Comparative study of vectorial morphological operations in different color spaces

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ABSTRACT

In this paper, we present the results of the extension of the mathematical morphology to color images by treating multi-channel data as vectors. The approach presented here uses the HSI and related color spaces (intuitives). A modification of the lexicographical order for vectorial processing is developed. The importance of this new method lies on automatic selection of elements of the HSI and realted color spaces to form an ordering structure. The achievement of the algorithm is realized through the introduction of a weight factor to reduce the high preference of the first component of the classic lexicographical order. Experimental results demonstrate the improvement of this new method.

Keywords: Mathematical morphology, color images, vectorial processing.

1. INTRODUCTION

From the last years the color image processing has been subject of research. The use of color in image processing makes easier the tasks of high-level artificial vision. First, for a similarity with the human vision (completely chromatic) and second, for an increment of the information of the images, up to three times more information than in a monochrome image, what eases the localization, recognition and distinction of the objects [1,2].

Mathematical morphology, which is based on set operations, provides an approach to the development of nonlinear signal processing operators that incorporate shape information of a signal. The mathematical morphology has demonstrated to be a powerful tool for noise suppression, texture analysis, shape analysis, edge detection, skeletonization... [3]

From the results obtained in binary processing, Serra established the requirements for the extension of the morphological operations to grayscale or more complex images. According to Serra, the images have to be able to be represented by a numerical space that has a complete lattice structure [4,5,6].

The color images are represented by color pixels defined by a three-dimensional color space. The value at each image pixel is a 3D color vector. However there is not a generalized order for vectors (multivariate pixels In color images the pixels are represented by vectorial values, where each vector element is a greyscale image: $\mathbf{P}(x,y) = [P_1(x,y), P_2(x,y), P_3(x,y)]^T$ [7]. Trahanias and Venetsanopoulos [8] sumarize several techniques for ordering multivariate data. The two main approaches to processing are the *marginal ordering,* and the *vectorial ordering*. In [9] Comer and Delp comment differences between marginal and vectorial processing. With marginal ordering, each component P_1, P_2 or P_3 is ordered independently and the operations are applied in each color channel of the image .

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The use of marginal ordering in color image processing is the most straightforward approach. Nevertheless, this method may introduce visual changes in color and may also be unacceptable in applications that use color for object recognition (as in our case). A vector method for morphological processing is more advisable to avoid the above-mentioned disadvantages. In vectorial ordering only one processing is done on three-dimensional data (Fig. 2). In vectorial data there are several ways of establishing the order:

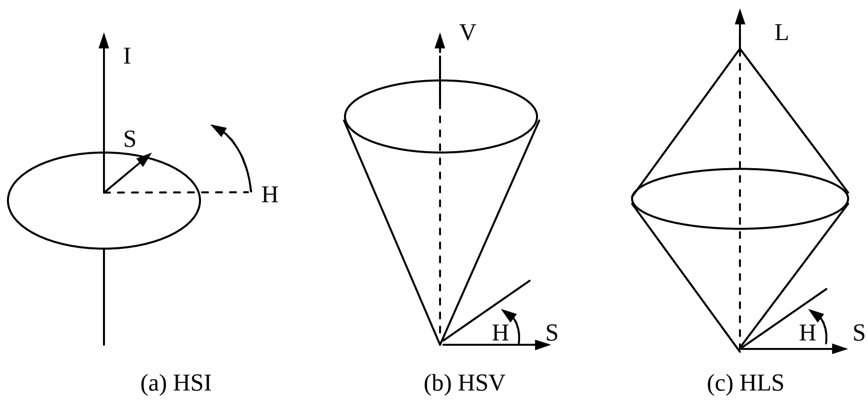
- Ordering by one component.
- Canonical ordering.
- Ordering by distance.
- Lexicographical order…

In *ordering by one component* the ordering is decided by just one element. In *canonical ordering* all three components of a color space must have either higher or lower values than another vectorial color. In *ordering by distance*, a distance function is used as an order measure. The *lexicographical method* is the order in which words are arranged in dictionaries: firstly, the order is decided with a chosen component, followed by a second element, and finally by a third value. In [10] these methods are discussed in greater detail.

