Perspectives on the Analysis of Graphical Documents

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Abstract : *Graphics Recognition is a branch of document analysis that focuses on the recovery of graphical information in documents. Graphics consist of spatial arrangements of symbols ; examples include engineering drawings, maps, architectural drawings, music scores, tables, and charts. In this paper we overview the main topics in the last decade. We also hypothesize on the emerging research interests that will be relevant in the future, namely retrieving and indexing by shape signatures in digital libraries and user interaction by sketching interfaces.*

Keywords : Graphics Recognition, Technical Drawings, Symbol Recognition and Spotting, Sketching Interfaces.

1 Introduction

In a broad sense, document contents can be classified in two categories, namely *mostly text* or *mostly graphics*. Graphics Recognition (GR) is the subfield of Document Image Analysis (DIA) that focuses on the latter one, i.e. the analysis of graphical information. Traditionally Graphics Recognition has been concerned on the interpretation of technical documents such as engineering drawings, maps, architectural plans, music scores, schematic diagrams, tables, and charts. In such disciplines graphics are the main way to express information and interact with the machine. With the progress of digital imaging and scanning, and the advent of CAD and GIS frameworks, in the early 80's there was an incipient interest in converting paper drawings and maps to electronic formats for storing and editing. In the beginning, the purpose was just digitization. Afterwards, geometric analysis of images resulted in the fist vectorization systems. New application domais were considered like architectural plans, or drawings with diagrammatic notation (musical scores, flow charts, tables). Progressively the interest shifted to the semantic level, i.e. the goal was to extract more complete knowledge to improve the efficiency of document management. Techniques from the Pattern Recognition and Artificial Intelligence domains were incorporated for symbol recognition, discriminating text from graphics, interpreting and validating diagram syntax, 3D reconstruction, etc. On the other hand, the advances in the *digital pen* and *digital ink* paradigm involved the inclusion of the user in the document lifecycle, allowing him/her to provide on-line graphic annotations by means of friendly user interfaces. The progress also allowed the processing of large sets of graphic documents for retrieval and navigation purposes.

From a metodological point of view many different tasks are involved in the analysis of graphical information, covering all steps of image analysis systems : from low-level techniques, such as binarization, noise removal, text-graphics separation or vectorization, to pattern recognition methods for symbol and shape recognition and knowledge-based systems for semantic interpretation.

This paper does not intend to be *another survey* on Graphics Recognition. We overview the progress in the field in the last decade and make our personal hypothesis for the forthcoming years. Thus, in section 2 we review the main topics of interest in the last years, according to the publications of the IAPR Graphics Recognition Workshop series (GREC). In section 3 the emerging topics are stated and the future directions are discussed and illustrated with some examples. Finally, section 4 is devoted to conclusions.

2 A brief overview on the last decade

Since more than ten years ago, researchers coming from both academia and industry form an active GR community. The main forum of this community is the GREC Workshop series that can be seen as the indicator that measures the evolution of the field. Throughout the six editions of GREC workshops in the last ten years, we can made some conclusions that help to sketch the future trends. Recently, Tombre overviewed that in [TOM 06a]. Table 1 summarizes the amount of publications in the corresponding post-workshop books of GREC workshops, according to the most relevant subtopics. This taxonomy does not have to be taken exactly because some publications could be assigned more than one category. For example, vectorization papers are implicitly papers on technical drawings, symbol indexing is related to symbol recognition, etc. Let us further discuss on the different topics.

2.1 Image-level processsing and enhancement

Low-level processing problems receive a regular amount of contributions but rather marginal. Low-level processing includes pixel-based processes for noise removal, binarization, image enhancement, geometric transformations, etc. In general, the above pixel oriented methods are not exclusive to the GR domain but common among all the DIA areas. Although there is still room for improvements, good solutions already exist for these problems. In addition, research tends to focus on the highest abstraction levels, i.e. syntactic and semantic stages devoted to extract knowledge from documents. This makes accurate low-level results unnecessary

	GREC 95	GREC 97	GREC 99	GREC 01	GREC 03	GREC 05
Low-level processing	16%	7%	0%	10%	6%	6%
Vectorization & primitive extraction	16%	13%	10%	16%	6%	19%
Technical drawings & maps	21%	30%	29%	19%	18%	0%
Layout analysis & diagrammatic notations	16%	13%	6%	13%	3%	8%
Applications, systems & architectures	0%	13%	10%	13%	12%	6%
Symbol & shape recognition	11%	13%	23%	6%	18%	25%
Retrieval, indexing & spotting	5%	0%	6%	10%	15%	11%
Sketching interfaces	0%	0%	3%	10%	18%	8%
Performance evaluation	16%	10%	13%	3%	6%	6%
Historical documents	0%	0%	0%	0%	0%	11%

TAB. 1 – Evolution of publications in GR areas throughout GREC workshop

because the effort is shifted to the high-level expert systems.

