Describing 2D Objects by using Qualitative Models of Color and Shape at a Fine Level of Granularity

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Abstract

Service robots need a cognitive vision system in order to interact with people. Human beings usually use their language to describe their environment and, as qualitative descriptions can be easily translated into language, they are more understandable to people. The main aim of this paper is to define an approach which can obtain a unique and complete qualitative description of any two-dimensional object appearing in a digital image. In order to achieve this, first, Museros and Escrig's approach for shape description is extended, secondly, a characterization of the objects in the image according to its regularity, its convexity and the number of edges and kind of angles that its shape has, is explained, and finally, a qualitative model for color naming based on HSV coordinates is defined. An application that provides the qualitative description of all two-dimensional objects contained in a digital image has been implemented and promising results are obtained.

Introduction

Human beings describe objects by using language. Generally, nouns and adjectives are used to define properties of the objects and these nouns and adjectives are qualitative labels that can be used easily to identify and compare objects.

Objects contained in a digital image can be described by extracting its qualitative features in a string. In order to determine if two images contain the same objects, it is not necessary to compare each pixel of one image with the corresponding pixel of the other image, as it is done in traditional computer vision, and only a comparison between the strings that define the qualitative description of the objects contained in these images is needed. Therefore, a more cognitive and faster comparison is achieved. Moreover, as the description obtained is qualitative (it deals with relative or defined-by-interval values of color and shape, rather than absolute values) the uncertainty obtained by quantitative methods when they compare, pixel to pixel, two images containing highly similar objects to the human eye or the same objects but at similar but not the same positions in the images, is solved.

According to the kind of representation used, approaches dealing with qualitative shape description can be classified into: (1) axial, (2) primitive-based, (3) topology- and logic-based, (4) cover-based and (5) ordering and projection-based approaches.

Axial approaches describe the shape of objects qualitatively by reducing it to an "axis" which reflects some symmetry or regularity within the shape. The shape of these objects can be generated by moving a geometric figure or "generator" along the axis and sweeping out the boundary of the shape (Leyton 05, 88; Brady 83).

Primitive-based approaches describe complex objects as combinations of more primitive and simple objects, such as: generalized cylinder and geon-based representations, which describe an object as a set of primitives plus a set of spatial connectivity relations among them (Biederman 87; Flynn and Jain 91); and constructive representations, which describe an object as the Boolean combination of primitive point sets or halfplanes (Damski and Gero 96; Gero 99; Requicha 80; Brisson 89, 93).

Topology and logic-based approaches use topological and logical relations to represent shapes (Cohn 95; Randell, Cui, and Cohn 92; Clementini and Di Felice 97).

Cover-based approaches describe the shape of an object by covering it with simple figures, such as rectangles and spheres (Del Pobil and Serna 95).

Ordering and projection-based approaches describe different aspects of the shape of an object by either looking at it from different angles or by projecting it onto different axes (Wang and Freeman 90; Schlieder 96; Damski and Gero 96; Museros and Escrig 04).

In this paper, we will focus on Museros and Escrig's qualitative model for shape description which describes objects qualitatively by naming the main qualitative features of the vertices and the maximal points of curvature detected in the shape of the object. This model is successfully used to describe the shape of tile edges which are automatically assembled into a ceramic mosaic by a robot arm. This qualitative approach deals with the uncertainty introduced by the fact that two tiles manufactured for a cell of a ceramic mosaic are never exactly identical but any one of them fits on that cell. It is also focused on the shape that real manufactured tiles can have. Not all imagined 2D objects can be made on tiles as sharp curves or very acute angles in the shape would cause the tile to break.

In this paper, we present an extension of Museros and Escrig's approach for shape description in order to obtain a unique and complete qualitative description of any 2D object appearing in a digital image. Our extension of that approach consists on (1) describing qualitatively not only the maximal points of curvature of each curve, but also the qualitative features of its starting and ending points; (2) identifying the kind of edges connected by each vertex (such as two straight lines, a line and a curve or two curves); (3) adding the feature of qualitative compared length to the description of the points of maximum curvature; (4) expressing the compared length of the edges of the object at a fine level of granularity, and (5) defining the type of curvature of each point of maximum curvature at a fine level of granularity. Moreover, our approach also characterizes each object by naming it, according to its number of edges and kind of angles that its shape has, by describing its convexity and regularity, and by naming its color according to a qualitative model defined by using Hue Saturation and Value (HSV) color coordinates.

This paper is organized as follows. First, Museros and Escrig's approach is outlined. Then, the problems that this approach has at describing some objects are described. After that, how our approach extends Museros and Escrig's approach in order to solve the previous problems is explained. Next, how our approach characterizes 2D objects from the description of its sides and angles is presented. Then, the qualitative model for color naming included in our approach is described. Next, the structure of the string provided by our approach in order to describe all the two-dimensional objects contained in a digital image is shown. Finally, the results of our application and our conclusions and future work are summarized.

Outlining Museros and Escrig's Approach for Shape Description

Museros and Escrig's approach extracts the edges of each object in an image by applying Canny edge detector and then describes qualitatively the main points of the edges extracted: vertices which connect two straight lines and points of maximum curvature. It also obtains the RGB color and the centroid of each object.

