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A structural representation for the understanding of line drawing images

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Abstract

In this paper, we are concerned with the problem of finding a good and homogeneous representation to encode line drawing documents (which may be handwritten). We propose a method in which the problems induced by a first step skeletonization have been avoided. First, we achieve a vectorization of the image that enables a fine description of the drawing using only vectors and quadrilateral primitives. A structural graph is built based on these primitives extracted from the initial line drawing image. The objective is to manage attributes relative to elementary objects so as to provide a description of the spatial relationships (inclusion, junction, intersection, etc.) that exist between the graphics in the images. This is done by this representation that provides a global vision of the drawings. The capacity of the representation to evolve and to carry high semantical information is highlighted too. Finally, we show how an architecture using this structural representation and a mechanism of perceptive cycles could enable a good quality interpretation of line drawings.

key words : vectorization, feature extraction, structural representation, line drawings

1 Introduction

The classical aim of vectorization is to convert raster images into a vector form. It is a fundamental task in the interpretation process of line drawings because it is used as a preliminary step. Further interpretation requires that the obtained result gives a fine description of the raster image to the highest possible extent. So a lot of vectorization techniques have been developed in various domains and a large number of methods is now available [1,2,3,4]. These methods are mostly adapted to thin shapes but not to the other kinds of data that need to be extracted too (text, filled shapes, ...). We think most of the problems in document understanding are due to this processing way. This paper tries to show that more robust representations than usual vectorization can be defined to represent a drawing. Vectorization is often sufficient to store a line drawing but some problems occur when interpretation has to be achieved.

This paper describes first a new vectorization algorithm that provides a fine description of the drawing using vectors and quadrilaterals primitives. Then, we show that, based on these primitives, a structural graph could give essential information about relationships between the objects constituting the drawing.

The obtained results are commented on several images and show that this process leads to a good representation of line drawings. Then, the mechanism allowing the evolution of this initial representation is quickly described and shows that a good handling of the higher level entities (curves, text, ...) can finally be obtained using this structural representation.

2 Freehand line drawings and Vectorization techniques

2.1 Freehand line drawings

Each document has its own structure, chosen so that the information transmitted is easily understood and reusable by the readers. Freehand drawings constitute a particular category; they are made up of fluctuating lines, solid areas, hatched areas, text, etc. Shapes to recognize in these drawings are generally polygons, lines, circles, and other elementary geometric objects. The variable quality of the lines requires setting up specific line-recovery and correction algorithms before or during the recognition phase. Moreover, research done in this field [5,6,7] emphasizes the difficulty of this task, even for a human reader. The classical techniques of vectorization, text localization, curve localization and so on can only be used after some modifications, so that they take into account this fluctuating aspect of freehand lines. The vectorization algorithm we propose in the following of the paper enables the analysis of such drawings.

2.2 Well known vectorization techniques

Vectors are compact forms that describe the geometry of a graphical object with a small number of attribute values. For thin shapes, the median axis and the line length may be considered. Line drawings are essentially made of straight line segments and of arc lines so many automatic reading systems begin the analysis process with a skeletonization. Then, next treatments are made easier but this method induces some problems due to the information loss such as line thickness. After that, a structure more sophisticated than the pixel has to be chosen to encode the skeleton : some critical points have to be selected. Most often, the approximation uses linear elements (segments) and the vectorization of the image is realized

[8]. Unfortunately, the control points (of the polygonal lines) are not always figuring well the initial shape as can be seen on the examples of Fig. 1. Furthermore, skeletonization is not at all adapted to the study of filled shapes.

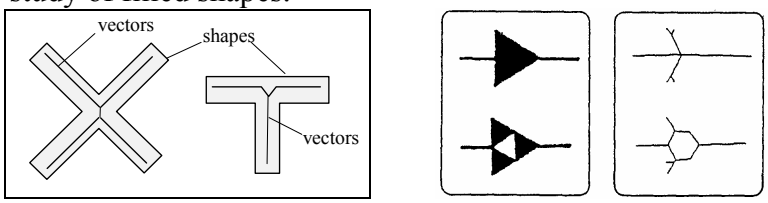


FIG. 1. EXAMPLES : SKELETON DOES NOT FIGURE THE SHAPE WELL

If an image of line drawing essentially consists in lines and curves, there are other kinds of shapes like solid shapes and text zones. To process such graphics, it is essential to generate an appropriate representation for these graphics (not only for thin lines). These problems are sometimes solved by vectorization methods based on opposite contours matching [9] instead of using a skeleton or by combining information given by skeleton and knowledge given by contours to improve the final result [10]. In this last paper, Shimotsuji group presents a precise line detection method that uses both contour and skeleton to preserve both the line connectivity and the shape of the original line but does not speak about how this method performs non thin shapes (filled shapes, text areas, …). Nevertheless, they bring some new results that can be applied successfully in some applications. C. Shih and R. Kasturi [11] have proposed an interesting method to take care of solid regions. It is based on the MSM algorithm but we think the authors did not really use it to treat the large filled areas during the whole process. Furthermore, other problems (text representation, freehand drawings) still remain unsolved.

Besides, a straight line segment is not always the most adapted feature for drawings that may contain some curves. Non-rectilinear shapes that are numerous in hand-drawn entities are badly represented, and problems occur when their relationships with other parts of the drawing (especially links between straight lines and curves - Fig. 2) are to be stored. Few studies tackle the problem of the extraction and of the coding of curves [4]. For this, OZZ and SPT algorithms of D. Dori's team [12] seem to provide quite good solutions.

