Symbol and Shape Recognition

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Abstract. The different aspects of a process for recognizing symbols in documents are considered and the techniques that have been most commonly used during the last ten years, in the different application fields, are reviewed. Methods used in the representation, description and classification phases are shortly discussed and the main recognition strategies are mentioned. Some of the problems that appear still open are proposed to the attention of the reader.

1 Introduction

A significant part of many documents is made of entities which can be classified as symbols, i.e. as sets of graphic signs or shapes which are entrusted with the task of ideally and/or synthetically represent something. In the framework of document processing, symbols are characterized by the semantics attributed to them and by the rules used to build them. In fact, symbols are generally not free shapes, but they are formed according to rules, whose knowledge can help for their recognition. From an operative point of view, it is worth noting that, on the contrary of other entities (e.g. characters making up a piece of text, which are singled out only after the text region has been delimited in its whole), symbols are generally distributed over the document, thus the procedure to search for them has to be in some way peculiar. From this point of view, isolated characters or short strings may be considered symbols.

From the point of view of symbol recognition, the documents of interest for automatic processing can be roughly grouped into three large families:

∀ Technical Drawings, including Electrical and Electronic Circuits, Logic Diagrams, Flow Charts, Mechanical Drawings, Architectural Drawings, Facility Drawings (also referred as Utility Maps) which for their part include documents such as Electric Power Maps, Gas and Telephone Maps, Piping and Instrument Diagrams.

∀ Maps, including Geographic, Topographic, Cadastral and Hydrographic maps.

∀ Others, including a miscellany of documents containing special types of symbols, such as Musical Scores, Mathematical Symbols, Logos, Structured Chemical Formulas.

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Within this large variety of documents, there is a still larger variety of entities that are considered symbols. Symbols can be simple 2-D (substantially) binary shapes, made by sets of line segments possibly forming loops so as foreground regions of various shapes; they can be complex gray level or color shapes like for some logos, so as simple silhouettes within a frame, like for some geographic symbols. Characters, present together with graphics in almost every drawing or map, are symbols above all, although they are generally specially treated.

In any case, symbols may appear isolated, or embedded in a net of lines. Moreover, they can touch, partially overlap each other, or intersect other line. The problems with symbol recognition depend not much on their intrinsic shape variability or on the complexity of the features characterizing them, but on the fact that they are more or less embedded in a context which is often very crowded. Often symbols must be located in an apparent clutter of other signs.

To rely on a priori knowledge about the nature of the document is generally necessary to locate candidate symbols or regions of interest where to apply specific recognition techniques. It is therefore not surprising that a number of different approaches have been devised for the different application fields considered.

On the other hand, the whole field of image recognition (both by man or machine) is characterized by the fact that many of the analysis methods developed are very application dependent. This is due to the fact that the characteristics of images belonging to different application areas may be quite different and such that their interpretation requires specific knowledge. Even for a human being, the skill for interpreting, e.g. a geographic map, requires the knowledge of criteria and conventions which led to its production, as well as to have developed a set of methods and strategies which the experience taught to be especially effective for extracting the information held by the document. Methods and strategies used in one case may reveal effective also in case of images of a different type, but to solve some problems peculiar to a given type of images, methods may be needed which can seldom be exported outside that image type. It is not a case that often the right interpretation of an image can be given only after having attributed it to a type (or having received information about its type) and thus having made implicit or explicit reference to the techniques for accessing its informative content.

Although it remains unavoidable that peculiar problems require peculiar treatment, there are, however, methods and tools for automatic image analysis which can be used in different frameworks, so that a substantial part of the analysis process of any particular class of images could be built up with a suitable combination of them. With special reference to the problem of symbol and shape recognition in a document, a number of techniques have been tested in the past years. Many of them can be profitably used with different types of symbols in different contests. Particular contests will always require special processing.

Generally speaking, the process leading to the interpretation of an image evolves through three main phases: during the first, that will be called here Representation Phase, the scope is to put the image in a form more suitable for the subsequent processing so as to locate and outline the entities of interest. The second phase is devoted to give a description of the located entities, while the third phase attempts to classify them. Of course, a strategy has to be defined for controlling the whole recognition process.

In the ideal case, one could devise a strategy according to which:

∀ The document is first preprocessed in order to obtain a more convenient representation of it; the type of preprocessing may at least partly depend on the type of document.