Vertices of each object are described by a set of three elements <A_j, L_j, C_j> where:

$A_j \in$ {*right, acute, obtuse*};

$C_j \in$ {*convex, concave*} and

$L_j \in$ {*smaller, equal, bigger*}

- **A_j** or the qualitative amplitude of the angle j is calculated by obtaining the circumference that includes the previous and following vertices of vertex j (j-1 and j+1) (Figure 1). If vertex j is included in that circumference, then the angle is *right*. If vertex j is external to the circumference, then the angle is *acute*. Finally, if vertex j is in the interior of that circumference, that is, included in the circle that this circumference defines, then the angle is *obtuse*.
- **C_j** or the convexity of the angle, defined by the edges related to vertex j, is calculated by obtaining the segment from the previous vertex (j-1) to the following vertex (j+1). If vertex j is on the left of that segment, then the angle is *convex*. If vertex j is on the right of that oriented segment, then the angle is *concave* (Figure 1).
- **L_j** or the relative length of the two edges related to vertex j is obtained by comparing the Euclidean distance between two segments: the segment defined from vertex j-1 to vertex j and the segment defined from vertex j to vertex j+1. If the first distance obtained is smaller/equal/bigger than the second one, the relative length between the two edges in vertex j is *smaller*/*equal*/*bigger*, respectively.

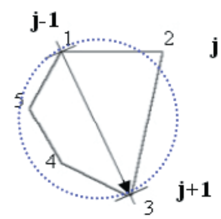


Figure 1. Characterization of a vertex j which connects two straight segments.

The **points of curvature** of each object are characterized by a set of three elements <*curve*, TC_j, C_j> where:

$TC_j \in$ {*acute, semicircular, plane*} and

$C_j \in$ {*convex, concave*}

- **TC_j** or the type of curvature in point j is obtained by comparing the size of the segment defined from the starting point of the curve (j-1) to the centre of the curve (*da* in Figure 2) with the size of the segment defined from the centre of the curve to the point of maximum curvature (j) (*db* in Figure 2). If *da* is smaller than *db*, the type of curvature in j is *acute*; if *da* is equal to *db*, the type of curvature in j is *semicircular*; and finally, if *da* is bigger than *db*, the type of curvature in j is *plane*.
- **C_j** or the convexity of the point of curvature j is calculated by obtaining the segment from the previous vertex (j-1) to the following vertex (j+1). If vertex j is on the left of that segment, then the angle is *convex*. If vertex j is on the right of that segment, then the angle is *concave*.

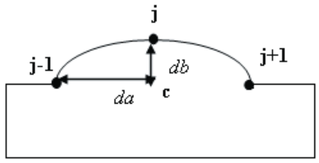


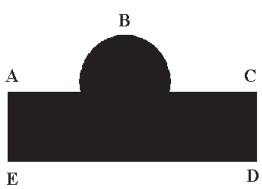
Figure 2. Characterization of a point of maximum curvature.

Thus, the complete description of a 2D object is defined as a set of qualitative tags as:

[Type, Color, [A_1,C_1,L_1] | [*curve*,TC_1,C_1], …,
[A_n,C_n,L_n] | [*curve*,TC_n,C_n]]

where *n* is the total number of vertices and points of curvature of the object, **Type** belongs to the set {*without-curves, with-curves*}, **Color** describes the RGB colour of the object by a triple [R,G,B] for the Red, Green and Blue coordinates and $\mathbf{A_1,\ldots,A_n}$, $\mathbf{C_1,\ldots,C_n}$, $\mathbf{L_1,\ldots,L_n}$ and $\mathbf{TC_1,\ldots,TC_n}$, describes the angles and edges of the shape of the object, depending on its type (straight segment or curve), as it has been previously explained.

Finally, as an example, Figure 3 shows the qualitative description provided by Museros and Escrig's approach of a 2D object containing straight edges and curves.



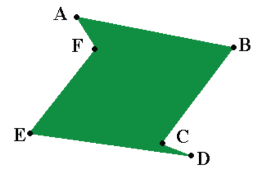
QualitativeShapeDesc(S)=
[with-curves, [0, 0, 0],
[
A: [right, convex, smaller],
B: [curve, convex, acute],
C: [right, convex, bigger],
D: [right, convex, smaller],
E: [right, convex, bigger]
],
].

Figure 3. Qualitative description of a 2D object containing straight segments and curves.

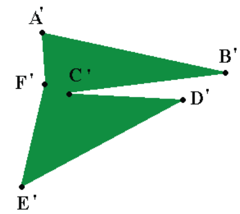
Problems of Museros and Escrig's Approach Describing Some Objects

As Museros and Escrig's approach was focused on describing manufactured tiles that could be assembled in a mosaic, it did not consider 2D objects with sharp curves or very acute angles which are very fragile and hardly ever used in mosaics. However, as our current purpose is to describe any 2D object contained in a digital image, no kind of shape can be discarded and this has allow us to find some situations where the qualitative description obtained when describing two different objects could be ambiguous.