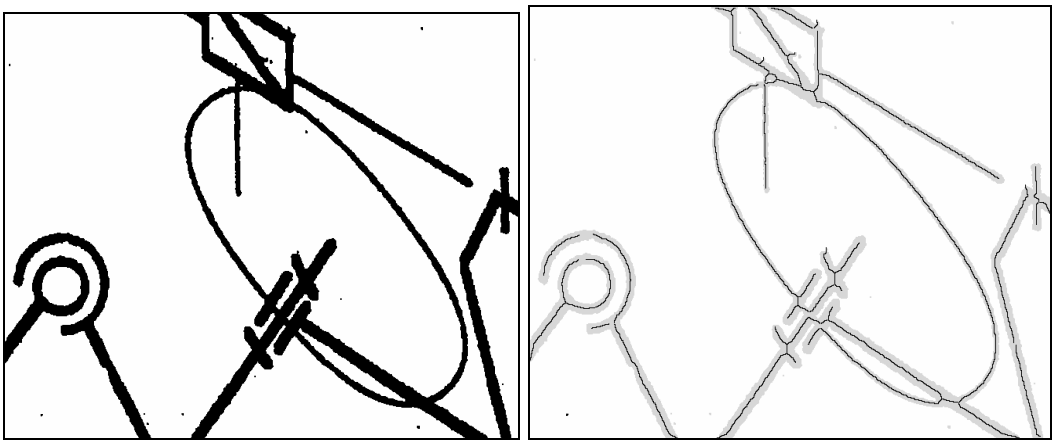


FIG. 2. INITIAL IMAGE AND ITS SKELETON

All these examples show that the bitmap image has to be simplified in order to build a representation of its contents. This transformation should have some properties that enable to realize :

- the conservation of the information that is contained in the image,
- the reduction of the data storage place,
- the simplification and the adaptability of the new representation space to the further processing.

It is difficult to elaborate a representation that respects these three constraints. In practice, a compromise has to be reached in which the most important aspects of the problem are taken into account first.

The common remark that can be done about the above vectorization methods is that they all need first to realize a segmentation of text or of solid shapes. This segmentation is often based on heuristical knowledge to separate the different kinds of shape layers constituting the drawing. Most of time, this phase uses non optimal criteria, and furthermore, once this separation phase is realized, each layer is processed separately by various methods. Of course, these methods are adapted to the kind of data that needs to be extracted but in fact various representations are needed to describe all the shapes that are present in the image and they differ a lot the one from the other. The comparison and the combination between results obtained on each layer is then a difficult task and back-tracking is therefore impossible to achieve without restarting the whole analysis all over again.

3 A representation using vectors and quadrilaterals

The proposed method has been implemented on both a HPUnix workstation and a PC Pentium III (450MHz, Windows98). The interpretation process starts from the binary raster image of the drawing generally scanned at 300dpi and is made up the following steps :

```
Vector_Construction();
Do
        Vector_Merging();
Until number of merging = 0;
Quadrilateral_Construction();
Do
        Quadrilateral_Sorting();
        Quadrilateral_Merging();
Until number of merging = 0;
Graph_construction();
```

Each step of this algorithm is described in details in the next section. This method have been tested and works with no significant differences (except processing time) on images scanned from 200dpi to 600dpi seeing that most of the parameters are not determined in an absolute way. Experiments were carried out on images of line drawings like the one shown in figures 6 and 12. The processing time (with the Pentium machine) on an image of 1536x2068 pixels (digitized at the resolution of 300dpi) is shown on table 1.

Processing	Time (sec)
Vector construction and merging	1.5
Quadrilaterals construction and merging	0.8
Graph construction	0.5
Total	2.8

Table 1 : Processing time.

3.1 Vectors

A binary shape can be described in an equivalent way by its contour and by the pixels of the black regions which constitute it. We chose to describe the shapes by their **contours** using Vector primitives. This choice was motivated by several points: Let only mention two of them. An information on main line direction can be obtained by a local survey of contours. The thickness of a line is calculated as the distance between two opposite frontiers.

To achieve the description, we chose the polygonal approximation method suggested by Wall [13]. This method tries to stay in the digital space and is based on an area computation. The threshold used concerns the permissible accumulated error by area unit. Then our algorithm is robust to an increase of the resolution. The vertices of the polygonal line are the control points. The obtained vectors are stored in a chained list (SV) according to the order provided by the contour tracking (Fig. 3). To improve the performances of the control point selection (on freehand drawings) and to decrease the sensitivity toward the chosen threshold, this study of the contours is conducted at different «levels of details» : the final approximation is operated in an iterative way (always using the same algorithm) on the newly obtained points. The number of control points is thus reduced by merging some vectors. This process is repeated until stabilisation that is to say until no fusion of vectors is any more possible. The number of iterations before stabilisation generally varies from 2 to 5 according to the image characteristics (curvature, hand-written or printed,...).

A vector is associated to a portion of the outlines of the drawing elements. In order to keep in mind the position of the line itself, the vector has such an orientation that the shape remains on the right side of the vector. Each element of the vector class has the following attributes :

- initial pixel : P1
- final pixel : P2
- length
- angle (with respect to the horizontal line)

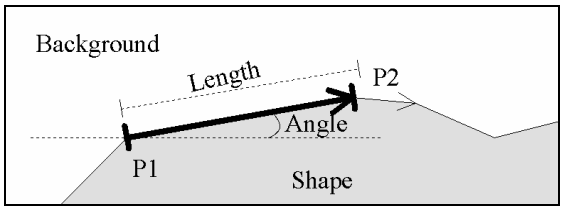


FIG. 3. VECTOR PRIMITIVE

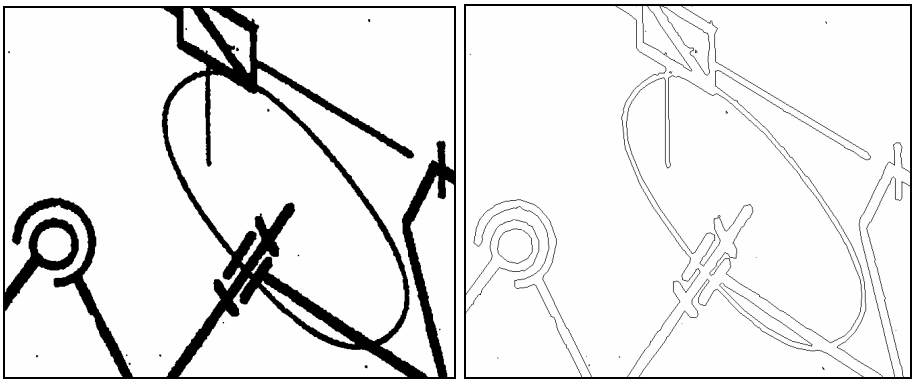


FIG. 4. VECTORS PROVIDED BY THE POLYGONAL APPROXIMATION OF CONTOURS

The image representation by Vectors corresponding to the contours allows to keep almost all the information and gives a very faithful approximation of the drawing (Fig. 4), but vectors are too simple and do not provide sufficient information on the structure of the document to start the interpretation. In order to obtain and easily manage some additional data, it is necessary to define a more advanced description tool.