The lattice description of morphology allows morphological theorems and techniques to be applied to images other than binary o grayscale [4,5,6] A lattice is a partially ordered set in which any two elements possess a least upper bound (called supremun) and a greatest lower bound (infimun). The supremun and the infimun are represented by the symbols and , respectively. A lattice is complete if every subset of the lattice has a unique supremun and infimun. The morphological operations must fulfill this latter condition. In order to calculate a dilation or an erosion the supremun and infimun notion is very important. In vectorial color image a dilation is a lattice operator that distributes the vectorial supremun and an erosion is a lattice operator that distributes the vectorial infimun.

2. HSI and Related Color Spaces for Processing

The color receptors in the human eye (cones) absorb light with the greatest sensitivity in the blue, green and red part of the spectrum, the signals from the cones are further processed in the visual system [11]. Nevertheless, a person cannot make intuitive estimates of the blue, green and red components of a determined color. In the perception process, a human can easily recognize basic attributes of color: intensity (brightness, lightness) I, saturation S and hue H. The hue represents the impression related to the dominant wavelength of the color stimulus. The saturation corresponds to relative color purity. Colors with zero saturation are gray levels. Maximum intensity is sensed as pure white, minimum intensity as pure black. The H, S, I components of the HSI color model are calculated from formulae expressing approximately the psychophysical sense of these notions from the RGB coordinate system to a cylindrical model of perceptions (Fig. 1.a) [1,7].



(a) HSI (b) HSV (c) HLS

Fig. 1: Intuitive color spaces.

Two other derivations of the generic HSI color space are applied usually in computer graphics and image processing: HSV and HLS. Figures 1.b and 1.c illustrate the geometric interpretation of these models. They differ of the original HSI model in the expression of the intensity and saturation values. For the HSV model the colors become less saturated when the intensity approaches minimal level. In HLS the colors become less saturated when the intensity approaches minimal or maximal levels. Important advantages of the HSI, HSV and HLS models over other color spaces are:

- Good compatibility with the human intuition, they are *intuitive* color spaces.
- Separatibility of chromatic values from achromatic values… [1,7]

For image processing a color system based on the human perception of color (HSI, HLS or HSV) may be more beneficial. It is necessary to consider the importance of each information channel for the processing of real images. The different color components do not have the same definition of the edges and details of this images. The chromatic signals of saturation and hue have less definition of edges and details that the achromatic signal of intensity, luminance or value [2,7]. In the next section we use a relation of order between pixels that considers this fact.

3. The Order in the Intuitive Color Spaces

For the vectorial approach of the mathematical morphology we need a complete lattice structure in the color space chosen for the processing. Now, the key point is to define a well order relationship in the color model of the pixels. A image can be represented by HSI as follows:

$$f : \mathbb{Z}^2 \rightarrow \mathbf{R}^3 : \mathbf{X} = (x,y) \} \mathbf{P} = (H,S,I) \qquad (1)$$

where $0 \le S \le 1$, $0 \le I \le 1$ and $0º \le H \le 360º$. In a discrete lattice these values are scaled to integers in the range 0 to 255. Due to the specific shape of the HSI, HLS and HSV space, a problem arises with some order methods. Saturation and value are totally ordered sets, but hue is not. Hue is angle valued, H(x,y) γ [0,2π). Hue is also module coordinate: a hue angle $\theta = \theta + 2\pi$. In addition, one cannot order hue from lowest to highest values. It does not make any perceptual sense to say, for example, that blue is greater than red. To order hues, Hanbury [12] and Peters [13] use a hue-valued structuring function. Hues are ordered according to the absolute value of a distance function between the image hue and a reference hue. The hue circles are partially ordered through the magnitude of the distance:

$$d(H_i, H_{ref}) = \begin{cases} \left|H_i - H_{ref}\right| & \text{if } \left|H_i - H_{ref}\right| \le \pi \\ 2\pi - \left|H_i - H_{ref}\right| & \text{if } \left|H_i - H_{ref}\right| > \pi \end{cases} \qquad (2)$$

The infimun in the hue set is the reference hue and the supremun is ((infimun + π)mod 2π). Fig. 2 shows the lattice of the hue circle in red (θ= 0º) as the reference hue (infimun). Dilation of hue is defined as the selection of the image hue value with the greatest absolute distance. Likewise, erosion of hue is defined as the selection of the hue pixel value that generates the least hue difference measurement.