The first ambiguous situation is shown in Figure 4, in which two objects that appear very different to the human eye obtain the same qualitative description of shape. In order to solve this problem, our approach has extended Museros and Escrig's approach by substituting the qualitative model of compared length used to describe the relation between the edges of a 2D object by another qualitative model of compared length at a fine level of granularity.

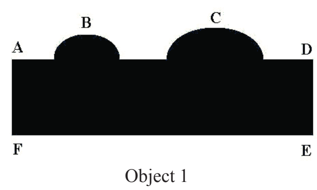


QualitativeShapeDesc(S)=
[without-curves, [0, 128, 0],
[
A: [acute, convex, smaller],
B: [acute, convex, bigger],
C: [acute, concave, bigger],
D: [acute, convex, smaller],
E: [acute, convex, bigger],
F: [obtuse, concave, bigger],
],
].

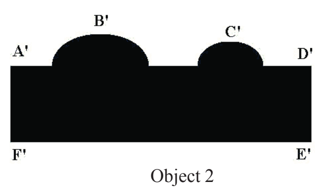


QualitativeShapeDesc(S)=
[without-curves, [0, 128, 0],
[
A': [acute, convex, smaller],
B': [acute, convex, bigger],
C': [acute, concave, bigger],
D': [acute, convex, smaller],
E': [acute, convex, bigger],
F': [obtuse, concave, bigger],
],
].

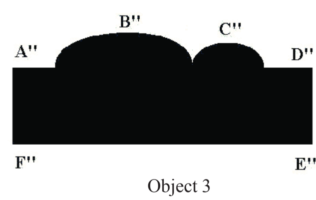
Figure 4. Ambiguous situation in which two different two-dimensional objects are described by using exactly the same qualitative features.



QualitativeShapeDesc(S)=
[without-curves, [0, 0, 0],
[
A: [right, convex, bigger],
B: [curve, convex, plane],
C: [curve, convex, plane],
D: [right, convex, smaller],
E: [right, convex, smaller],
F: [right, convex, bigger],
],
].



QualitativeShapeDesc(S)=
[without-curves, [0, 0, 0],
[
A': [right, convex, bigger],
B': [curve, convex, plane],
C': [curve, convex, plane],
D': [right, convex, smaller],
E': [right, convex, smaller],
F': [right, convex, bigger],
],
].



QualitativeShapeDesc(S)=
[without-curves, [0, 0, 0],
[
A'': [right, convex, bigger],
B'': [curve, convex, plane],
C'': [curve, convex, plane],
D'': [right, convex, smaller],
E'': [right, convex, smaller],
F'': [right, convex, bigger],
],
].

Figure 5. Ambiguous situation in which two objects containing different kind of curves in different positions are described by the same qualitative features.

The second ambiguous situation is shown in Figure 5. All the three objects have the same qualitative description because, as the starting and ending points of the curves are not described, the straight edge between the curves in Objects 1 and 2 is not described. Moreover, if the starting and ending points of the curves are not described, we are not able to find out the compared length between an edge of the object and the following or previous curve, therefore, we could not establish a relation of size between the curves and we could not distinguish between the Objects 1 and 2 in Figure 5. In order to solve this situation, our approach describes the starting and ending points of every curve as any other vertex in the object and obtains the compared length of the edges that start and end in these points of the curves. Moreover, our approach also defines a qualitative model for describing the type of curvature of a curve at a fine level of granularity, so that we could distinguish plane curves (C'' in Object 3 of Figure 5) from very plane curves (B'' in Object 3 of Figure 5), for example.

Next sections will show how our approach for shape description can deal with these ambiguous situations obtaining successful results.

Extending Museros and Escrig's Approach for Shape Description

In this section, our extension for Museros and Escrig's approach for shape description is presented. This extension consists on (1) describing qualitatively not only the maximal points of curvature of each curve, but also the qualitative features of its starting and ending points; (2) identifying the kind of edges connected by each vertex (such as two straight lines, a line and a curve or two curves); (3) adding the feature of qualitative compared length to the description of the points of maximum curvature; (4) expressing the compared length of the edges of the object at a fine level of granularity, and (5) defining the type of curvature of each point of maximum curvature at a fine level of granularity.

According to our approach, the relevant points of the shape of a 2D object are described by a set of four elements:

$$\langle KEC_j, A_j \mid TC_j, L_j, C_j \rangle$$

where,

$KEC_j \in$ {*line-line, line-curve, curve-line, curve-curve, curvature-point*};

$A_j \in$ {*right, acute, obtuse* / j is a vertex};

$TC_j \in$ {*very-acute, acute, semicircular, plane, very_plane* / j is a point of maximum curvature};

$L_j \in$ {*shorter-than-half (sth), half (h), larger-than-half (lth), equal (e), shorter-than-double (std), double (d), larger-than-double (ltd)*}

$C_j \in$ {*convex*, *concave*};