2.2 Vectorization and primitive extraction

Vectorization and primitive segmentation is still there. It plays a central role in the analysis of technical drawings (mostly consisting of linear primitives). It is not clear what vectorization ought to be, or ought to output. Actually it is not an isolated step and its goodness depends on the pursued goal of the whole system. For that reason, commercial vectorization systems provide a set of parameters that can be set by the user, or customized in terms of document categories. Tombre et al. [TOM 00] discussed some qualitative elements which should be taken into account in the different steps of a vectorization method. A good vectorization can be evaluated in terms of accuracy, number and type of primitives (lines, arcs, splines, etc.), the use of context information, the possibility of user operation. Some of these parameters are rather contradictory, e.g. a very accurate vectorization might result in a high number of small segments. Universal methods risk to be useless when applied to particular use cases. It seems that the progress leads to do not neglect the inclusion of the user in the vectorization process to assist the system, and to use domain-specific knowledge to improve the performance.

From a methodological point of view, three major families of vectorization methods exist. The most popular is to compute the skeleton of the line drawing image by a thinning or ridge operator [NAG 90, HIL 02b]. These approaches tend to displace the junction points and to be sensitive to image irregularities. Another family of methods is based in line following or line contour matching [HAN 94]. These methods are more precise in junction finding but their performance decreases in complex images. Finally, sparse-pixels approaches is considered to be a third family of methods [DOR 99]. These approaches do not analyze all the image pixels but detect vectors by analyzing key points in terms of local neighbouring configuration. Arcs are a singular primitive that has received further study in vectorization approaches [ELL 02, HIL 02a].

2.3 Technical drawings applications

The development of applications for interpreting domain-specific graphical documents and converting to CAD and GIS frameworks have been focus of interest since the beginning. The interpretation of scanned engineering drawings in manufacturing industries, and the conversion of maps to GIS platforms were the problems that originated the research in GR. A number of complete systems for paper-to-digital format conversion exist in domains like electrical and engineering drawings [JOS 92, BOO 04], architectural plans [AHS 01, SAN 04], maps [SAM 96, LEV 02], musical scores or other diagrammatic notations [BLO 92, COU 01]. In general, such systems firstly detect basic primitives like lines, arcs and regions using standard vectorization methods. Secondly they identify composing elements using shape recognition approaches. Finally, it is important to notice the use of rules representing domain-dependent knowledge in both segmentation and recognition steps. However, in the last years less interest appears to be on developing complete systems. A possible reason is that commercial products exist and the interest has shifted from a scientific to an engineering point of view. On the contrary, individual tasks involved in complete systems are still there, like vectorization, or have experienced an incresing interest like symbol and shape representation and recognition.

2.4 Symbol recognition

Symbol recognition is, according to the amount of publications, the topic of major interest in GR. A lot of effort has been made in the last decade to develop good symbol and shape recognition methods inspired in either structural or statistic pattern recognition approaches. In [LLA 02] we reviewed the state-of-the art of symbol recognition. A comprehensive list of references on symbol recognition can be found there. The problem during years has been objectively comparing such methods. Domain-dependent methods exist but their performance strongly decreases when we try to generalize. A great advance has been the organization of contests on symbol recognition [DOS 06]. Contests not only have been useful to define performance evaluation protocols but to generate benchmarking material available for future progress. An important concern of symbol recognition, related to performance evaluation, is the scalability, i.e. how a symbol recognition method degrades with a growing number of prototypes. Most methods are just tested with databases of a few number of prototypes, but real applications use to manage sets of hundreds of prototypes. Since the recognition performance tends to degrade with large databases, the robustness against scalability is strongly required to be studied. Another focus of interest on symbol recognition has been the duality ”segment-to-recognize” or ”recognize-to-segment”. Performant methods exists to recognize isolated symbols, but in some domains symbols can not easily be segmented out of their context. This leads to the next topic *symbol spotting*.