3.2 Quadrilaterals

A stage of Vector matching permits the generation of quadrilateral primitives. Each quadrilateral is defined by a couple of Vectors (on each part of the two opposite frontiers of a thin shape). This description could be compared to the Shih and Kasturi's one based on trapezes [11]. In our case, in order to obtain a more robust description of thin shapes, the construction of the Quadrilaterals is realised by the following few steps :

- Step 1 : matching of the Vectors (elements of SV) in order to construct the quadrilaterals
- Step 2 : sorting of the quadrilateral sequence according to proximity
- Step 3 : merging of the neighboring Quadrilaterals (in the same way as for the Vectors)

3.3 Step 1 : Matching

The matching algorithm begins by selecting the vector (V1) with maximum length in the list of the non matched vectors, then it seeks for the two nearest opposite vectors, according to the distance between their extremities (d1 and d2 on Fig. 5) verifying some criteria. The matching of V1 with one of the two selected vectors takes place only if conditions (matching criteria) are verified. For the moment, these criteria have been empirically chosen but they are issued from the physical properties of the thin lines (parallelism and presence of black pixels between them).

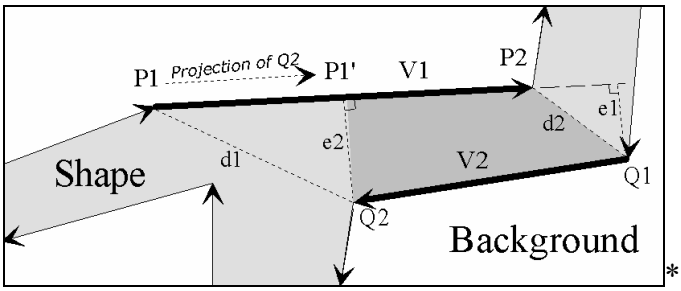


FIG. 5. MATCHING OF THE VECTORS DURING QUADRILATERAL CONSTRUCTION

In order to improve the matching, some vectors can be decomposed into two son vectors; the clipping point is obtained by projection of a vector extremity on the other vector (Fig. 5 : P_1'). So, the lengths of the two paired vectors are more similar. The second son vector stays in the list of the non matched vectors.

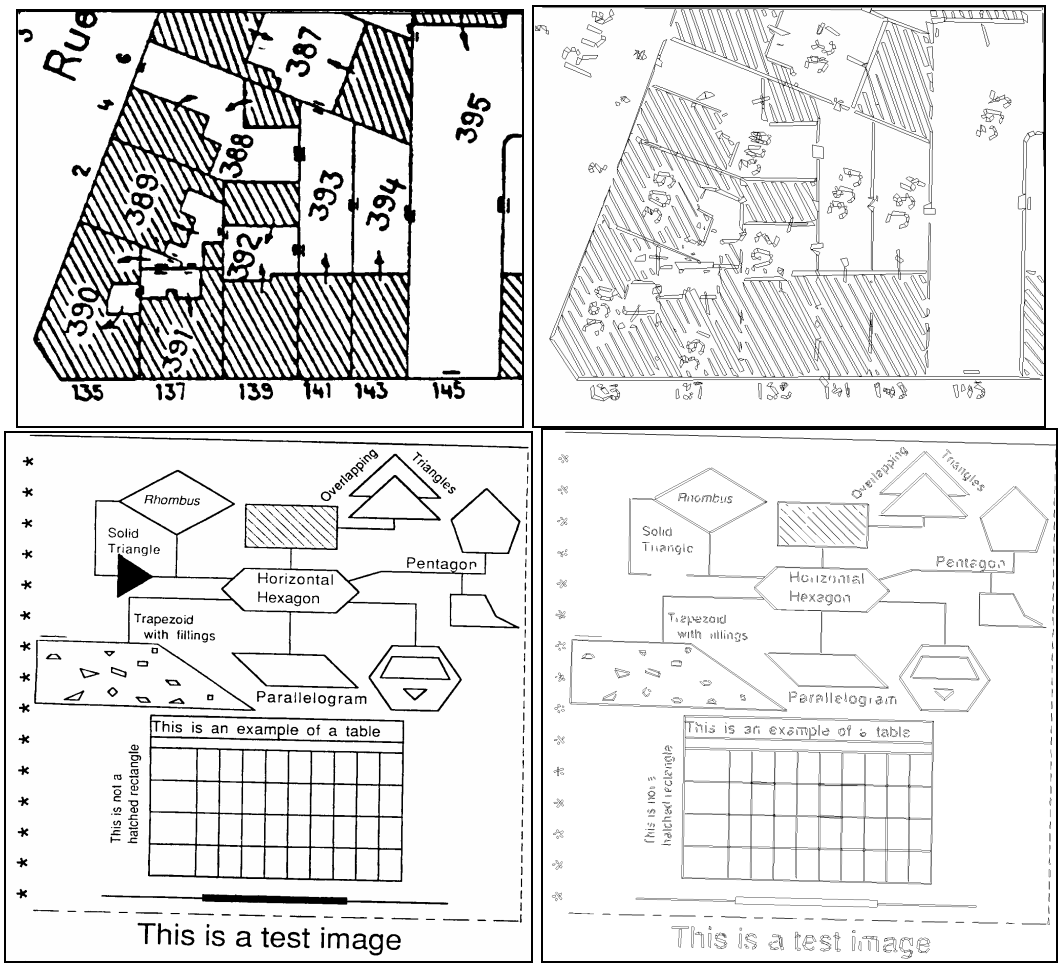


FIG. 6. TWO INITIAL IMAGES AND THEIR QUADRILATERAL REPRESENTATIONS

The matching process stops when no more matching is achievable (according to the criteria). The attributes of each quadrilateral are those obtained from the component vectors by an heritage process. Two additional ones: both thickness e1 and thickness e2 (Fig. 5) are computed too. The obtained quadrilaterals and their attributes are stored in a chained list SQ.

A result (of the matching stage) is presented on Fig. 6 Most of the vectors that have not been matched are corresponding to the contours of filled shapes (Fig. 7).