- **KEC_j** or the <u>Kind of Edges Connected</u> by each vertex is described by the tags: *line-line*, if the vertex j connects two straight lines; *line-curve*, if the vertex j connects a line and a curve; *curve-line*, if the vertex j connects a curve and a line; *curve-curve*, if the vertex j connects two curves; or *curvature-point*, if the vertex j is a point of maximum curvature of a curve.
- **A_j** or the <u>qualitative amplitude of the angle</u> j is calculated as it has been described in Museros and Escrig's approach.
- **TC_j** or the <u>type of curvature</u> in the point of maximum curvature j is calculated by obtaining *da* and *db* parameters, as it has been previously explained in Museros and Escrig's approach. However, our approach uses a qualitative model at a fine level of granularity in order to represent the type of curvature of each point of maximum curvature. Our *Reference System for describing the Type of Curvature at a fine level of granularity* has three components:

  $$TCRS_{fg} = \{UC, TC_{LAB}, TC_{INT}\}$$

  where, UC or Unit of Curvature refers to the relation obtained after dividing the values of *da* and *db* previously calculated; TC_{LAB} refers to the set of qualitative labels which represent the type of curvature; and TC_{INT} refers to the intervals associated to each type of curvature, which are defined in terms of UC.

  TC_{LAB} = {*very-acute*, *acute*, *semicircular*, *plane*, *very-plane*}

  TC_{INT} = {]0 uc, 0.5 uc],]0.5 uc, 0.95 uc[, [0.95 uc, 1.05 uc],]1.05 uc, 2 uc [, [2 uc, ∝[/ uc = *da* / *db*}.

- **C_j** or the <u>convexity of the angle</u> defined by the edges related to vertex j is calculated as it has been described in Museros and Escrig's approach.
- **L_j** or the <u>relative or compared length</u> of the two edges connected by vertex j. According to the kind of these edges, its length is calculated as follows:
  - If vertex j connects two straight lines (such as vertex A in Figure 6), the length of the first edge is the Euclidean distance between vertex j-1 to vertex j (that is the length of the segment IA in Figure 6) and the length of the second edge is the Euclidean distance between vertex j to vertex j+1 (that is the length of the segment AB in Figure 6).
  - If vertex j connects a line with a curve, so it is the starting point of a curve (such as vertex B in Figure 6), the length of the first edge is the Euclidean distance between vertex j-1 to vertex j (that is the length of the segment AB in Figure 6) and the approximate length of the second edge is the Euclidean distance between vertex j and the maximum point of curvature j+1 (that is the length of the dashed line BC in Figure 6).
  - If vertex j connects a curve with a line, so it is the ending point of a curve (such as vertex F in Figure 6), the approximate length of the first edge is the Euclidean distance between the point of curvature j-1 and the vertex j (that is the length of the dashed line EF in Figure 6) and the length of the second edge is the Euclidean distance between vertex j and vertex j+1 (that is the length of the segment FG in Figure 6).

– If vertex j connects two curves, so it is the ending point of a curve and the starting point of another curve (such as vertex D in Figure 6), the approximate length of the first edge is the Euclidean distance between the point of curvature j-1 and vertex j (that is the length of the dashed line CD in Figure 6), and the approximate length of the second edge is the Euclidean distance between the vertex j and the point of curvature j+1 (that is the length of the dashed line DE in Figure 6).
– If vertex j is the point of maximum curvature of the curve (such as C in Figure 6), the approximate length of the first edge is the Euclidean distance between the starting point of the curve j-1 and the point of maximum curvature j (that is the length of the dashed line BC in Figure 6), and the approximate length of the second edge is the Euclidean distance between the point of maximum curvature j and the ending point of the curve j+1 (that is the length of the dashed line CD in Figure 6).

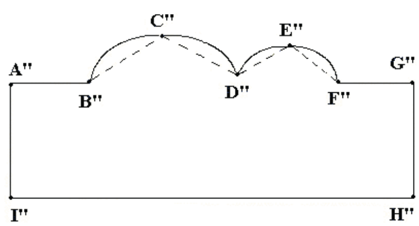


Figure 6. Adding new relevant points to the description of the shape of a 2D object and describing how to obtain the approximate length between each pair of consecutive points.

Finally, our approach uses a qualitative model at a fine level of granularity in order to represent the relative or compared length of the two edges connected by a vertex or point of maximum curvature. Our *Reference System for the Compared Length at a fine level of granularity* has three components:

$$CLRS_{fg} = \{Ucl, CL_{LAB}, CL_{INT}\}$$

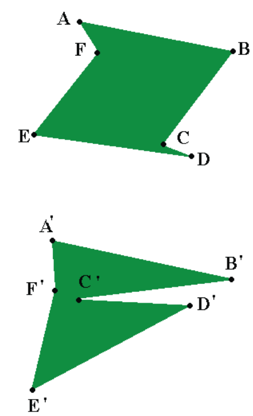
where, Ucl or Unit of compared length refers to the relation obtained after dividing the length of the first edge and the length of the second edge connected by a vertex; CL_{LAB} refers to the set of qualitative labels which represent the compared length; and CL_{INT} refers to the intervals associated to each compared length, which are defined in terms of Ucl.