2.5 Symbol indexing and spotting

Symbol indexing and spotting is a topic of increasing interests since the late 90's. The idea of *text mining* as a way to retrieve information from large information databases has also been applied to GR. Graphical patterns are used more and more as indexes for accessing and navigating large collections of documents. Recently, Tombre et al. discussed on that topic in [TOM 06b]. Indexing and retrieval by graphical content is a particular application of symbol recognition. New challenges arise when it comes to dealing with large databases of technical documents. Usually, new designs re-use data from previous projects or component libraries. Locating such components is sometimes a slow task that requires a visual examination. Symbol spotting and indexing provide solutions to that problem [TOM 03, MUL 00, FON 03].

The use of *signatures* is useful for indexing purposes. It is a compact and discriminant representation of a bidimensional shape able to be used as a key for indexing large documents. Hence, symbol spotting refers to quickly look for instances of symbols in documents. It can be performed in both supervised or unsupervised way, i.e. having symbol pattern signatures organized in a library of models, or just looking for recurring graphical pattern signatures in the documents. Symbol spotting generally involves an efficient organization of signatures in a kind of hash table that allow to quickly index given a query shape.

2.6 Sketching interfaces

A sketch is a line drawing image consisting of a set of hand drawn strokes drawn by a person using an input framework. Thus, by *sketching* or *calligraphic interface* we designate those applications consisting in the use of digital-pen inputs for creation or edition of handwritten text, diagrams or drawings. Devices as PDAs or TabletPCs incorporate such kind of digital-pen input protocols. Interesting applications of digital-pen protocols are freehand drawing for early design stages in engineering [DAV 02], biometrics (signature verification), query by sketch in image database retrieval, or augmenting and editing documents. Some interesting contributions are [CAE 02, LAN 01] for designing GUI, [DAV 02] for designing mechanical engines, or [FON 04, RIG 00] for retrieval by shape content.

In a recent review, Liu [LIU 04] considered three levels in a general architecture of an on-line GR system. The first level recognizes primitives while the user is drawing freehand strokes. The second level recognizes composite objects, i.e. combines primitives corresponding to consecutive strokes using information on their spatial arrangement and classifies them in terms of a given set of symbol models. Finally, the third level uses semantics related to the domain to interpret the drawing and beautify and re-display it. Online sketch processing, especially in the primitive-level extraction, has the added value of using dynamic information. It allows to use curvature, speed or pressure information of strokes. On-line recognition also involves symbol recognition where symbols can be classified in two categories : freehand symbols and gestures.

2.7 Performance evaluation

A pervasive request among the GR community is the generation of evaluation studies for assessing and comparing the accuracy, robustness and performance of various GR methods and algorithms in some systematic and standard way. Usually, the algorithms are only evaluated by the subjective criteria of their own developers, and based on qualitative evaluation reported by human perception. Liu an Dori [LIU 98] distinguished three components to evaluate the performance of GR algorithms. First, the design of a sound ground truth covering a wide range of possible cases and degrees of distortion. Secondly, a matching method to compare the ground truth with the results of the algorithm. Finally, the formulation of a metric to measure the "goodness" of the algorithm. The GR community has fostered in the last years the activities around benchmarking, performance evaluation, reference ground-truthed data sets, etc. A number of contests have been held in GREC Workshop series for dashed line detection, vectorization, arc detection and symbol recognition.

2.8 Old Document Analysis

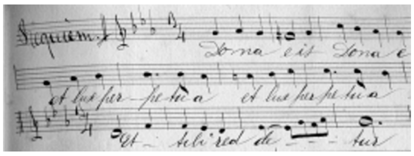
As it can be seen in table 1, Old Document Analysis ant conversion to digital libraries is an application that has received a lot of interest recently. The aim is not only to digitize cultural heritage documents but also to extract knowledge to build metadata that is used to access to digital libraries. Old documents are heterogeneous, examples are unique manuscripts written by well known scientists, artists or writers ; letters, trade forms, official documents, maps, newspapers that help to reconstruct historical sequences in a given place or time ; artwork elements like stamps, illustrations, covers, etc. The works found in the literature mostly focus on collections containing mostly text information. Graphical objects use to be neglected in querying by content document archives. Some works analyze graphical information [JOU 05, SUR 05]. Graphics like charts, stamps, drop caps, logos contain rich information that should also be considered in the metadata creation. In addition, signatures characterizing images would allow comparing them and, hence indexing by image similarities.

