Adaptive spatio-colorimetric classification

Michèle Gouiffès
michele.gouiffes@ief.u-psud.fr

IEF Institut d'Electronique Fondamentale UMR 8622
Université de Paris XI ORSAY, France
Introduction

- **Color classification methods**:
  - Clusters of colors in the color space
  - Modes in color histograms

- **Spatio-colorimetric classification**: introduction of spatial information in the attributes to classify
  - Classical classification methods using extended attributes: vector of neighbors pixels [Ferri 92]
  - Neural network [Campadelli 97]
  - Fuzzy classification [Noordam 00]
  - Homogram [Cheng 03]: fuzzy homogeneity vectors
  - Pyramid of connectedness degrees [Fontaine 01]. Spatial color compactness degree [Macaire 06].
Introduction

Our approach:
Use of the connectedness degree in a more time-effective classification method.

A two-stage technique:
- monochromatic analysis and reduction of colors
- trichromatic analysis

Future applications: segmentation in road sequences
The connectedness degree

- **First order probability of a color interval**

  Trichromatic components $c_i=(c_1, c_2, c_3)$
  Monochromatic color intervals of size $2w+1$: $I(c_i, w)=[c_i-w, c_i+w]$

  First order probability of a color interval:
  
  $$P_1(I(c_i, w)) = \sum_{a \in I(c_i, w)} P_i(a)$$

- **Second order probability of a color interval**

  Occurrence probability $P_{oc}(a, b)$: probability that colors $a$ and $b$ are neighbors (8-connectedness)
  Co-occurrence probability $P_{cc}(a, b) = \frac{1}{8} \sum_{a \in N(b)} P_{oc}(a, b)$

  Second order probability of a color interval:
  
  $$P_2(I(c_i, w)) = \sum_{a \in I(c_i, w)} \sum_{b \in I(c_i, w)} P_{cc}(a, b)$$

  An interval $I$ on the R component
The connectedness degree

- Connectedness degree
  \[ D(I(c_i, w)) = \frac{P_2(I(c_i, w))}{P_1(I(c_i, w))} \]

- Property: maximun when the interval \( I(c_i, w) \) corresponds to one or several connected components in the image, i.e to a meaningful color interval in terms of connectedness.

- Previous works on the connectedness degree:
  - [Fontaine00]: gray images, multi-level 2D data structure.
    - By analyzing different sizes of intensity interval, the relevant intensity classes are computed by extracting some signatures in this representation.
  - [Fontaine01]: extension to color.
    - Multi-level pyramid of connectedness for each bichromatic histogram.
    - 3 pyramids are required to extract each meaningful color interval ⇒ not time-effective.
The procedure

1. **Marginal analysis** of color connectedness degree on each color component independently.
   - Extraction of the most meaningful color intervals on each color component (local maxima of degree)
   - Reduction of the number of monochromatic colors

2. **Combination of colors**

3. **Vectorial analysis**: analysis of the trichromatic connectedness degrees.

Possible following stages:

- Segmentation through a labeling process.
- Detection of specific regions.
First stage: marginal analysis

- Searching for local maxima of connectedness degree for $w=1 \ldots w_{\text{max}}$

$$w_i = \{ w \mid D(I(c_i, w+1)) < D(I(c_i, w)), \ w < w_{\text{max}} \}$$
The procedure

- First stage: marginal analysis
  - Searching for local maxima of connectedness degree for $w=1 \ldots w_{\text{max}}$

$$w_i = \{ w \mid \Delta I(c_i, w+1) < \Delta I(c_i, w), \ w < w_{\text{max}} \}$$

- Local maximum of $\Delta(I(c_i, w))$

$I_i = [c_i - w_i, c_i + w_i]$
The procedure

- Color combination
  - Color are sorted in decreasing order of degree
  - Pixels are classified in that order
  - Reduction of the number of colors

Each color of the interval inherits the centroid color and will not be treated anymore by a less relevant interval.
The procedure

Combination of monochromatic components ⇒ all possible trichromatic values

Color combination \( c_n \) for \( n=1\ldots N \) gets:
the color vector \( c(n)=(c_1(n), c_2(n), c_3(n)) \)
Vectorial analysis

Cubic color interval $I(c_n, d)$ in the color space, centered around the color $c(n)$ and of size $(2d+1, 2d+1, 2d+1)$:

For $n=1..N$

$$I(c_n, d) = [c_1(n) - d, c_1(n) + d], [c_2(n) - d, c_2(n) + d], [c_3(n) - d, c_3(n) + d]$$
The procedure

1\textsuperscript{st} order probability of the 3D interval:

First order probabilities $P_1(I(c_n,d))$ of the colors intervals $I(c_n,d)$:

$$P_1(I(c_n,d)) = \sum_{a \in I(c_n,d)} P_1(a)$$

where $P_1(a)$ is the occurrence probability of the color $a$.