CL_{LAB} = {*shorter-than-half (sth), half (h), larger-than-half (lth), equal (e), shorter-than-double (std), double (d), larger-than-double (ltd)*}

CL_{INT} = {]0 ucl, 0.4 ucl], [0.4 ucl, 0.6 ucl], [0.6 ucl, 0.9 ucl[, [0.9 ucl, 1.1 ucl],]1.1 ucl, 1.9 ucl[, [1.9 ucl, 2.1 ucl],]2.1 ucl, ∝[/ ucl = (length of 1st edge) / (length of 2nd edge)}.

Finally, in Figures 7 and 8 it is shown how our approach for shape description can solve the ambiguous situations previously presented in Figures 4 and 5.

Our new reference system for describing length, which defines the compared length of the edges of the objects at a fine level of granularity ($CLRS_{fg}$), helps to clarify the differences between the two objects in Figure 7. As it can be seen in that figure, the qualitative description of length for vertices C and C' and D and D', respectively, are not the same, as they were in Figure 4.



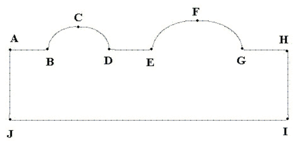
QualitativeShapeDesc(S)=
[
A: [line-line, acute, convex, sth],
B: [line-line, acute, convex, std],
C: [line-line, acute, concave, **ltd**],
D: [line-line, acute, convex, **sth**],
E: [line-line, acute, convex, std],
F: [line-line, acute, concave, ltd],
].

QualitativeShapeDesc(S)=
[
A': [line-line, acute, convex, sth],
B': [line-line, acute, convex, std],
C': [line-line, acute, concave, **std**],
D': [line-line, acute, convex, **lth**],
E': [line-line, acute, convex, std],
F': [line-line, acute, concave, ltd],
].

Figure 7. Qualitative description of 2D objects obtained by our approach, which solve the ambiguous situation presented in Figure 4.

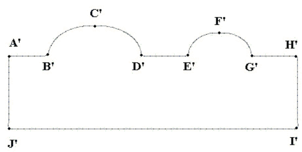
Figure 8 shows that our approach solves the ambiguous situation presented in Figure 5 by (1) adding the qualitative description of the starting and ending points of each curve and by (2) defining qualitatively the type of curvature of each point of maximum curvature by using our new reference system for describing the type of curvature at a fine level of granularity ($TCRS_{fg}$).

As it can be seen in Figure 8, our approach can describe segments between two curves (such as segments DE and D'E' in Object 1 and 2, respectively, at Figure 8) and vertices connecting two curves (such as vertex D'' in Object 3 at Figure 8). Therefore, Object 1 and 2 at Figure 8 can be distinguished by their qualitative descriptions, which obtain different compared length descriptions for vertices B and B', D and D', E and E' and G and G', respectively. Object 3 can be distinguished from Objects 1 and 2 because its qualitative description has a vertex less to describe. Moreover, our approach can describe the difference on the type of curvature of both curves in Object 3 (C'' and E'' in Figure 8) which are described by distinct qualitative tags (*plane* and *very-plane*).



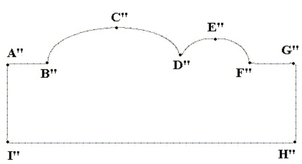
Object 1

QualitativeShapeDesc(S)=
[
A: [line-line, right, d, convex],
B: [line-curve, obtuse, **lth**, concave],
C: [curvature-point, plane, e, convex],
D: [curve-line, obtuse, **e**, concave],
E: [line-curve, obtuse, **lth**, concave],
F: [curvature-point, plane, e, convex],
G: [curve-line, obtuse, **std**, concave],
H: [line-line, right, h, convex],
I: [line-line, right, sth, convex],
J: [line-line, right, ltd, convex]
].



Object 2

QualitativeShapeDesc(S)=
[
A': [line-line, right, d, convex],
B': [line-curve, obtuse, **h**, concave],
C': [curvature-point, plane, e, convex],
D': [curve-line, obtuse, **std**, concave],
E': [line-curve, obtuse, **e**, concave],
F': [curvature-point, plane, e, convex],
G': [curve-line, obtuse, **e**, concave],
H': [line-line, right, h, convex],
I': [line-line, right, sth, convex],
J': [line-line, right, ltd, convex]
].



Object 3

QualitativeShapeDesc(S)=
[
A'': [line-line, right, d, convex],
B'': [line-curve, obtuse, h, concave],
C'': [curvature-point,**very-plane**, e, convex],
D'': [curve-curve, obtuse, **ltd**, concave],
E'': [curvature-point, **plane**, e, convex],
F'': [curve-line, obtuse, e, concave],
G'': [line-line, right, h, convex],
H'': [line-line, right, sth, convex],
I'' : [line-line, right, ltd, convex]
].

Figure 8. Qualitative description of objects obtained by our approach, which solve the ambiguous situation presented in Figure 5.

Characterizing 2D Objects from the Features Extracted

In Museros and Escrig's approach, a qualitative tag is included in order to distinguish if the object has curves or not (*with-curves*, *without-curves*), so that the comparison process can be accelerated. However, a more accurate characterization of the objects (according to geometry principles) can be defined by using the qualitative features described for each vertex.