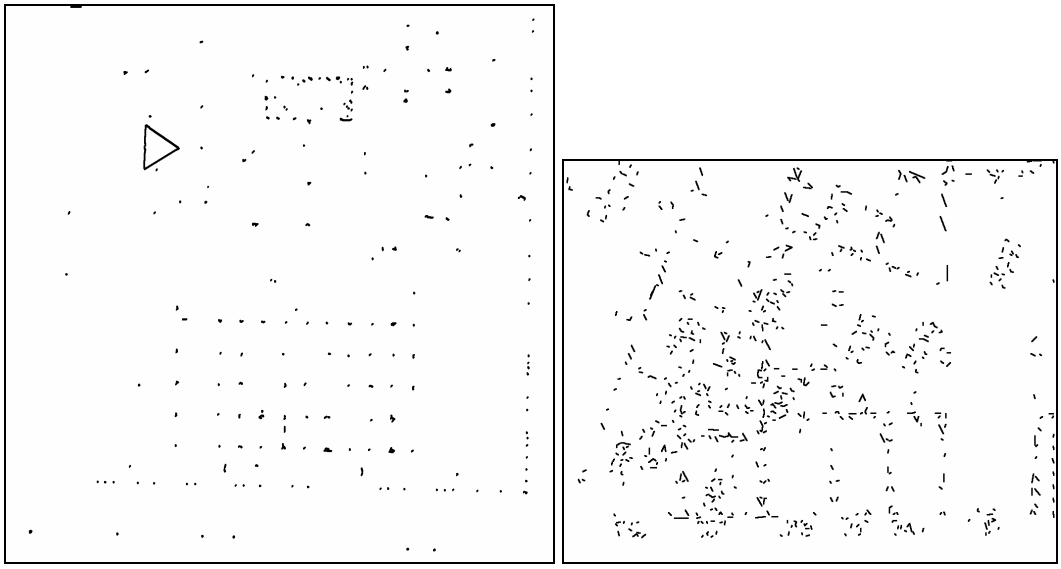


FIG. 7. VECTOR REPRESENTATION ASSOCIATED WITH THE IMAGE IN FIGURE 6

3.4 Step 2 : Sorting

The merging (of the quadrilaterals) can only occur after the Quadrilaterals have been sorted according to their proximity. For this, we have to define a distance δ (figure 8) between Quadrilaterals.

Quadrilaterals are sorted so as to reproduce at best a potential chronological order of the line drawing (scribe). The main problem is the choice of the starting point. Once this point has been chosen, a search of the nearest neighboring Quadrilateral allows, step by step, to build the line course until finding an ending Quadrilateral with no other neighbor.

Q and Q' are two quadrilaterals (see figure 8 for the notations) :

IF |angleQ - angleQ'| < Π/8 **AND** Black_between (Q,Q') **THEN**

$\delta(Q,Q') = \mathrm{Min}(P_1P_2'+Q_2Q_1',P_1Q_2'+Q_2P_1', P_2P_1'+Q_1Q_2', P_2'Q_1+Q_1'P_2)$

ELSE

$\delta(Q,Q') = +\infty$

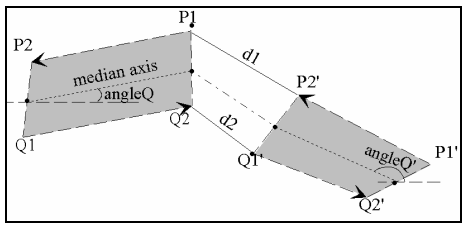


FIG. 8 : DISTANCE BETWEEN TWO QUADRILATERALS

For the choice of the starting Quadrilateral, we decided to select the one that has the farthest neighbor. The probability that this Quadrilateral corresponds to an extremity of line is then maximum (fig. 9).

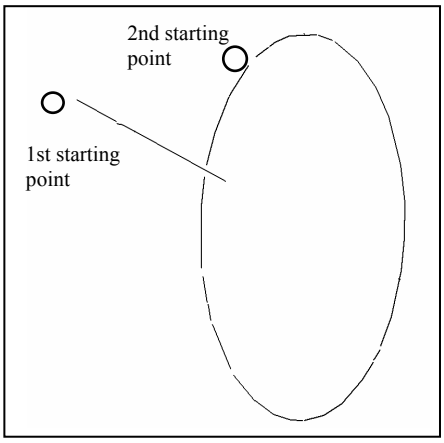


FIG. 9 : TWO FIRST CANDIDATES FOR THE STARTING POINT OF THE STROKES

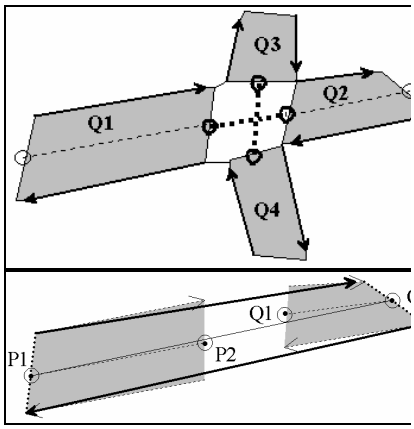
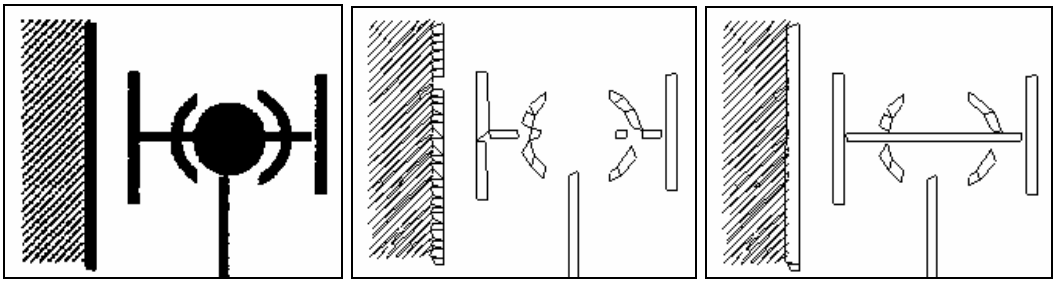


FIG. 10 : FUSION OF QUADRILATERALS

3.5 Step 3 : Merging

Previously we have stated the principle of working at different levels of detail (to take into account freehand drawings), so the algorithm of polygonal approximation used during the vector merging step is applied to the Quadrilateral median segment extremities (figure 10). Of course, the algorithm involves the attributes of the Quadrilaterals (in particular the thickness) to operate or reject a fusion of 2 quadrilaterals. Figure 11 illustrates the importance of this merging step.