2\textsuperscript{nd} order probability of the 3D interval:

Second order probabilities $P_2(I(c_n,d))$ of the colors intervals $I(c_n,d)$:

$$P_2(I(c_n,d)) = \sum_{a \in I(c_n,d)} \sum_{b \in I(c_n,d)} P_{cc}(a,b)$$

where the co-occurrence probabilities $P_{cc}(a,b)$ of two colors $a$ and $b$ are computed as:

$$P_{cc}(a,b) = \frac{1}{8} \sum_{a \in N(b)} P_{oc}(a,b)$$

considering the 8–connexity and a neighborhood $N$ around $b$.

Connectedness degree of the 3D interval:

Connectedness degree $D(I(c_n,d))$ of the interval $I(c_n,d)$:

$$D(I(c_n,d)) = \frac{P_2(I(c_n,d))}{P_1(I(c_n,d))}$$
The procedure

Final clustering

- Trichromatic color intervals are sorted in decreasing order of connectedness degrees.
- The colors in $I_a$ inherit the color $a$, then the colors in $I_b$ inherit the color $b$ and so on...

Decreasing values of $\mathcal{G}(I_n)$:
Example

Initial image
(Kodak image data base)

Classification result
after 1\textsuperscript{st} stage

$\Rightarrow 576$ colors (9 on R, 8 on G, 8 on B)

$d_{\text{max}} = w_{\text{max}} = 10\%$ of image range
Example

Classification result after 1\textsuperscript{st} stage

Classification result after 2\textsuperscript{nd} stage

\( s(I_n) \) Connectedness degrees of color intervals \( I_n \)

\( d \) Width of color intervals \( I_n \)
Results

Initial image
(Kodak image data base)

Classification result (27 classes).
The regions boundaries are drawn in white.

Extraction of wide homogeneous regions in the image
Results

\[ d_{\text{max}} = w_{\text{max}} = 10\% \text{ of image range} \]

Initial image

After first classification (648 trichromatic values)

After second classification (35 classes)
Results

**RGB**

- $w_{\text{max}} = 25$, $d_{\text{max}} = 50$
  - 45 classes
- $w_{\text{max}} = 25$, $d_{\text{max}} = 25$
  - 46 classes
- $w_{\text{max}} = 15$, $d_{\text{max}} = 50$
  - 132 classes

**HSV**

- $w_{\text{max}} = 25$, $d_{\text{max}} = 50$
  - 58 classes
- $w_{\text{max}} = 25$, $d_{\text{max}} = 25$
  - 58 classes
- $w_{\text{max}} = 40$, $d_{\text{max}} = 40$
  - 24 classes
Results

Classification results computed on the Kodak color image data base (23 images).

- **Nb 1**: the total number of combined colors computed by the marginal analysis of the connectedness degrees,
- **Nb 2**: the final number of classes computed by the analysis of the vectorial connectedness degree,
- the executing times

Results computed on a processor Intel(R) T2300 1.66 Ghz with a 1Go RAM memory
Results (RGB)

Computation times increase with high values of $d_{\text{max}}$ (large cubic intervals). BUT classification results are almost similar.

Computation times increase with low values of $w_{\text{max}}$ (larger number of 1D intervals) AND production of a large number of classes (over classification)

(a) Results on the Kodak images in the RGB space with parameters $w_{\text{max}} = 25$ and $d_{\text{max}} = 50$

<table>
<thead>
<tr>
<th></th>
<th>Nb 1</th>
<th>Nb 2</th>
<th>Mean time (in sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>336</td>
<td>15</td>
<td>6.73</td>
</tr>
<tr>
<td>Maximum</td>
<td>968</td>
<td>64</td>
<td>24.81</td>
</tr>
<tr>
<td>Mean</td>
<td>598.7</td>
<td>32.8</td>
<td>12.70</td>
</tr>
</tbody>
</table>

(b) Results on the Kodak images in the RGB space with parameters $w_{\text{max}} = 25$ and $d_{\text{max}} = 25$

<table>
<thead>
<tr>
<th></th>
<th>Nb 1</th>
<th>Nb 2</th>
<th>Mean time (in sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>336</td>
<td>15</td>
<td>3.02</td>
</tr>
<tr>
<td>Maximum</td>
<td>968</td>
<td>69</td>
<td>21.08</td>
</tr>
<tr>
<td>Mean</td>
<td>598.7</td>
<td>35.4</td>
<td>7.20</td>
</tr>
</tbody>
</table>

(c) Results on the Kodak images in the RGB space with parameters $w_{\text{max}} = 15$ and $d_{\text{max}} = 50$

<table>
<thead>
<tr>
<th></th>
<th>Nb 1</th>
<th>Nb 2</th>
<th>Mean time (in sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>1560</td>
<td>28</td>
<td>21.09</td>
</tr>
<tr>
<td>Maximum</td>
<td>3136</td>
<td>153</td>
<td>49.30</td>
</tr>
<tr>
<td>Mean</td>
<td>2178.3</td>
<td>71.18</td>
<td>35.15</td>
</tr>
</tbody>
</table>

(d) Results on the Kodak images in the HSV space with parameters $w_{\text{max}} = 25$ and $d_{\text{max}} = 25$

