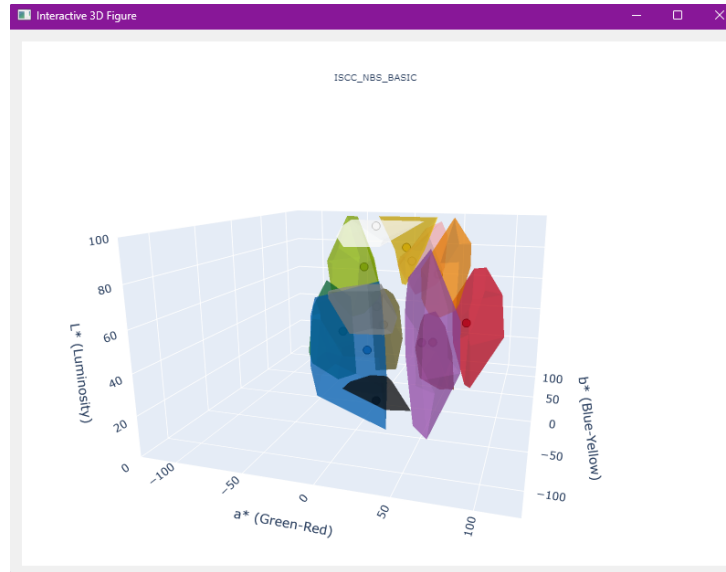


Figure 7: Interactive 3D view with navigation and inspection tools.

- **Data view and editing:** Alongside the graphical representation, each fuzzy color's linguistic label and crisp representative are shown, following the conceptual spaces framework [4] (Figure 8).

Model 3D Data

Name: ISCC_NBS_BASIC

L	a	b	Label	Color	
80.55	27.17	8.08	Pink		✕
41.81	66.9	46.51	Red		✕
66.19	36.09	72.49	Orange		✕
31.81	40.78	31.62	Brown		✕
80.79	3.18	82.19	Yellow		✕
39.15	-4.64	36.09	Olive		✕
68.84	-34.11	69.66	Yellow-Green		✕
35.85	-38.0	23.19	Green		✕
43.65	10.63	-54.36	Blue		✕
46.14	46.8	-38.16	Purple		✕
98.89	-0.53	1.44	White		✕
56.01	0.37	0.13	Gray		✕

Add New Color Apply Changes

Figure 8: Detail view of fuzzy color Data window.

The space can be edited—new colors added with **Add New Color** or existing ones deleted. Changes must be confirmed with **Apply Changes** to update both the file and visualization.

5.3 Image Manager Module

This module enables the application of fuzzy color spaces to image analysis and supports two main operations:

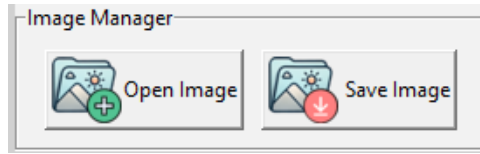


Figure 9: Image Manager module, showing the panel for loading and saving images.

The **Open Image** button allows loading images (jpg, jpeg, png, bmp). Multiple images can be opened and moved freely within the interface. Images can be closed via the red X in their top-right corner (Figure 10).



Figure 10: Loaded image with UI controls for closing and applying fuzzy color mappings.

By clicking the arrow on the left edge of each image frame, color space application options become available (after loading a fuzzy color space):

- **Color Mapping:** Displays the degree of membership of a specific fuzzy color across the image (Figure 11).

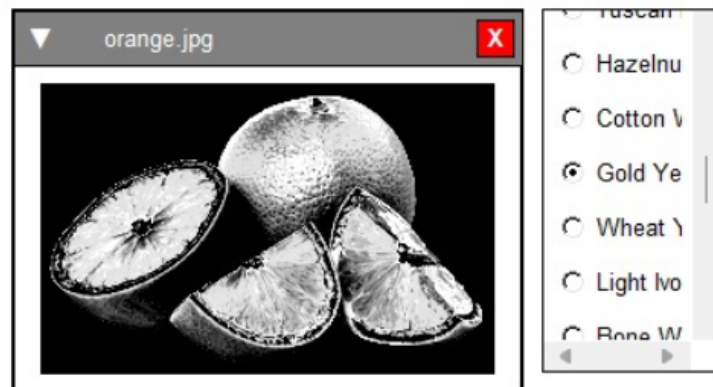


Figure 11: Fuzzy color mapping showing pixel-wise degrees of membership to a selected color of the *bruguer acrylic* color space.

- **Color Mapping All:** Reconstructs the entire image by assigning each pixel the fuzzy color with the highest membership. Two palettes are available: a custom-generated one and the original palette (toggle via **Alt. Colors**) (Figure 12).



Figure 12: Full image color mapping using *bruguer acrylic* colors space and alternate color palettes.

- **Original View:** Restores the original image for comparison or further processing.

If any modifications are made, the **Save Image** button enables exporting the processed image to a user-selected location.