(a) (b) (c)

FIG. 11 : THE MERGING STEP : (A) INITIAL IMAGE, (B) BEFORE MERGING, (C) AFTER MERGING

The set of quadrilaterals finally obtained is representative of the thin shapes in the initial document (figure 12). It is obvious that our representation is always very close to the initial drawing and that our method is quite well adapted to many types of documents.

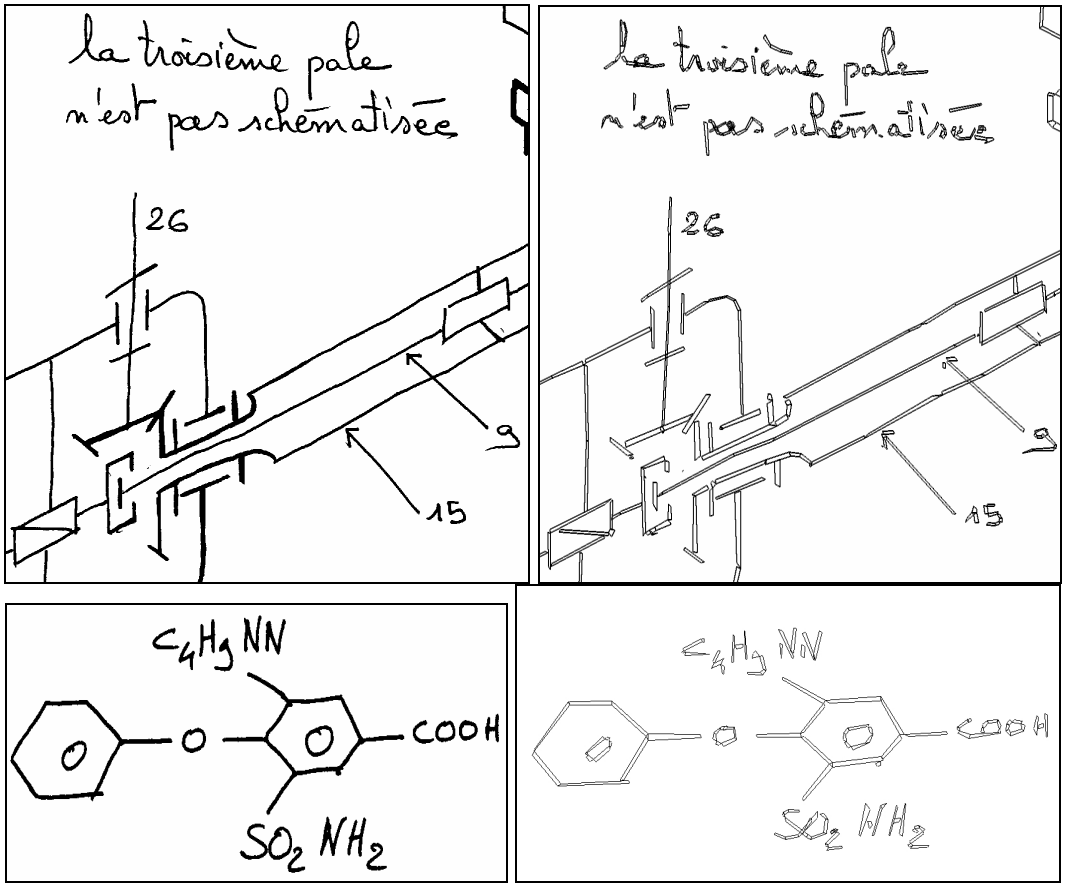


FIG. 12. TWO INITIAL IMAGE AND THEIR REPRESENTATION

3.6 Structural graph

The construction of vectors and quadrilaterals corresponds to a global approach (and a first representation) of the document. As recommended by K. Tombre in [14], we limit to this construction what is usually called the "vectorization" step. To recognize high level elements (technical/chemical symbols, polygons, circles, …), we found it necessary to organize the data extracted so as to use the context more appropriately during interpretation. A graph representation is the best qualified to link the different objects making up a drawing in relation to their neighborhood; it is also the most suitable to figure the structural relationships between primitives.

The quadrilaterals extracted are the nodes of the graph and arcs linking these nodes indicate the relationships existing between the primitives. The graph represents the global structure of a line drawing. Constructing a graph means calculating a zone of influence for each primitive. Arcs will describe the nature of the links between the primitive being studied and those belonging to its zone of influence. The previous table (Fig. 13) lists the types of relationships used to construct the graph.

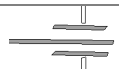
Type of relationship between objects	Example
T junction → T	
Intersection → X	
Parallel relation → //	
L junction → L	
Two successive lines → S	

FIG 13: DIFFERENT TYPES OF INTERACTION

Figure 14 describes the construction process of the part of the graph corresponding to Quadrilateral 0 (SQ element).

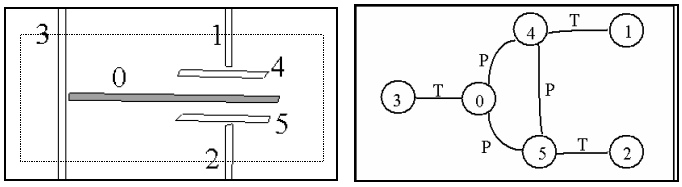


FIG. 14: ZONE OF INFLUENCE OF THE QUADRILATERAL 0 AND THE CORRESPONDING GRAPH.

The description in graph form is labeled, each quadrilateral has different attributes which characterize its neighborhood as much as possible. In particular, to each of the two extremities is associated a number corresponding to the number of lines with this same extremity. Consequently, an isolated line is characterized by two integers with the value 1. For instance, this allows easy localization of chemical elements [15].

Figure 15 shows the structural graphs obtained, representative of chemical formulas. For the first image (Fig. 15), the textual components have been taken out to improve the readability of the graph.

It can be emphasised that this whole stage should be seen as the method we have elaborated to obtain a primal description of the thin shapes and of their relationships using simple features included in a structural graph.