The characterization defined for our approach consists on: (1) giving a name to the object that could represent it geometrically, (2) describing the regularity of its edges and (3) defining the convexity of the whole object.

Therefore, **objects without curves** can be characterized by a set of three elements:

[Name, Regularity, Convexity]

where,

Name ∈ {*triangle, quadrilateral, pentagon, hexagon, heptagon, octagon, …, polygon*}
Regularity ∈ {*regular, irregular*}
Convexity ∈ {*convex, concave*}

- **Name** is the name given to the object depending on its number of edges (or vertices qualitatively described) and it can take values from *triangle* to *polygon*;
- **Regularity** indicates if the object have *equal* angles and *equal* edges (so it is *regular*), or not (so it is *irregular*);
- **Convexity** indicates if the object has a *concave* angle (so it is *concave*) or not (so it is *convex*).

However, for triangular and quadrilateral objects a more accurate characterization can be made.

Triangular objects can be characterized as *right*, *obtuse* or *acute triangles* according to the kind of angles they have, and as *equilateral*, *isosceles* or *scalene triangles* according to the relation of length between its edges. Therefore, the element **Name** for a triangle is made up by three elements:

triangle–Kind_of_angles–Sides_relation

where,

Kind_of_angles ∈ {*right, obtuse, acute*}
Edges_Relation ∈ {*equilateral, isosceles, scalene*}

- **Kind_of_angles** indicates if the triangle has got a right angle (so it is *right*), an obtuse angle (so it is *obtuse*), or if all its angles are acute (so it is *acute*); and
- **Edges_relation** shows, if the edges of the triangle are all equal (so it is *equilateral*), or two equal (so it is *isosceles*), or none equal (so it is *scalene*).

Quadrilateral objects can be also characterized more accurately as *square, rectangle* or *rhombus* depending on the compared length between its edges and on its kind of angles. Therefore, the element **Name** for a quadrilateral is made up by two elements:

quadrilateral–Type_quadrilateral

where,

Type_quadrilateral ∈ {*square, rectangle, rhombus*}

- **Type_of_quadrilateral** specifies if the quadrilateral is a *square* (if all their angles are right and their edges equal), a *rectangle* (if all their angles are right and their opposite edges are equal), or a *rhombus* (if all their edges are equal and their opposite angles are equal).

On the other side, **objects with curves** can be also characterized by a set of three elements:

[Name, Regularity, Convexity]

where,

Name ∈ {*circle*, *ellipse*, *polycurve*, *mix-shape*}
Regularity ∈ {*regular, irregular*}
Convexity ∈ {*convex, concave*}

- **Name** is the name given to the object depending on its properties: *mix-shape* (if the shape of the object is made up by curves and straight edges), *polycurve* (if the shape of the object is made up only by curves), *circle* (if the shape of the object is a polycurve with only four relevant points, two of them defined as semicircular points of curvature) and *ellipse* (if the shape of the object is a polycurve with only four relevant points, two of them defined as points of curvature with the same type of curvature, that is, both *very-plane*, *plane*, *acute* or *very-acute*).

- **Regularity** regarding to curves is not defined by our approach from the point of view of geometry. We consider 2D objects with circular or elliptical shapes as *regular* and the rest of objects with curvaceous shapes as *irregular*.
- **Convexity** of objects with curvaceous shapes is defined in the same way as for objects containing only straight edges: if an object has a *concave* vertex or point of curvature, that object is defined as *concave*; otherwise it is defined as *convex*.

Finally, as an example, the characterization of objects in Figures 7 and 8 are given. Objects in Figure 7 will be characterized as [*hexagon*, *irregular*, *concave*], and objects in Figure 8 will be characterized as [*mix-shape*, *irregular*, *concave*].

Describing Color Qualitatively

In order to describe the color of 2D objects qualitatively, our approach translates the Red, Green and Blue (RGB) color coordinates obtained by Museros and Escrig's approach into Hue Saturation and Value (HSV) coordinates. HSV coordinates are less affected by changes of lighting than RGB and more suitable to be translated into a qualitative model of color defined by intervals.

Our approach uses the formulas described by (Agoston 2005) in order to translate from RGB to HSV coordinates. In these formulas, r, g, b are the values of RBG coordinates in the interval [0, 1] and *max* and *min* are defined as the greatest and the least value of r, g, b, respectively. Therefore, HSV coordinates are calculated as:

$$h = \begin{cases} 0 & \text{if } \max = \min \\ 60^\circ \times \frac{g-b}{\max - \min} + 0^\circ, & \text{if } \max = r \text{ and } g \geq b \\ 60^\circ \times \frac{g-b}{\max - \min} + 360^\circ, & \text{if } \max = r \text{ and } g < b \\ 60^\circ \times \frac{b-r}{\max - \min} + 120^\circ, & \text{if } \max = g \\ 60^\circ \times \frac{r-g}{\max - \min} + 240^\circ, & \text{if } \max = b \end{cases}$$

$$s = \begin{cases} 0 & \text{if } \max = \min \\ \frac{\max - \min}{\max + \min} = \frac{\max - \min}{2l}, & \text{if } l \leq \frac{1}{2} \\ \frac{\max - \min}{2-(\max + \min)} = \frac{\max - \min}{2-2l}, & \text{if } l > \frac{1}{2} \end{cases}$$