∀ Then symbols are searched for in the representation, on the basis of some general features possibly shared by all the symbols: this process produces a number of candidate symbols.

∀ Each candidate symbol is described in terms of more detailed features so as to obtain a feature vector or a structural description.

∀ Finally the description is feed into a classification stage which attributes it to a class (i.e. recognizes the description as that of a specific symbol which has been previously learned or which exists in a database of prototypes).

This scheme, with variants, has been actually used by many researchers in various applications. As for graphic documents, specific actions are performed during each of the mentioned phases with the aim of locating and processing symbols. Processes in which the three phases mentioned above are not simply distinguishable, or some of them are merged, have of course been proposed. A desirable feature of a recognition system would also be that of having the capacity to going back to a previous phase, to try to improve the results, in case a decision cannot be reliably taken. However, this feature is rarely present in actual recognition systems.

A number of good review papers completely or partly dedicated to problems related to symbol recognition in documents, have been presented in the last few years [1-9]. In the following, the field will be shortly reviewed from a different point of view. Some of the techniques which, in the three mentioned phases, are more commonly used, or have been proposed, for processing symbols will be shortly discussed, attempting to understand which are applicable to different kinds of documents and are well established as regards the obtainable results, and which are tailored to specific application fields.

2 Representation Phase

At the lowest level of the vision process, the information is usually processed without using any knowledge about the considered image. The aim is that of extracting the information which is retained more significant for the next analysis (e.g., sharp intensity variations). The result of preliminary processing is generally still an image, which is one of the possible representations of the original one (alternative with respect to row data). Successive processing steps can lead to further representations, with the scope of achieving a more convenient way to supply those information about an image which are considered necessary and sufficient for a given processing task.

The main aims of the representation phase are to reduce noise and amount of data, to outline the image components and to represent them in such a way that not significant differences among their various instances are smoothed. However, not always information can be aggregated in a single way or independently of semantics. In some cases, the representation phase can be intended as a first step towards the abstraction process leading from a specimen of a class to the prototype of that class. Information about the image representation is stored in a suitable data structure.

With reference to documents containing symbols, techniques widely applicable in this phase are binarization, thinning, polygonal approximation, run length coding, curve fitting, connected component labeling, mathematical morphology operations, Hough or other transformations, etc.

An idea of the frequency with which different techniques have been used in the different symbol recognition systems reported in the reference list of this paper can be got from Table I, where the approximate percentage of systems using each different technique is shown, for each different phase. The sum of the percentages is not necessarily equal to 100, because different techniques are sometimes used within the same recognition system; e.g. a representation may be used for locating candidate symbols or regions including them and a different one for recognition purposes. Same systems illustrated in more than one paper have been considered only once. The reference list includes papers published during the last ten years in the application fields considered: technical and facility drawings [10-33], maps of various types [34-46], musical scores [47-51], logos [52-55] and others [56-59].

Documents are generally scanned at a spatial resolution ranging from 150 to 400 dpi, but low resolution is preferred whenever possible. In the large majority of cases, documents are intrinsically black and white images, so the first step is their binarization. This may not be convenient with some color maps and logos. For good quality documents, binarization is presently not a problem. Although a number of thresholding and edge detection algorithms are available [60],[61], low contrast or degraded documents may still constitute a problem.

After binarization and some very preliminary processing (e.g., black and white noise cleaning), the most common choices are:

∀ to operate directly on the bit map
∀ to transform the bit map into a run-length coded image (referred also as a LAG)
∀ to thin the image and represent it as a graph or a linked list (this step is often performed later in the process)

Whatever the choice made, a common initial step is Connected Component Labeling. Connected component labeling is used for a number of purposes: generally it is a way for segmenting a document into regions among which to select those corresponding to potential symbols or including symbols. When applied on the foreground it allows locating components among which to search for isolated symbols. An alternative point of view is using it to clear the field of everything is certainly neither a symbol nor is connected to symbols (especially used as a first step for candidate character location). Connected component labeling applied on the background allows finding regions bounded by lines, i.e. loops. This technique is widely used in electronic circuit drawings. Of course symbols must then be selected among all loops found. In order to separate symbols made by thick foreground regions from the rest of the drawing (supposed to be made of thin lines) mathematical morphology operations have been used.