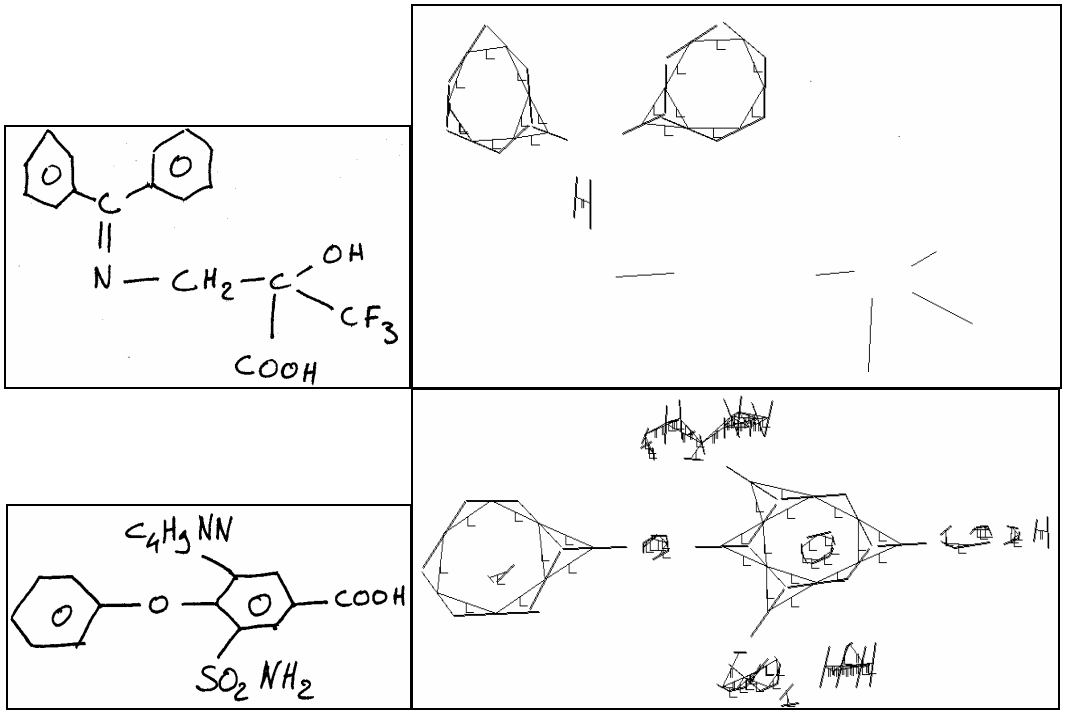


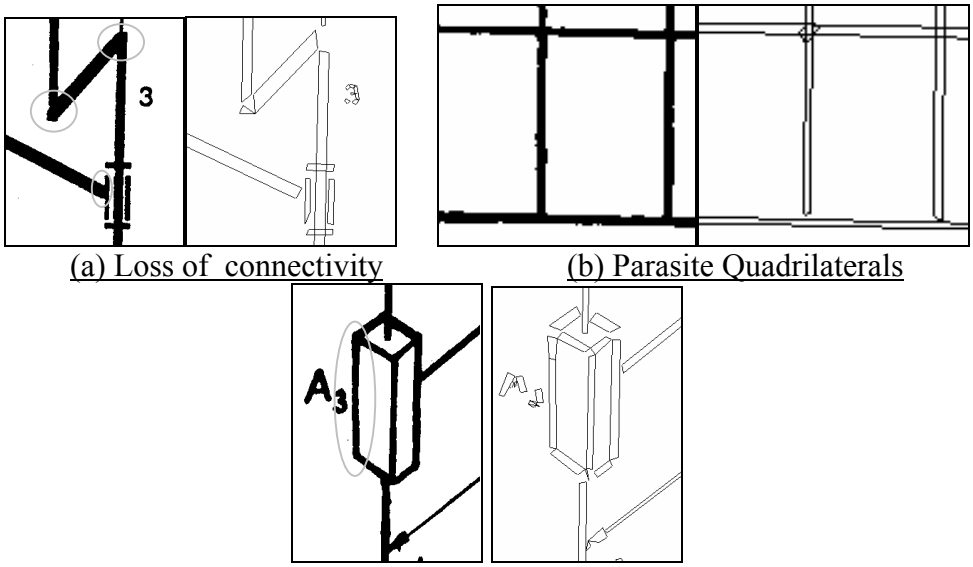
FIG. 15: EXAMPLES OF SOME GRAPHS WITH SCANNED CHEMICAL FORMULA

Thanks to this representation, the following process of entity extraction will not use the bitmap image itself but a higher level structure. Compared with the use of pixels as elementary features, more information is then available. So this data structure can be considered as a sufficient intermediate representation able to adapt itself in order to describe different types of freehand drawings (technical drawings, chemical formulas, musical scores, cadastral maps, …).

4 The pros and cons of this representation

First, let us talk about the negative points of this representation. The first drawback of the algorithm is that the representation of crossing lines or lines with angular points is not directly perfect. Nevertheless, an improvement can be noticed with respect to many previous methods. The continuity of some lines at crossing point is figured.

Some examples are shown in figure 16. In figure 16b, the double reconstitution of crossing lines can be observed corresponding to the superposition of 2 entities. And last, the line (Quadrilateral) thickness management could provoke some decompositions of one line in several Quadrilaterals (figure 16c), in particular when hand-drawn documents are concerned.



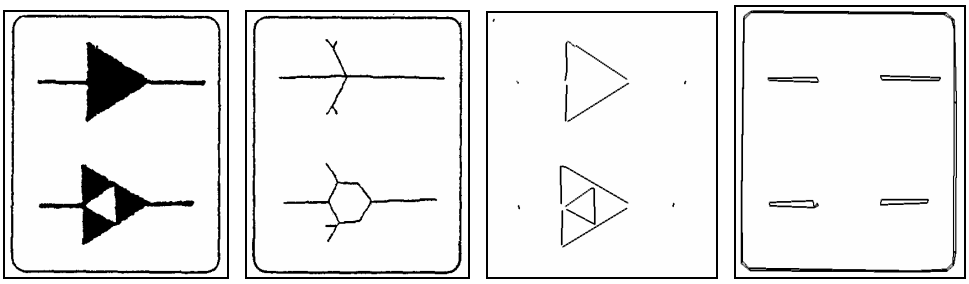
(a) Loss of connectivity (b) Parasite Quadrilaterals

(c) Degenerate Quadrilaterals

FIG. 16 : SOME DIFFICULTIES THAT OCCUR WITH QUADRILATERALS

Besides, this representation has solved some problems concerning low level processing :

• The filled shapes and junctions or extremities of lines are notably less deteriorated than with a real skeletonization (very frequent in classical vectorization). Figure 17 allows comparison.