5.4 Typical Workflow

The following is a representative workflow demonstrating how the system is used to analyze image colors with fuzzy color spaces:

1. **Load Image:** Open the *Image Manager Module* and use **Open Image** to select the image for analysis.
2. **Create Color Space:** In the *Fuzzy Color Space Manager*, click **New Color Space** and choose the image-based method. Use DBSCAN to extract dominant colors, adjusting the threshold as needed. Add more images with **Add New Image Colors** if desired.
3. **Edit Colors:** Review and optionally rename or remove colors. Click **Create Fuzzy Color Space** to name and save the space.
4. **Visualize:** Load the saved space in the *Visualization Module* using **Load Color Space**. Explore its structure in 3D with **Interactive Figure**.
5. **Analyze Image:** Return to the *Image Manager Module* and apply:
 - **Color Mapping** to view how a selected fuzzy color maps onto the image.
 - **Color Mapping All** to segment the image by fuzzy color membership.
6. **Save Results:** Use **Save Image** to export the processed image.

This workflow enables a complete analysis pipeline from raw image input to perceptually structured representation using fuzzy color spaces.

5.5 Additional Case Studies

To further illustrate the flexibility and practical utility of the PyFCS GUI, this manual includes references to a series of **additional case studies** available in the project’s GitHub repository. These examples complement the main illustrative scenario and demonstrate how the software can be effectively applied in a variety of real-world contexts.

While the core functionality is demonstrated through a single, focused example, the structure of PyFCS GUI is designed to support broader domains where nuanced color representation and perceptual modeling are essential. The additional case studies highlight applications in:

- **Digital Art & Palette Design:** Extracting dominant tones from artworks or prototypes to build fuzzy color spaces that reflect perceptual transitions between hues.
- **User Interface Design:** Developing adaptive and accessible color themes, such as color-blind-friendly palettes, based on perceptual clustering.
- **Cultural Heritage Restoration:** Comparing faded pigments with hypothesized original colors, incorporating uncertainty in chromatic reconstruction through fuzzy modeling.

5.5.1 Case Study: Chromatic Exploration of *Starry Night Over the Rhône*

This case study illustrates how PyFCS GUI can be used to extract and analyze the dominant chromatic components of an artwork. In this example, we apply the software to a digital reproduction of Vincent van Gogh’s *Starry Night Over the Rhône*, a painting well known for its rich blue hues and contrasting highlights.

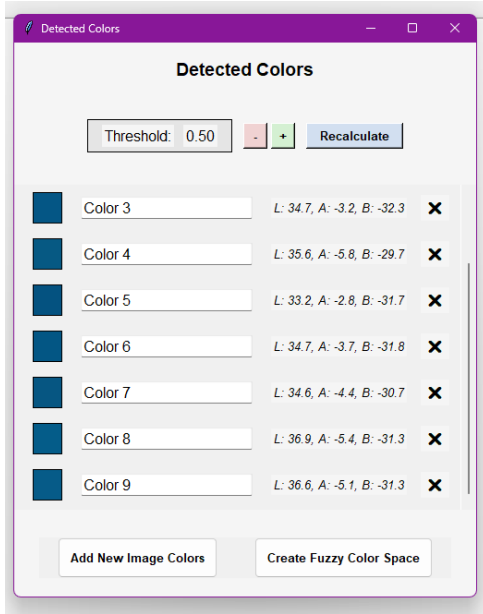
The input image (Figure 13a) is first analyzed using the fuzzy color space construction module. By adjusting the extraction threshold, users can control the granularity of color detection and clustering. Two different thresholds are explored:

- With a **lower threshold**, the algorithm isolates only the most dominant and distinct tones, resulting in a concise fuzzy color space composed of **9 representative colors** (Figure 13b). This setting is useful for identifying key perceptual anchors or dominant visual impressions.
- With a **higher threshold**, a more detailed fuzzy color space is constructed, capturing a wider range of perceptual variations and subtle transitions within the image. In this case, the algorithm identifies up to **64 distinct chromatic tones** (Figure 13c), offering a richer representation of the artwork’s color complexity.

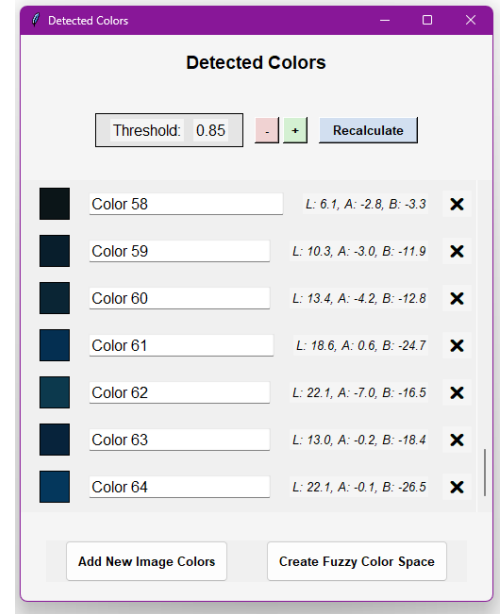
This example demonstrates the tool’s ability to support color-based exploration in digital art and visual analysis, enabling users to navigate between abstraction and fine-grained chromatic detail through simple parameter adjustments.