3 Emerging Topics

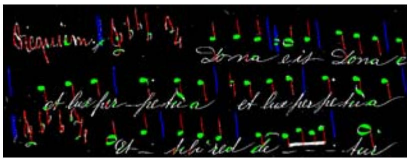
We identify two emerging general interests among the GR community at large. Firstly, document collections are stored in large data warehouses and this requires the definition of (graphical) indexes to efficiently access to their contents. Secondly, GR is close to the field of Human Computer Interaction (HCI) when dealing with multimodal interfaces that include on-line handwritten input. Sketching interfaces involve symbol recognition, either freehand drawings or gestures. Let us further describe these two issues.

3.1 The access to large document databases

The generation of *digital libraries* raises the information research problem and the navigation problem among these corpus. The problem is to determinate some cues within an adaptive manner, in regard with the various ways of representation of the document information, like textual zones, graphic zones, printed or handwritten pages, and so on. The si-

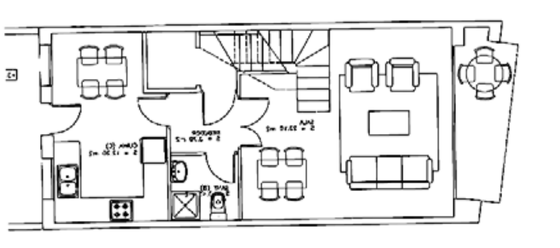


(a) Original image

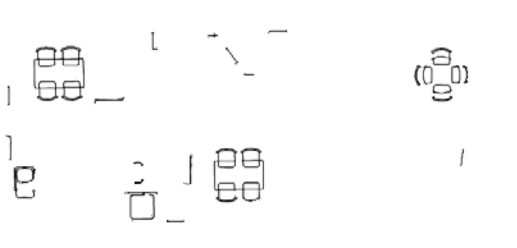


(b) Primitive detection and staff line removal

FIG. 1 – Analysis of old handwritten musical scores



(a) Original image



(b) Spotting the symbol *table*

FIG. 2 – Indexing by symbol signatures

gnature computed on the basis of these cues will bring useful metadata on semantic knowledge concerning research and navigation processes. Such goal requires efforts in developing semantic-based systems to acquire, edit, organize, share and use the knowledge embedded in documents.

Documents stored in libraries may contain graphic contents as drawings, stamps, logos, drop caps, form or table layout, etc. that provide rich information to consider in the metadata creation. Some collections as musical scores or maps have mainly graphical content. Two issues have to be considered, namely the definition of *graphical signatures* and their organization in *indexation structures*. As with the text, it is necessary to define shape and symbol signatures as descriptors for graphic contents allowing to perform graphic query, in order to retrieve documents with a specific (for example a stamp or a logo) or similar drawings. An ideal graphical signature should be simple but discriminative. Since it describes bidimensional shapes, it is formulated in terms of basic local features (e.g. orientation, curvature, gray level, etc.) and relational or contextual information among local primitives (e.g. length ratio, relative angles, etc.). A second key issue relies on the organization of graphical metadata in some hashing or indexation structures allowing to quickly retrieve those documents (or document zones) that likely contain a given graphical query. Voting schemes like Hough-based approaches or geometric hashing are useful tools. Informally speaking, a shape is represented as a combination of basic primitives and features among them $S(p_1, \ldots, p_n, f_1, \ldots, f_m)$. Similarly, the documents of the database are splitted in primitives $p'_1, \ldots, p'_k$ and features $f'_1, \ldots, f'_l$ of the same alphabets. A hash table is constructed by clustering and sorting the features f'_i. Thus, given a query shape S^q, the hash table can be seen as an indexation function $h(f_i^q)$ that returns valid locations of the features belonging to the signature of the query shape. Symbol and shape spotting does not only allow to index large document databases but also to separate the different classes of graphical objects and providing the equivalent of an "hyper-text" navigation in the document : from the legend to the symbols in the drawing, for instance.

A particular application field with increasing interest is the *analysis of old documents* to digitally preserve and provide access to historical document collections residing in libraries, museums and archives. Such archives of old documents are a unique public asset, forming the collective and evolving memory of our societies. The interest is to create digital libraries with enriched documents, i.e. adding semantical metadata to digital images of the scanned documents. Such metadata is intended to describe, classify and index documents by their content. It would allow anywhere anytime natural access to such a cultural and scientific heritage. In Fig. 1 we show some recent results of primitive segmentation in handwritten musical scores of the 19th century [FOR 06]. The difficulty on the interpretation of such documents is increased due to paper degradation and the lack of a standard in musical notation.