<table>
<thead>
<tr>
<th></th>
<th>Nb 1</th>
<th>Nb 2</th>
<th>Mean time (in sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>160</td>
<td>20</td>
<td>2.72</td>
</tr>
<tr>
<td>Maximum</td>
<td>567</td>
<td>66</td>
<td>10.07</td>
</tr>
<tr>
<td>Mean</td>
<td>377.5</td>
<td>50.77</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Results computed on a processor Intel(R) T2300 1.66 Ghz with a 1Go RAM memory
Results

**RGB**

- $w_{\text{max}} = 25$, $d_{\text{max}} = 50$
  - 45 classes

- $w_{\text{max}} = 25$, $d_{\text{max}} = 25$
  - 46 classes

- $w_{\text{max}} = 15$, $d_{\text{max}} = 50$
  - 132 classes

**HSV**

- $w_{\text{max}} = 25$, $d_{\text{max}} = 50$
  - 58 classes

- $w_{\text{max}} = 25$, $d_{\text{max}} = 25$
  - 58 classes

- $w_{\text{max}} = 40$, $d_{\text{max}} = 40$
  - 24 classes
**Results (HSV)**

- A lower number of classes at 1st stage:
- Regions are more homogeneous than in RGB (Hue: material homogeneity, independence from shadows and specular reflection)
- More time-effective

---

(a) Results on the Kodak images in the RGB space with parameters $w_{max} = 25$ and $d_{max} = 50$.

<table>
<thead>
<tr>
<th></th>
<th>Nb 1</th>
<th>Nb 2</th>
<th>Mean time (in sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>336</td>
<td>15</td>
<td>6.73</td>
</tr>
<tr>
<td>Maximum</td>
<td>968</td>
<td>64</td>
<td>24.81</td>
</tr>
<tr>
<td>Mean</td>
<td>598.7</td>
<td>32.8</td>
<td>12.70</td>
</tr>
</tbody>
</table>

(b) Results on the Kodak images in the RGB space with parameters $w_{max} = 25$ and $d_{max} = 25$.

<table>
<thead>
<tr>
<th></th>
<th>Nb 1</th>
<th>Nb 2</th>
<th>Mean time (in sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>336</td>
<td>15</td>
<td>3.02</td>
</tr>
<tr>
<td>Maximum</td>
<td>968</td>
<td>69</td>
<td>21.08</td>
</tr>
<tr>
<td>Mean</td>
<td>598.7</td>
<td>35.4</td>
<td>7.20</td>
</tr>
</tbody>
</table>

(c) Results on the Kodak images in the RGB space with parameters $w_{max} = 15$ and $d_{max} = 50$.

<table>
<thead>
<tr>
<th></th>
<th>Nb 1</th>
<th>Nb 2</th>
<th>Mean time (in sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>1560</td>
<td>28</td>
<td>21.09</td>
</tr>
<tr>
<td>Maximum</td>
<td>3136</td>
<td>153</td>
<td>49.30</td>
</tr>
<tr>
<td>Mean</td>
<td>2178.3</td>
<td>71.18</td>
<td>35.15</td>
</tr>
</tbody>
</table>

(d) Results on the Kodak images in the HSV space with parameters $w_{max} = 25$ and $d_{max} = 25$.

<table>
<thead>
<tr>
<th></th>
<th>Nb 1</th>
<th>Nb 2</th>
<th>Mean time (in sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>160</td>
<td>20</td>
<td>2.72</td>
</tr>
<tr>
<td>Maximum</td>
<td>567</td>
<td>66</td>
<td>10.07</td>
</tr>
<tr>
<td>Mean</td>
<td>377.5</td>
<td>50.77</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Results computed on a processor Intel(R) T2300 1.66 Ghz with a 1Go RAM memory.
Results

**RGB**

\[ w_{\text{max}} = 25, \quad d_{\text{max}} = 50 \]

45 classes

\[ w_{\text{max}} = 25, \quad d_{\text{max}} = 25 \]

46 classes

\[ w_{\text{max}} = 15, \quad d_{\text{max}} = 50 \]

132 classes

**HSV**

\[ w_{\text{max}} = 25, \quad d_{\text{max}} = 50 \]

58 classes

\[ w_{\text{max}} = 25, \quad d_{\text{max}} = 25 \]

58 classes

\[ w_{\text{max}} = 40, \quad d_{\text{max}} = 40 \]

24 classes
Other examples

- **Segmentation of the road (obstacles detection)**

Conversion RGB to HSV

Classification

Segmentation + detection

White pixels = road pixels

(color, location, area size)
Conclusion

- Two-stages classification procedure based on the color connectedness degrees
  - monochromatic analysis and color combination
  - trichromatic analysis (on a reduced number of colors)

- Qualitative and quantitative evaluation on the Kodak image data base:
  - Provides homogeneous regions in the image.
  - The 2 parameters involved ($w_{max}$ and $d_{max}$) can be reasonably fixed to 10% of the color range.

- Possible extensions to segmentation by labeling the classes
- Future works: road applications.
Other examples

- **Classification saturated areas/unsaturated ones**

Initial images in the RGB space

Images in the $C_1 C_2 C_3$ space: unsaturated regions in black

Unsaturated colors