$$v = \max$$

From the previous values of HSV coordinates obtained, our approach defines a qualitative model in order to name the color of the objects. Our *Reference System for Qualitative Color* description has five components:

$$\text{RSQC} = \{\text{UV, US, UH, QC}_{\text{LAB}}, \text{QC}_{\text{INT}}\}$$

where, UV or Unit of Value refers to Value coordinate in HSV, which is defined in the interval [0, 100]; US or Unit of Saturation refers to Saturation coordinate in HSV, which is defined in the interval [0, 100]; UH or Unit of Hue refers to Hue coordinate in HSV, which is defined in the interval [0, 360]; QC_{LAB} refers to the qualitative labels which represent the color of the 2D object; and QC_{INT} refers to the intervals of HSV coordinates associated to each color, which are defined in terms of UV, US and UH and which depends on the application. QC_{LAB} and QC_{INT} have been defined by using five different sets which relates the color name with its corresponding UV, US and UH values:

$$QC_{LAB} = \{QC_{LABi} \,/\, i = 1..5\}$$
$$QC_{INT} = \{QC_{INTi} \,/\, i = 1..5\}$$

where,

QC_{LAB1} = {*black*}
QC_{INT1} = {[0 uv, 20 uv] / ∀ UH ∧ US}

QC_{LAB2} = {*dark-grey, grey, light-grey, white*}
QC_{INT2} = {]20 uv, 40 uv],]40 uv, 70 uv],]20 uv, 90 uv],]90 uv, 100 uv] / ∀ UH ∧ US ∈ [0 us, 20 us]}

QC_{LAB3} = {*red, reddish-orange, orange, yellow, yellowish-green, green, vivid-green, emerald-green, turquoise-blue, cyan, blue, violet, lilac, pink, fuchsia* }
QC_{INT3} = {[340 uh, 360 uh] ∧ [0 uh, 15 uh],]15 uh, 21 uh],]21 uh, 48 uh],]48 uh, 64 uh],]64 uh, 79 uh],]79 uh, 100 uh],]100 uh, 140 uh],]140 uh, 165 uh],]165uh, 185uh],]185 uh, 215 uh],]215 uh, 260 uh],]260 uh, 285 uh],]285 uh, 297 uh],]297 uh, 320 uh],]320 uh, 335 uh] / ∀ UV ∈]60 uv, 100 uv] ∧ US ∈] 50 us, 100 us]}

QC_{LAB4} = {*dark-* + QC_{LAB3}}
QC_{INT4} = { QC_{INT3} / ∀ US ∧ UV ∈] 20 uv, 60 uv] }

QC_{LAB5} = {*pale-* + QC_{LAB3}}
QC_{INT5} = { QC_{INT3} / ∀ UV ∧ US ∈] 20 us, 50 us]}

Finally, as an example, the qualitative color of objects in Figures 4 and 5 are given. As it is shown in Figure 4, the RGB color coordinates for both objects are [0, 128, 0], which are [120 uh, 100 us, 50 uv] on HSV color coordinates which corresponds to the qualitative color *dark-vivid-green*. Moreover, as it is shown in Figure 5, the RGB color for all the objects are [0, 0, 0], which are [0 uh, 0 us, 0 uv] on HSV and which corresponds to the qualitative color *black* according to our qualitative model for color naming.

Final Shape Description by Our Application

Finally, an application that provides the qualitative description of shape of all two-dimensional objects contained in a digital image has been implemented.

In general, the structure of the string provided by the application, which describes any image composed by N two-dimensional objects, is defined as a set of qualitative tags as:

[[Name, Color, Regularity, Convexity, Type, VerticesDesc $]_1$,
…,
[Name, Color, Regularity, Convexity, Type, VerticesDesc $]_N$]

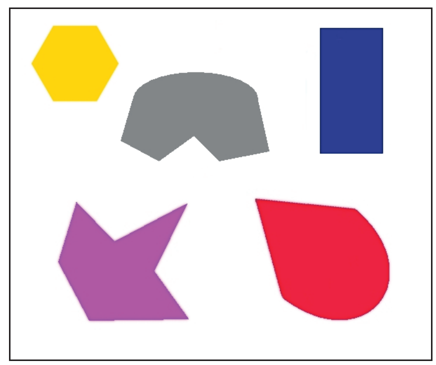
where,

Name = {*triangle, quadrilateral,…, polygon, circle, ellipse, polycurve, mix-shape*}
Color = {*black, white, grey, …, red, orange, yellow, …, violet, pink*}
Regularity = {*regular, irregular*}
Convexity = {*convex, concave*}
Type = {*without-curves*, *with-curves*}
VerticesDesc = [[KEC_j, A_j | TC_j, L_j, C_j],…,
[KEC_{numP}, A_{numP} | TC_{numP}, L_{numP}, C_{numP}]]
where,
$KEC_j \in$ {*line-line, line-curve, curve-line, curve-curve, curvature-point*};
$A_j \in$ {*right, acute, obtuse* / j is a vertex};
$TC_j \in$ {*very-acute, acute, semicircular, plane, very_plane* / j is a point of maximum curvature};
$C_j \in$ {*convex, concave*};
$L_j \in$ {*shorter-than-half (sth), half (h), larger-than-half (lth), equal (e), shorter-than-double (std), double (d), larger-than-double (ltd)*}