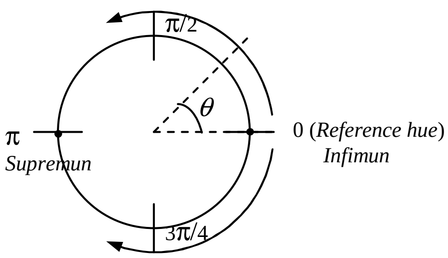


Fig. 2: Hue circle. Reference hue (infimun) in 0º.

Peters does not address how a pixel is chosen if two distinct color vectors have identical distance measurements. Hanbury uses an angle criterion. In this situation, we define infimun or supremun as being chosen by the positioning of the pixels on the structuring element. This way, we impose a total ordering on the hue component.

3.1 Classic lexicographical method

We use the lexicographical method in order to form a complete lattice structure in HSI and related color spaces. This algorithm requires an internal order in each of the components of the color models and another order or preference between the components [10,14]. There are a number of ways to order the HSI components relative to another. The preference or disposition of the components depends on the application and the properties of the images. Ordering with luminance in the first place is the best way to preserve the contours of the objects in the image. In situations where the objects of interest are highly colored or in which only objects of a specific color are interesting, the operations with hue in the first position should be the best. Nevertheless, this last one does not happen in real images. The luminance is the attribute that offers greater definition of scenes in real images. This way, in HSI and related color spaces, the order realtionship I $\rightarrow$ H $\rightarrow$ S has demonstrated to be the one that better visual results offers [14]. For an image *f* and two vector pixels $f(x_i,y_i)=\mathbf{P}_i$ and $f(x_j,y_j)=\mathbf{P}_j$, we define the lexicographical order o_{lex} as follows:

$$\mathbf{P}_i \underset{lex}{<} \mathbf{P}_j \quad \text{if} \quad \begin{cases} I_i < I_j \\ \text{or} \\ I_i = I_j \quad \text{and} \quad d(H_i, H_{ref}) < d(H_j, H_{ref}) \\ \text{or} \\ I_i = I_j \quad \text{and} \quad d(H_i, H_{ref}) = d(H_j, H_{ref}) \\ \quad \text{and} \quad S_i < S_j \end{cases} \tag{3}$$

4. Color Morphology

For color morphology we define the erosion, dilation, and more complex operations as vector operations [4,8,10,14]. This paper only considers a flat structuring element *K* for the morphological processing. The vector erosion ε_v of *f* by *K* at the point (*x*,*y*) is defined as follows:

$$\varepsilon_{vK}(f)(x,y) = \min_{\substack{o_{lex} \\ (s,t)\in K}} f(x+s, y+t) \tag{4}$$

Similarly, the dilation δ_v of *f* by *K* is expressed by the following equation:

$$\delta_{vK}(f)(x,y) = \max_{\substack{o_{lex} \\ (s,t)\in K}} f(x+s, y+t) \tag{5}$$

The new definition of $\min_{o_{lex}}$ and $\max_{o_{lex}}$ is important because they are now vectorial operations. The $\min_{o_{lex}}$ and $\max_{o_{lex}}$ are equivalent to vectorial set operators of infimun $\wedge_v$ and supremun $\vee_v$, respectively. The infimun and supremun are calculated by the order of o_{lex} defined in (3):

$$\mathbf{P}_i \wedge_v \mathbf{P}_j = \begin{cases} \mathbf{P}_i & if \quad \mathbf{P}_i \le \mathbf{P}_j \\ \mathbf{P}_j & if \quad \mathbf{P}_i > \mathbf{P}_j \end{cases} \qquad \mathbf{P}_i \vee_v \mathbf{P}_j = \begin{cases} \mathbf{P}_i & if \quad \mathbf{P}_i \ge \mathbf{P}_j \\ \mathbf{P}_j & if \quad \mathbf{P}_i < \mathbf{P}_j \end{cases} \tag{6}$$