Figure 2 illustrates a symbol spotting framework. In that case, vectorial signatures have been defined in terms of relational features among segments of vectorized floor plans. Symbol instances are quickly localized by serching those document zones that receive highest votes after indexing signatures in a hash table [RUS 06].

3.2 The role of the user in the GR workflow

The role of the user in the GR cycle is also an important concern. The user intervention in a GR process should not be seen as negative but a natural issue. A recognition and understanding process may need the feedback from the user to set particular parameters, to validate decisions taken by the system when there is uncertainty or just to interact with the system to edit the document or drive the process. The input

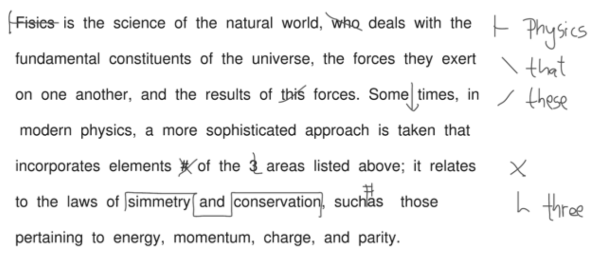


FIG. 3 – Automatic interpretation of proofreading sketches

mode influences the interfacing approach to be considered. While scanning a paper-based document is the classical input mode, the advent of new digital pen devices makes sketching interfaces, i.e. on-line input, a growing interest. Graphics are a good way for expressing ideas. It is well known the expression "one picture is worth a thousand words". According to a particular diagrammatic notation, graphics allow to communicate information. The user interaction by means of pen strokes is a powerful tool to draw new graphic documents, to digitally augment paper documents, to edit documents by sketchy gestures or to index by shape using graphical queries. Sketching interfaces make closer the domains of GR and HCI. On-line input of drawings by a tablet or a digital pen in HCI is a mode of natural, perceptual, and direct interaction. It allows not only to input graphic objects to the system, but to process them in real time and, hence to give instant feedback to the user. GR systems based on digital pen devices can take advantage of dynamic information as speed, pressure or order of strokes. In section 2.6 outstanding references to recent work on sketch understanding in different applications have been reported.

A recent contribution that combines the topics of symbol spotting and user interaction is the concept of "on-the-fly" symbol recognition [REN 06]. In that case, the role of the user is not to draw symbols but to reinforce the recognition process. Thus, a dynamic recognition of symbols is performed and the user reinforces the symbol spotting results by a relevance feedback mechanism. It allows an usupervised recognition of symbols in a large database of documents without a priori knowledge. In Fig. 3 whe show our recent work on the use of sketches as proofreading gestures of existing documents. The system is able to recognize symbols annotated on the documents and translate them into edition actions. A new version of the document is then generated by updating it with the editions of the proofreader.

4 Conclusions

Graphics Recognition is a mature but dynamic field. The first applications to recognize graphic diagrams date from ten years ago. The field has moved a little bit away from pure recognition and retroconversion purposes to other issues that have received much more interest recently. Among these emerging topics, we have identified two major issues. First, digital libraries of graphic-rich documents exist, and the user has to retrieve documents containing a particular graphical entity (for example an engineer or an architect wanting to reuse old projects instead of starting from scratch). Other scenarios deal with large documents, and the user wants to spot a given symbol for navigating and edit purposes. A particular application with increasing interest and strong relation to digital libraries is the conversion of hitorical archives to a digital format. A second topic that has arisen in the last years is the increasing relevance of the user role. In particular, whereas classical systems were designed as fully automatic and the user was only asked to set up some parameters, the new platforms do not see the user intervention as negative but a natural issue. A confirmation of this trend is the use of sketching interfaces. Applications with digital pen and digital ink protocols are more and more widespread.

Some traditional topics of GR are still there. In particular, symbol recognition continues at the heart of GR systems. One of the ”hot topics” of symbol recognition is the problem or recognition without previous segmentation. This arises the problem of symbol spotting that has been stated above. Vectorization is still addressed, there is room for improvements in, for instance, the accuracy in primitive detection. The actual goal of vectorization in relation to the subsequent processing steps is still an open discussion. Finally, let us state some future trends that are implicit in the above challenges. Firstly, the collaboration with close fields within document analysis (text and page layout analysis, color document analysis) or other such as Semantic Web, Data Mining or Human Computer Interaction. Secondly, since the concept *document* has a broader sense, exploring new document media, in particular electronic formats like pdf, xml or svg.

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