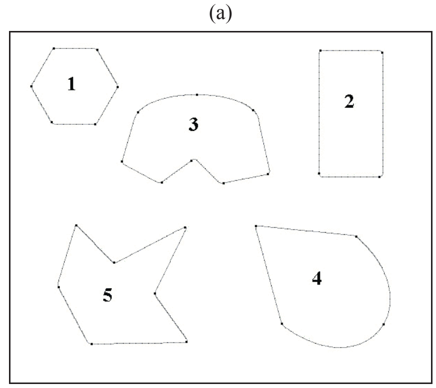
As a result of the application which implements our approach, the qualitative description of the 2D objects contained in the image shown by Figure 8 is presented. The string obtained describes the five objects of the image in the order presented in Figure 8b. Objects containing vertices with smaller coordinates x and y are described first, considering that, in traditional computer vision, the origin of reference systems (x = 0 and y = 0) is located on the upper-left corner of the image. Figure 8b also shows the location of the vertices detected by our approach. For each object, the first vertex detected is that with smaller coordinate x, while the first vertex described is the second vertex with smaller coordinate x, because, in order to obtain the qualitative description of a vertex, the previous and following vertices are used.

Finally, the qualitative description obtained by our application for the image in Figure 8 is the following one:

```
[
 [[hexagon, yellow, regular, convex, without-curves],
   [
    [line-line, obtuse, e, convex], [line-line, obtuse, e, convex],
    [line-line, obtuse, e, convex], [line-line, obtuse, e, convex],
    [line-line, obtuse, e, convex], [line-line, obtuse, e, convex]
   ]
 ],

 [[quadrilateral-rectangle, dark-blue, irregular, convex, without-curves],
   [
    [line-line, right, d, convex], [line-line, right, h, convex],
    [line-line, right, d, convex], [line-line, right, h, convex]
   ]
 ],

 [[mix-shape, grey, irregular, concave, with-curves],
   [
    [curvature-point, very-plane, e, convex],
    [curve-line, obtuse, lth, convex], [line-line, right, std, convex],
    [line-line, obtuse, std, convex], [line-line, obtuse, e, concave],
    [line-line, obtuse, lth, convex], [line-line, obtuse, lth, convex],
    [line-curve, obtuse, lth, convex]
   ]
 ],

[[mix-shape, red, irregular, convex, with-curves],
  [
   [line-curve, obtuse, e, convex], [curvature-point, acute, e, convex],
   [curve-line, obtuse, e, convex], [line-line, acute, e, convex]
  ]
],

[[heptagon, pink, irregular, concave, without-curves],
  [
   [line-line, acute, std, convex], [line-line, obtuse, lth, concave],
   [line-line, acute, e, convex], [line-line, obtuse, std, concave],
   [line-line, acute, lth, convex], [line-line, obtuse, std, convex],
   [line-line, obtuse, e, convex]
  ]
 ]
].
```



(a)



(b)

Figure 8. (a) Original image which has been processed by our application; (b) Output image after the processes of segmentation and location of the relevant points of the objects. The numbers of the objects have been added previously in order to arrange the qualitative description obtained.

Conclusions

In this paper, we have extended Museros and Escrig's approach for shape description in order to obtain a unique and complete qualitative description of any 2D object appearing in a digital image. Our extension consists of (1) describing qualitatively not only the maximal points of curvature of each curve, but also the qualitative features of its starting and ending points; (2) identifying the kind of edges connected by each vertex (such as two straight lines, a line and a curve or two curves); (3) adding the feature of qualitative compared length to the description of the points of maximum curvature; (4) expressing the compared length of the edges of the object at a fine level of granularity, and (5) defining the type of curvature of each point of maximum curvature at a fine level of granularity. Moreover, our approach also characterizes each object by naming it, according to its number of edges and kind of angles that its shape has, by describing its convexity and regularity, and by naming its color according to a qualitative model defined by using Hue Saturation and Value (HSV) color coordinates.

Our results show that situations where Museros and Escrig's approach could provide an ambiguous description of some two-dimensional objects are solved by using our extension of that approach.

Moreover, an application that provides the qualitative description of all two-dimensional objects contained in a digital image has been implemented and promising results are obtained.

Finally, as for future work, we intend to (1) extend our characterization of objects in order to detect and describe symmetries and parallel edges in the shape of an object; (2) extend our approach to add topology relations between the objects in the image (taking as a reference the way Museros and Escrig's approach describes objects with holes) in order to describe objects containing/touching/ occluding other objects/holes; (3) define qualitative orientation and distance relations between the objects in an image, so that we could obtain not only a visual representation of the objects, but also a spatial description of their location in the image; and (4) use the final string obtained by our approach in order to compare images and calculate a degree of similarity between them.

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