An example of morphological operation in a color image is shown in Figure 3. Figure 3.a illustrate the original image for processing. It is a real and very chromatic image. Figures 3.b, 3.c and 3.d show the result of processing. A erosion of the original image by a flat 3x3 structuring element is made with HSI (Fig. 3.b), HLS (Fig. 3.c) and HSV (Fig. 3.d) color spaces. The reference hue used for H-ordering is 0º. In the first erosion, the HSI space is used, with the lexicographical order: I $\rightarrow$ H $\rightarrow$ S. In the second one, the HSL space, with processing order L $\rightarrow$ H $\rightarrow$ S and finally, in the third, where the order is V $\rightarrow$ H $\rightarrow$ S. Visually, the differences are hardly imperceptible. These subtle differences are mainly due to the luminance component (intensity or value) of the color space which is chosen. The contribution of the saturation and hue components are nearly negligible.

(a)

(b) (c) (d)

Fig. 3. Vectorial morphology by lexicographical order in different color spaces. (a) original image. (b) erosion by HSI color space. (c) erosion by HLS color space. (d) erosion by HSV color space

If we observe the statistics of use of the color components in the lexicographical order, the crucial influence of the luminance is obvious. Around 95% of the processed pixels are sorted by the luminance, remaining the hue and the saturation with insignificant contributions. As the table illustrates, this rigidity of the lexicographical order with regard to the first component does not depend on the color space.

Color space	Use HSI elements (%)		
	I	H	S
HSI	94,23	4,50	1,26
HLS	94,22	4,42	1,35
HSV	95,09	3,59	1,31

Table 1. Use of the components in the lexicographical order.

Owing to these results, we propose a new lexicographical order, introducing a factor for weighting the excessive dependence of the classical lexicographical order on the first component. According to the value of this factor, the use of the luminance decreases or increases, with respect to the second component. Formally, the new vectorial order $o_{\alpha\text{-}lex}$ is defined as:

$$\mathbf{P}_i \underset{\alpha-lex}{<} \mathbf{P}_j \quad \text{if} \quad \begin{cases} (I_i+\alpha) < I_j \\ \text{or} \\ (I_i+\alpha) \geq I_j \\ \text{and} \quad d(H_i,H_{ref}) < d(H_j,H_{ref}) \\ \text{or} \\ (I_i+\alpha) \geq I_j \\ \text{and} \quad d(H_i,H_{ref}) = d(H_j,H_{ref}) \\ \text{and} \quad S_i < S_j \end{cases} \qquad \mathbf{P}_i \underset{\alpha-lex}{>} \mathbf{P}_j \quad \text{if} \quad \begin{cases} (I_i-\alpha) > I_j \\ \text{or} \\ (I_i-\alpha) \leq I_j \\ \text{and} \quad d(H_i,H_{ref}) > d(H_j,H_{ref}) \\ \text{or} \\ (I_i-\alpha) \leq I_j \\ \text{and} \quad d(H_i,H_{ref}) = d(H_j,H_{ref}) \\ \text{and} \quad S_i > S_j \end{cases} \tag{7}$$

The weight factor is defined between 0 and 255. The use of the first component of the lexicographical order is reduced by the value of α factor. For low values of α, the new lexicographical order will use luminance more times. According to α is increased, the hue and saturation will use instead of the luminance. The preference between the HSI elements is partially modified with this factor of weight according to the pixels values of the image. This way, the preference between components of HSI is more automatic.

4.1 Erosion of an image by α-lex

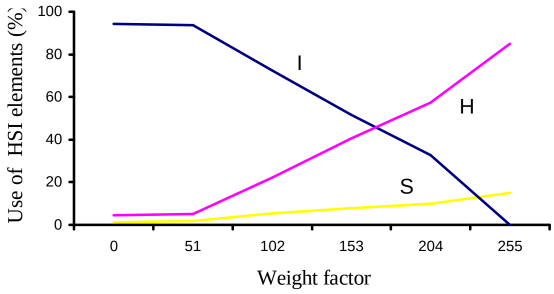
We use the new lexicographical order to calculate the erosion (by a 3x3 square and flat structuring element) of the original image of Figure 3.a. Figures 4.a, 4.b and 4.c show the results by differents values of α. Figure 4.a shows the erosion of the original image with α=51 (20% of its maximun value). In Figure 4.b, α=102 (40%) has been used. Finally, in Figure 4.c, α=153.