Initial Image Skeleton Vectors Quadrilaterals

FIG. 17 : ANSWERS TO PROBLEMS DUE TO SKELETONIZATION

• The quality of the representation of lines we obtain seems to be better than when using methods such as some other polygonal approximation algorithms where the obtained control points are not always very representative of the initial shape (as we can see on figure 18). This improvement essentially comes from the merging of the quadrilaterals.

Our representation allows to discriminate between filled shapes (Vectors) and thin shapes (Quadrilaterals), it allows to measure the main directions, the thickness of the lines, and their place in the image. These elementary features constitute a very important source of information that will be used all along the analysis.

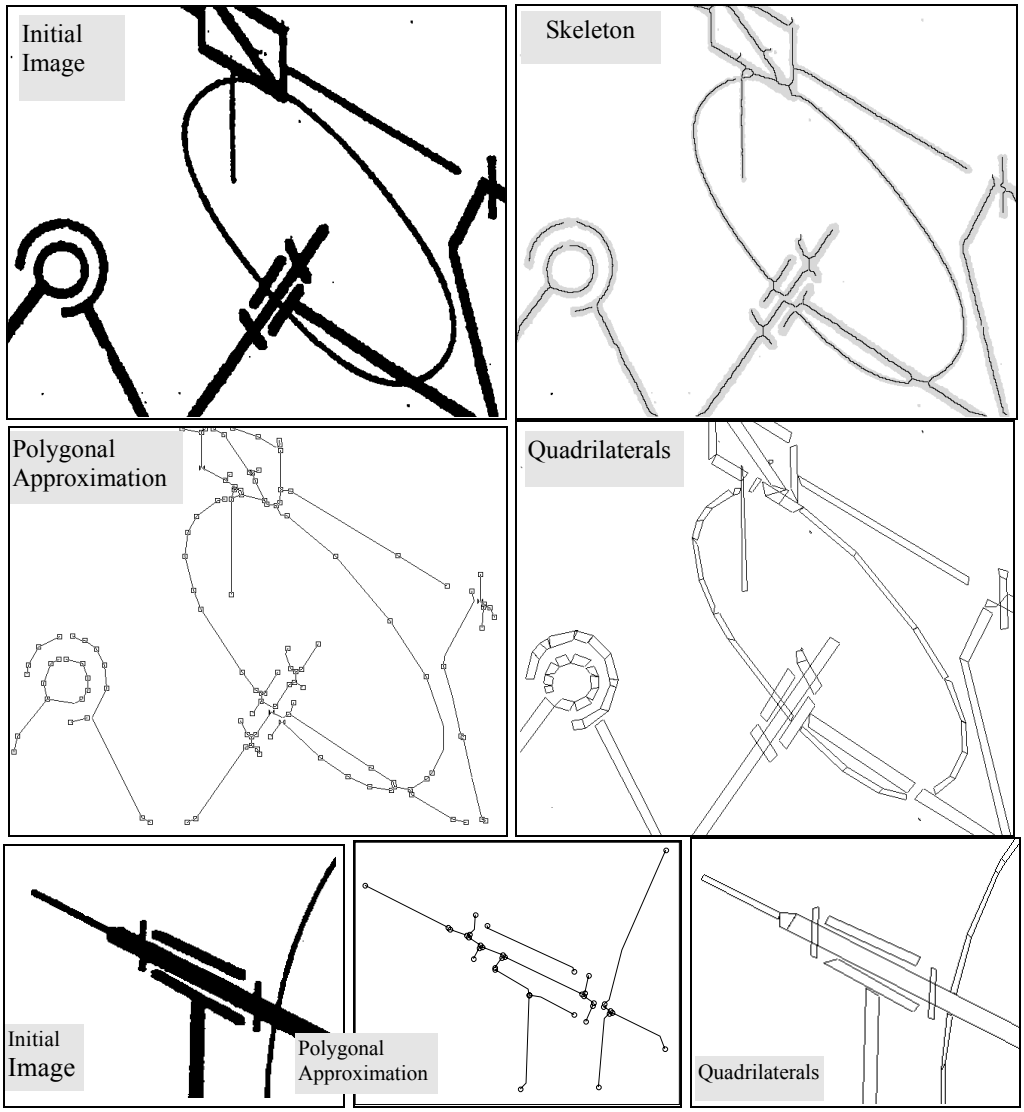


FIG. 18 : EXAMPLES OF ANSWERS TO PROBLEMS OF POLYGONAL APPROXIMATION

In the other hand, the structural graph gives very useful information about the relationships between elementary objects that have been extracted from the drawing. The relative position of the primitives in the initial image can be studied using the attributes of each node and arc of the graph (figure 19).

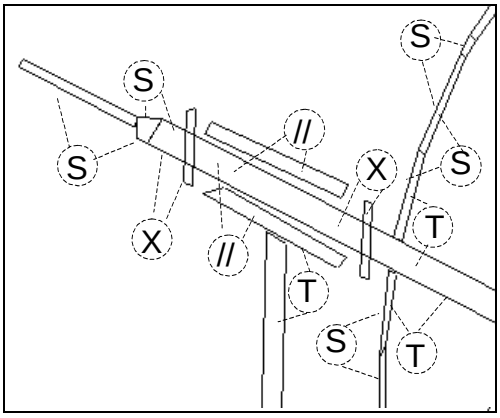


FIG. 19 : STRUCTURAL GRAPH ASSOCIATED WITH A PART OF THE IMAGE FIG. 18

5 Using the structural representation

At the beginning of the paper we have stated as an important property that a good representation needs to be adapted to nonlinear shapes too. So, using the structural graph and the initial image too, we are going to propose a way to rebuild the entities that are the curves and the other entities constituting the drawing. Our structural representation provides a good starting point for further studies to make the segmentation phase disappear. Several algorithms, each one tuned to a specific task (extraction of curves, text zones, dotted lines, mechanical entities, and so on), but all using the same representation, are involved in the interpretation of a document. A competition can be established between these processes. The originality of the global system relies then on the fact that the structural representation is able to evolve during the processing. Each primitive (Quadrilaterals, Vectors) can either be labeled as a possible element of a higher level entity or be erased when the higher level object that it is part of, has been recognized without any ambiguity. When a conflict occurs (two different values are associated with a single vector or quadrilateral primitive) it must be solved before going on in the analysis process. An automatic inconsistency management or some help from the user can be sometimes needed. The philosophy of J. den Hartog's method [16] is not very far from ours: Instead of achieving a real vectorization (that needs a layer segmentation), the image is decomposed in graphical primitives (global segmentation) by studying the segments and the junctions of a skeleton.