At a certain point of the analysis process, the thin parts of the drawing are often vectorized before further processing. This is also a widely employed method for image segmentation since, by suitably grouping the obtained vectors, it is possible to segment symbols from the rest of the document. Thinning [62] followed by polygonal approximation is the most common vectorization method. It has to be noted that the thinning algorithms more often used are based on contour peeling or on the iterative application of masks. The so obtained skeletons do not hold information on local thickness which can instead be useful, e.g. for discriminating filled symbols from empty ones (loops). Skeletons of the Medial Axis Transform type [63] preserve this information and are reversible. However, all of the above techniques can introduce shape distortions at the crossing and junction of lines and generally oblige to adopt more complex processing, not always effective, in the following stages. Several algorithms, which claim to have eliminated or at least reduced this problem, have been proposed in the last ten years. Some of them try to avoid that the distortions arise [64-74], other try to correct the distortions [75-81]. To our knowledge, however, no such algorithms came into common use. This may also depend on the fact that details on the algorithms such to allow their actual implementation have rarely been given. Vectorization can also be achieved starting from run length coding of the image or with other techniques like mesh crossing. Such different approaches should avoid the thinning side effects, but in fact may equally give place to several problems. Some authors prefer not to pass through vectorization, but to divide the drawing into primitive strokes and to work on this kind of representation.

Given a digital line, e.g. obtained by thinning, it is simplest to describe its geometric characteristics if it is transformed into a sequence of pieces of regular curves. This allows simpler structural descriptions of sets of such pieces. Digital curve fitting in its simplest form is polygonal approximation. Fitting with higher order functions can been used for obtaining a compact and effective representation of some sort of regular shapes, like circular arcs and more generally conical curves. An alternative way for detecting some regular shapes is the Hough transform that has been used to check collinearity of points [15],[50], e.g. for detecting character strings or separating connecting lines from symbols, and, by suitably choosing the representation plane, to highlight circular shapes [33].

A problem often present in this phase is the separation of symbols from lines and other symbols that possibly cross, overlap or touch them. Such situations are a standard in music documents, are very common in geographic, cadastral and topographic maps, may happen with technical drawings, but are generally less dramatic in logical circuit drawings. Effective methods have been proposed for some special case [82], but the general problem is still open.

Table 1. Frequency with which different techniques or features have been used in the different symbol recognition systems reported in the reference list of this paper. The approximate percentage of systems using each different technique or feature is shown, for each different phase. The sum of the percentages is not necessarily equal to 100, because different techniques are sometimes used within the same recognition system

REPRESENTATION PHASE		**%**
	Run length based representations (LAG etc.)	15
	Connected component labeling	69
	Thinning and polygonal approximation (graph)	58
	Thin-thick separation	12
	Internal and/or external contours	12
	Distance transform (3-4, Voronoi)	8
	Wavelet transform	4
	Hough transform	15
DESCRIPTION PHASE		
	Geometric and topologic features (n. of vectors, global shape descriptors such as A, P, shape factors, x-y projections, etc.)	38
	Moment invariants	15
	Fourier Transform	8
	Structural descriptions	23
	Syntactic descriptions	4
	Other (morphol. functions, special transforms)	12
CLASSIFICATION PHASE		
	Template matching	46
	Decision tree	12
	Neural net	15
	Graph matching	8
	Syntactic parser	4
	Statistical classifier	15
	Heuristic techniques	27
RECOGNITION STRATEGY		
	Bottom-up	85
	Top-down	15

3 Description Phase

It is possible to associate to this phase the methods which, starting from a representation of the image, give a symbolic description of it. According to the strategy adopted in the previous phase, such description may be of different level. Indeed, some kind of representation may already imply a description scheme.

A description may regard the whole image or the different subparts of it selected as candidate symbols. In the former case the data structure supporting the description has to be analyzed in order to find the substructures corresponding to symbols. This process can directly arrive to symbol classification, so including the next phase, or it can just suggest some candidates that have to be validated in the successive recognition step. In the latter case the description of each subpart is passed to the recognition module. In any case there is a problem of feature extraction and of selection of the data structure that support the description.

Since the largest family of symbols used in maps and technical drawings is made of simple geometric shapes and of their combinations, topological or geometric features are generally used for description. At preliminary steps of the analysis process simple and often global features are used, while at successive steps different or more detailed features are introduced. Recent reviews on shape analysis and the feature extraction problem can be found in [83], [84].