(a) *Starry Night Over the Rhône*.



(b) Fuzzy color space with 9 representative tones (low threshold).



(c) Fuzzy color space with 64 tones (high threshold).

Figure 13: Chromatic analysis of *Starry Night Over the Rhône* using PyFCS GUI.

Using the tools provided by the PyFCS GUI software 'Create Fuzzy Color Space', we generated a detailed color space composed of over **64 distinct colors**, accurately reflecting the chromatic diversity present in the painting. This enhanced color space enables targeted analysis based on the presence of specific tonalities within the image.

From this refined color representation, we proceeded to create a **color map focused exclusively on the presence of yellow**. This operation allows us to isolate and visualize only those regions of the painting where yellow tones are detected, highlighting their spatial distribution across the composition. To achieve this, the map was configured to



Figure 14: Color map highlighting only the regions corresponding to yellow tones.

include only the color vectors falling within the fuzzy range corresponding to yellow, as defined within the previously constructed color space.

The result is shown in Figure 14, where the illuminated areas created by the lampposts and their reflections on the water become clearly visible. These elements, rendered with vivid yellow strokes by Van Gogh, form a key component of the painting’s visual contrast.

5.5.2 Case Study: Chromatic Analysis of *Un dimanche après-midi à l’Île de la Grande Jatte*

This case study demonstrates the application of PyFCS GUI to the pointillist masterpiece *Un dimanche après-midi à l’Île de la Grande Jatte* by Georges Seurat. The painting’s technique—composed of small dots of pure color—creates a highly complex and rich distribution of hues, providing an ideal test for the software’s capability to extract detailed chromatic information.

Using PyFCS GUI with a **high extraction threshold**, the entire range of colors present in the image can be captured, revealing a comprehensive fuzzy color space that reflects the artwork’s intricate color variations.

This visualization of the full palette supports detailed analysis and offers valuable insights for digital art research, color theory studies, and palette design, by allowing users to perceive the subtle tonal gradations that compose the painting.

In this Figure 16, we can observe how the extracted fuzzy color space highlights a wide range of greens and blues found throughout the painting. These tones exemplify only part of the broader chromatic complexity captured by the system, which also detects many additional variations present in the original artwork. This level of detail allows for an in-depth perceptual analysis of color usage in pointillist compositions and demonstrates the potential of PyFCS GUI as a tool for visual deconstruction and palette exploration.



Figure 15: Un dimanche après-midi à l'Ile de la Grande Jatte.

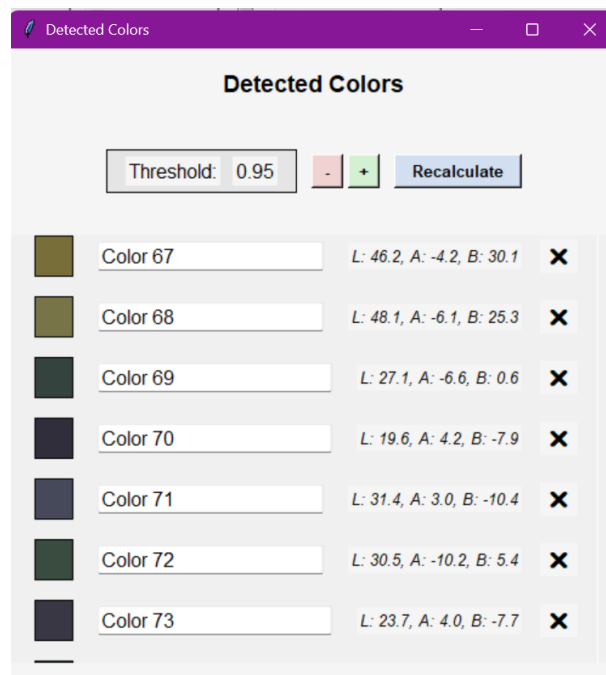


Figure 16: Fuzzy color space representing the full range of extracted tones with a high threshold.

6 Keyboard Navigation (or Shortcuts)

To enhance usability and improve accessibility—especially for users who may have difficulty using a mouse or trackpad—PyFCS GUI supports a set of intuitive keyboard shortcuts. These shortcuts enable users to perform common actions more efficiently and navigate the interface with ease.

Keyboard navigation improves the experience for users with motor impairments or those who simply prefer a keyboard-centric workflow. The available shortcuts are grouped below according to their function.

Global Shortcuts

- **Ctrl + O** — Open image
- **Ctrl + S** — Save image
- **Ctrl + W** — Close all images
- **Esc** — Toggle fullscreen

Color Space Management

- **Ctrl + N** — Create new color space
- **Ctrl + L** — Load color space
- **Ctrl + A** — Select all colors

Tab Navigation

- **Tab** — Switch to next tab
- **Shift + Tab** — Switch to previous tab
- **Ctrl + Tab** — Switch between 'Model 3D' and 'Data' tab

7 Contact and Support

- For technical support, please contact: rafaconejo@ugr.es

References

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