Let us specify one of the processes of our system. The "curve" algorithm will use the representation (structural graph) to locate hypothetical curves (set of successive quadrilaterals with 'S' relationships in the graph). The distinction between straight lines and curves is automatically achieved using Bézier curves. The method is relying on a change of the initial representation towards a more sophisticated one (Bézier), so only irrelevant information can be lost and no pattern can be omitted.

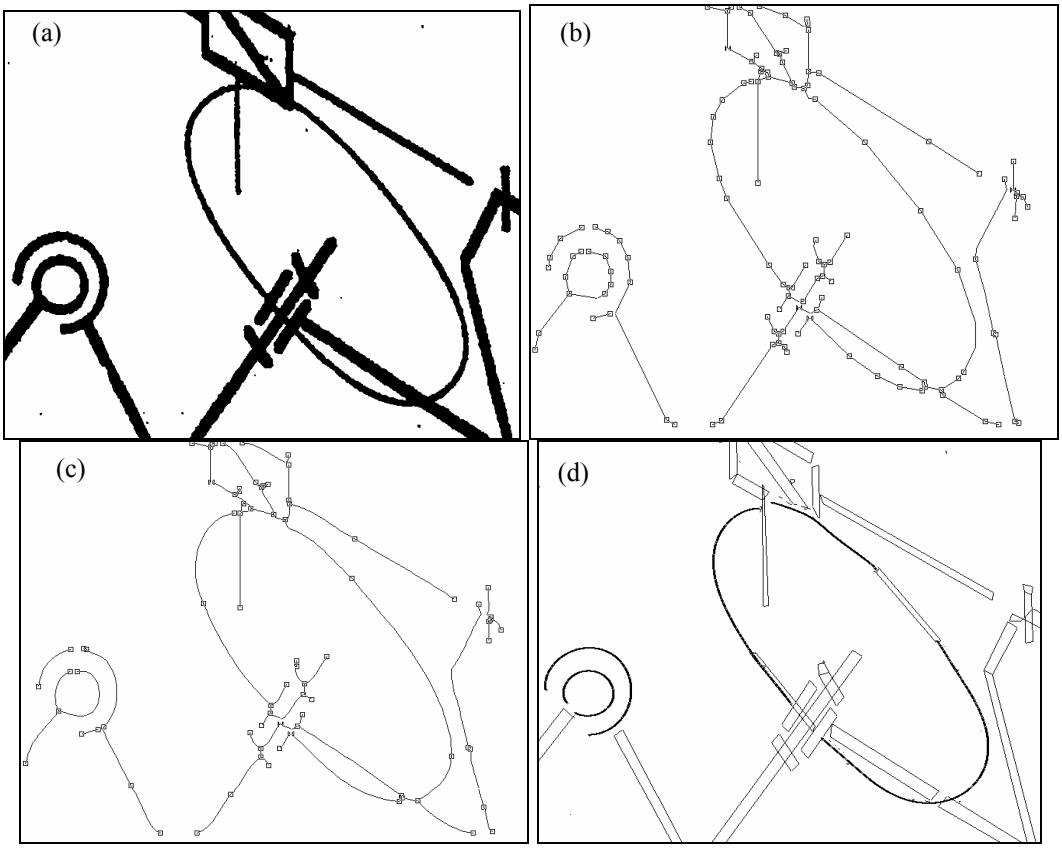


FIG. 20. CURVES (SKELETON) APPROXIMATION USING POLYLINES (B) OR BÉZIER(C) VERSUS OUR REPRESENTATION (QUADRILATERALS + BÉZIER) (D)

The only possible confusion is between rectilinear form and curve. An example of result given by this process is shown in Fig. 20_d and more details can be found in [17]. The curve algorithm uses the content of the graph to focus its attention on some precise zones in the image (hypothesis generation) that it studies in details (verification) in order to make the recognition (transformation).

In our global system, a mechanism of "perceptive cycles" [18, 19] allows the different processes to collaborate : they can be sequentially activated until the total understanding of document is carried on by the representation. Each activation of a process provokes an evolution of the representation. Besides, in order to minimise the interpretation errors, only evidences have to be extracted during each cycle. At the end of a cycle, the completion of the understanding is verified and a new cycle allows if necessary a new progression in the interpretation : some data, shifty at a given instant for a given process, could constitute an evidence for an other process. During a next activation, the representation would have been simplified and the number of ambiguousness reduced with regard to the current state.

6 Conclusion

The method we have proposed is only one part of a larger system. It deals with the elaboration of a first representation of a line drawing image which may be handwritten. A first

description of the document is obtained using vector and quadrilateral primitives. Then, the problematic segmentation phase is suppressed, the initial shapes are respected and the main information (of great importance for subsequent processes) is still available such as for instance line thickness or main line directions using primitive attributes.

We have illustrated that the structural graph based on these primitives provides essential information about relationships between the elementary objects constituting the initial drawing.

Thereafter, an improvement of the structural representation could be achieved by using a set of processes that deals with some specific local analysis of this representation. The task of each process is simplified because at first they only solve basic problems and after they are made aware of the extracted context for solving harder problems.

From this experiment, we conclude that the construction of a line drawing representation is a difficult task when we want to manage the associated knowledge. We also conclude that representations allowing iterations of knowledge acquisition, from the low levels until the high levels of the processing improve effectiveness. So, we will now concentrate our research on this fundamental point.

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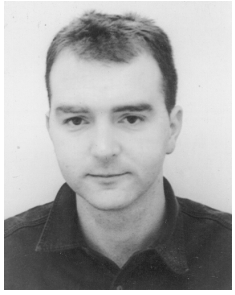

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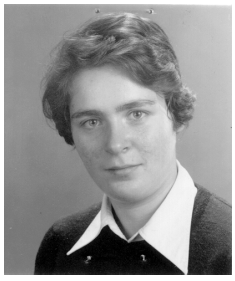

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