Different instances of a symbol, like of any other visual entity, almost never appear identical to a given prototype. This is especially true if they are represented directly by row data. Their shape may be corrupted by noise or there may be differences due to position, orientation and size. For certain types of documents, it is quite common that symbols touch or overlap other graphics. It is then convenient to select the features characterizing the representation of a symbol at a level sufficiently abstract to overcome the variability of its different instances. A particular representation may render some features more accessible than others, but is still susceptible of different descriptions, as a function of scope or of number of classes. If a description has to be used to faithfully reproduce the described entity, then it has to be quantitative and very detailed. On the contrary, for recognition purposes, it is more convenient to use few qualitative features, especially if there are few different classes and the variability inside a class is high. A description has to be oriented to the scope and be possibly stable, concise, sensitive, unique and accessible. For shape recognition purposes, descriptions should be invariant with respect to affine transformations (translation, rotation, scale changes). A list of the features most frequently used for symbol description can be found in Table I.

Among data structures, graphs are used to support structural descriptions of graphics and symbols. Graphs are especially suitable for representing structural information. They can be simple linked lists of pixels or line adjacency graphs, but can also describe polylines by associating graph nodes to the segments of the polygonal and graph edges to the spatial relations between adjacent segments. Graphs of this type are commonly used in methods based on the hypothesis that symbols are represented in terms of straight components as happens for the majority of technical drawings. More generally, Attributed Relational Graphs (ARGís) are a good support for structural descriptions of images: nodes and edges, with their associated attributes, describe respectively the components of interest and the interconnections among them. This is the case when higher level components, e.g. arcs or primitive shapes, are also used for representing the entities of interest.

However, descriptions are also frequently given in terms of vectors of ìunstructuredî measures (features) executed on the symbols. Generally such features do not include relations between parts. Examples of this kind of descriptors are geometric moments.

4 Classification Phase

In principle, classification implies training for prototype learning, a knowledge base and the skill for using this information together with contextual information. When the output of the description stage is a vector, a variety of well established statistical or neural network classifiers (K-NN, Back-Propagation, Learning Vector Quantization, etc.) are in use. Template matching, with different variants, is a simple technique often applied in the context of symbol recognition, in spite of the limitations generally imposed by the representation, as rotation and scale dependence, so that its applicability is limited to a few domains in the context of symbol recognition. It has been used for recognizing symbols in geographic maps [36], [37], [45] and is the first choice for logo recognition [52], [54], [55].

Logos are generally very conspicuous patterns easily identifiable in a document and often located in key points (upper-left or upper right in the page). Logos generally do not appear rotated. Because of these peculiarities logos are generally treated with simple techniques in the phase of segmentation and attention is focused on classification. Candidate logos can be extracted by simple algorithms using a priori-knowledge regarding the position in the page, the size, the fact that are made by graphics not embedded in text, and so on. Correlation between the image and a logo prototype has also been used. Logos are also described by feature vectors. Examples of used features are wavelet coefficients and geometric moments. Geometric moments are global shape features interesting in logo recognition because of their property of being insensitive to local deformations. Sometimes these features are used only in the first stage of the classifier. When different logos having similar appearance exist in the domain, the classification stage is carried out using more local features or multi-stage classifiers. Classification is carried out by feature based classification paradigms as statistical classifiers and neural networks.

Methods adopting graph descriptions carry out recognition by graph-matching algorithms. Isomorphism, graph-subgraph isomorphism and other similar techniques are generally adopted for finding occurrences of symbols in images described by graphs. In practice, inexact matching algorithms are the only effective because of noise and symbol shape variability (namely in case of hand-drawings). Error-correcting algorithms try to achieve the isomorphism by using, during the matching process, some predefined editing operations such as node and/or branch insertion, node merging, attribute value modification, etc.. Error-correcting isomorphism can be used for evaluating the distance between the sample graph and the prototype graph as the minimum cost of the transformations applied to one of the graph to obtain the other one (distance-based methods).

The computational complexity of graph matching techniques is, in general, rather high, even if for some classes of graphs, efficient algorithms have been proposed. In any case a reduction of time complexity and memory occupation has been obtained by using suitable look-ahead rules during the matching process [85]. Alternatively, a reduction of computational complexity has been achieved by pre-compiling the database of prototypes [11]. The latter technique is convenient when a single graph has to be matched against a large database of prototype graphs each made of a few nodes and edges and achieves a significant reduction of matching time, to the detriment of memory occupation.