Table 2 illustrates the use of the components of HSI according to α. We have made measurements for six values of α: (0, 51, 102, 153, 204, 255). Obvious, when α=255, the use of intensity is nonexistent. Figure 5 shows graphically the evolution of the use of hue, saturation and intensity for the morphological operation of erosion.

(a) (b) (c)

Fig. 4. Erosion by different values of α.

α	Use HSI elements (%)		
	I	H	S
0 (0%)	94,23	4,50	1,26
51 (20%)	93,57	5,12	1,71
102 (40%)	72,47	22,17	5,35
153 (60%)	51,57	40,48	7,94
204 (80%)	32,69	57,31	9,99
255 (100%)	0		



85,06
14,93

Table 2. Use of the components of HSI according to α.

Fig. 5: Use evolution of intensity, hue and saturation.

4.2 Dilation of an image by α-lex

Now, we use, for processing ,another image and another color space: the 'Lenna' image and the HLS color system. The morphological operation used to the processing of 'Lenna' is the dilation. The original image (Fig. 6.a) is dilated by a flat structuring element of 3x3. The result is shown in Figure 6.b. Like with erosion, in Table 3 we observe the high use of luminance, (93%) with respect to hue and saturation.

Color space	Use of HLS elements (%)		
	L	H	S
HLS	93,09	5,89	1,09

Table 3. Use of the components in the lexicographical order of HLS color space

The results of α-lex for the dilation of 'Lenna' can be seen in Figures 7 and 8. The original image is first dilated by a value of α=51, (Figure 7.a). Note that there are not many changes with respect to the dilation of Figure 6.b. Figure 7.b illustrates the dilation by α=102 (40% of its maximun value). Now, the luminance is only used in the 60% of the order decisions: the image regions with a luminance difference greater than the value of α, for example, the bonnet of Lenna with respect to background. Finally, in Figure 8.a and 8.b we show the results of processing with a high value of α.

(a) (b)

Fig. 6: Morphological processing to Lenna by lexicographical order on HLS. (a) Original image. (b) Dilation of Lenna by a flat structuring element of size 3x3.

Table 4 shows the statistics of use of the color components in the lexicographical order for six different dilations of the original image. The use of hue and saturation is normalized as it increases the value of α. The graphical evolution of the attributes of color in the lexicopraphical order can be seen in Figure 9.

(a) (b)

Fig. 7: Dilation by α-lexicographical order on HLS. (a) Dilation by α=51. (b) Dilation by α=102.

(a) (b)

Fig. 8: Dilation by α-lexicographical order on HLS. (a) Dilation by α=153. (b) Dilation by α=204.

α	Use of HLS elements (%)		
	L	H	S
0 (0%)	93,09	5,89	1,09
51 (20%)	90,70	8,08	1,21
102 (40%)	60,65	28,50	3,44
153 (60%)	41,78	51,43	6,77
204 (80%)	5,37	82,73	11,92
255 (100%)	0	87,43	12,56

Table 4. Use of the components of HLS according to α.

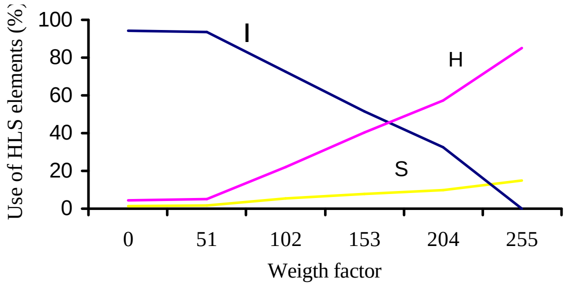


Fig. 9: Graphical evolution of luminance, hue and saturation.

CONCLUSIONS

In this paper a comparative study of vectorial mathematical morphology in different intuitive color spaces has been presented. We have develop a new lexicographical method in order to form a complete lattice structure in HSI and related color spaces. We have reduced the high dependency of the intensity in order decision with this method. The success of the algorithm has been demonstrated. Actually, we will continue the research of the extension of the mathematical morphology to color images. In future works, more complex morphological operations will be defined and concrete applications will be developed.

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