All the above techniques require that a set of prototypes have been defined. The most common way of obtaining prototypes is their definition by an expert of the application domain. This approach is feasible when the application requires a few prototype graphs of small size, but becomes more and more impractical when the number of prototypes and/or the graph size increase. The automatic generation of the prototypes is a complex problem in the most general case and only in the recent past some methods, working under specific hypotheses, have been proposed.

Frequencies of use of the most diffused classification methods employed in the recognition phase are listed in Table I. Hierarchical classification schemes, in different forms, are adopted in about 30% of systems.

5 Recognition Strategies

The process for recognizing symbols can be carried out according to a top-down or a bottom-up strategy. Bottom-Up strategies start from the lowest level representation (the bit-map) and evolve through representations of higher and higher level till to the final comparison between the sample and the set of the prototypes. Ascending to higher levels of abstraction Bottom-Up methods do not use a model of the object to be found. Top-Down strategies, vice versa, start from a model of the objects to be found and try to fit the model into the data. In successive iterations the process is refined by verifying the presence of more detailed features of the object to be found, described in the model. In practice bottom-up approaches have been used in more than 80 % of the recognition systems reviewed in this paper.

Among top-down approaches, verification based methods (hypothesize and test) use contextual knowledge and constraints, first to formulate and then to verify interpretation hypotheses [34]. The initial recognition of some features produces hypotheses instead of final recognition decisions. These approaches are basically designed to extract only the data of interest and then are especially valuable in a database environment where a specific query is asked about the raster image. They could be convenient in cluttered documents, since do not necessarily require that the objects of interest are preliminarily isolated or that other overlapping or touching graphics are removed.

They are especially suitable for taking advantage of the available knowledge base and of contextual information. Contextual reasoning is based on the assumption that all the objects in a map are interrelated. A typical strategy alternates a top-down process to generate search actions, a bottom-up process to recognize objects and a process to verify the results [35]. The detection of an object generates expectations about other objects in its neighborhood and then new search actions. This mechanisms allow consistency check: if attributing an object to a class implies the existence of another object, the verification of its existence reinforces the classification or, in the opposite case, may suggest to try a new classification or to try a different segmentation of the object.

Top-down approaches have been used for detecting symbols in maps and technical drawings (e.g., 12, 34, 35,) and revealed profitable for processing musical scores. A musical score is a complex document including a variety of graphic signs, lines, symbols and text that touch and overlap each other in many different ways. Some symbols are connected to form more complex symbols in a variety of different combinations. The main problems arise from these overlaps and connections that make segmentation a difficult task. There are a number of components in a musical score: staves, note heads (both filled-in and empty dots) with their possible appendixes, stem and beams, various symbols for modifying the note values, for specifying pauses etc. and finally text. Almost all the approaches start by detecting and eliminating the staves. For recognizing staves a bottom-up approach can apply thinning, polygonal approximation, and a final approximation of the polylines with single lines, standing for the staves. A top-down approach [48] starts from the assumption that staves are perfect straight lines, are five, are equally spaced and cannot be broken (in the model). A set of procedures estimates the distance of the staves in the given document, determines columns of five points belonging to the staves and then traces the set of five straight lines representing the staves.

6 Conclusions

The most commonly used techniques for symbol recognition have been shortly reviewed. Some problems requiring peculiar treatment have been mentioned. Considering the literature appeared on the subject during the last ten years, several problems appear still open and many questions can be consequently asked. Some of them are listed below.

What is the most convenient scanning resolution for the different applications? From 150 to 400 dpi have been used within the same field. Which are the acceptable recognition rates, error rates and reject rates for the different applications and what is the most appropriate way of measuring them: e.g., for each single document or in the average over a set of documents? Should errors be grouped according to their type?

Among the many techniques that are in use for symbol representation, description and recognition in the different application fields, which are the best for each given application area? Several of them are well established as regards the obtainable results and could be applied in different contexts. To what an extent are they transportable from one to another area?

There is the need for comparing both whole systems and different techniques for achieving the same subtask. Methods tested on a few drawings of different characteristics and quality, as it is often made, can neither be significantly evaluated nor compared between them, but where are the databases for testing different methods? Objective criteria should be adopted for evaluating system performance. How to assess accuracy, flexibility and efficiency of a system? How performance is affected by scale (i.e. number of symbols and, size of the document)? Given a system, what is the cost of updating it (the addition of new symbols requires total or partial readjustment)? How to evaluate the cost to benefit ratio for different applications?

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