A Graphic Matching Process for Searching and Retrieving Information in Digital Libraries of Manuscripts

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Abstract. This paper outlines ICRPad, a pattern recognition system based on a graphic matching algorithm, which works on images by shape contour recognition, without requiring any segmentation process. The algorithm starts the process from a region of interest (ROI) selected in the image, using it as a shape model and looking for similar patterns in one or many target images. The process was developed and tested with the aim of proposing a new approach for searching and retrieving information in digital libraries. This approach is based on the application of data science, the fourth paradigm of knowledge development in the scientific field, that is at the basis of science informatics, to studies in data humanities. Following this approach, the algorithm is applied to find new research hypotheses through the discovery of patterns directly inferred from large digital libraries.

Keywords: Graphic pattern · Pattern recognition · Digital libraries · Manuscripts
Graphic matching algorithm

1 Introduction

Historically, the development of knowledge in the scientific field has been carried out following two paradigms, the theoretical one and the experimental one. In the last two decades two additional paradigms have been established: the computer-based simulation one (*computational simulation* – Ken Wilson, Nobel prize in physics, 1982), also called the ‘third paradigm’, and the one based on data-driven scientific discovery (*data intensive scientific discovery* – Gordon Bell, 2012), also known as the ‘fourth paradigm’. While the third paradigm gave rise to *computational sciences* (e.g., computational biology), the fourth one is at the basis of *science informatics* (e.g., bioinformatics). The latter has gained acceptance thanks to the increasing availability of huge amounts of data that permit an *in silico* approach to knowledge generation.

To apply the same change of perspective in the humanities, one must start by observing that in the last decades significant effort has been spent in generating large humanistic databases that can be accessed online. Some examples are:

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- *Thesaurus Linguae Graecae*, that collects Greek literature since Homer (VIII sec. BC) to the fall of Byzantium (1453 AD) [http://stephanus.tlg.uci.edu/];
- *Integrated Archaelogical Database* (IADB), that addresses the data management requirements throughout the lifespan of archaeological excavation projects [http://www.iadb.org.uk/];
- *World Digital Library* (WDL), that collects digitized versions of rare books, maps, manuscripts, and photographs [https://www.wdl.org/en/];
- *Musisque Deoque*, a digital archive of Latin poetry [http://www.mqdq.it/public/];
- *Trismegistos*, a database concerning writings on papyrus [http://www.trismegistos.org/].

All these databases propose querying mechanisms of different levels of complexity, that mostly provide support to scholars in their specific searches (e.g., retrieving all poems written using a given prosody). However, this requires that scholars have previously set up accurate hypotheses that they want to confirm by searching through the digital archives. An opposite methodological approach is proposed by the fourth paradigm: Algorithms are applied to find new working hypotheses through the discovery of '*patterns*' directly inferred from large databases. For instance, groups ('clusters') of 'similar' poems might be identified in digital libraries or archaeological collections, or in literary corpora, and suggest new hypotheses on which an enquiry using traditional approaches can be started.

This paper presents an application of the fourth paradigm for allowing scholars to query and search large digital libraries of manuscripts using ICRPad, a patented digital recognition system. It embeds a graphic matching algorithm which works on images by shape contour recognition, without requiring any segmentation process of the image content [1]. The system has been tested on a dataset of manuscripts, and the results suggest the viability of a new approach to studies in data humanities.

2 Related Works

Contemporary digital databases commonly use recognition systems to convert digital images into machine-encoded texts, but to date no system works efficiently on images of manuscripts. Many research projects have been devoted to solve this problem by creating OCR or pattern recognition systems for digital cultural heritage. Nevertheless, these technologies have not yet shown sufficient effectiveness and functional efficiency so as to provide an immediately accessible indexing of the image content.

Although much research has been carried out, digital recognition has been successful on small databases and highly constrained domains only. There is not yet any valid system for querying, recognizing and searching large databases of historical manuscripts. Research is mainly based on two different approaches, either segmental or holistic. The segmental approach is undoubtedly the most used in a number of recent systems, especially in prototypes structured according to Hidden Markov Models (HMM) [2–7]. The holistic approach was preferred in some recent experiments, with results of great interest as regards the percentage of recognized content, but not significant as regards the number of processed images [8].

In detail, most research is based on:

- segmentation – shape models are created from segmented regions (portions of graphemes, graphemes, words, etc.) and then classified by reference to thesauri that support text matching, an both laborious and potentially very time-consuming operation;
- adaptation of existing processes (word spotting, HMMs, etc.) – overcomes text segmentation, but requires data extraction and matching processes that can detect and recover functions referring to statistical criteria; moreover, most of these prototypes run mainly on digital images of printed documents, but their effectiveness and usability on manuscripts are unknown;
- matching each word found in digital images either to the corresponding electronic text previously transcribed by an operator manually, or to reference thesauri of selected words preliminarily structured (again, manually) – this approach seriously limits the possibility of electronically recognizing a large quantity of historical texts, because it requires a long and complex preliminary manual work [9–20].

Further limits of these prototypes are the following:

- they have been tested on very small quantities of images, so there is no proof of their applicability to large digital databases;
- the above methodologies provide preliminary quite complex and time consuming human work, without noteworthy results, scarcely useful: indeed, excessive manual work greatly limits the possibility of indexing large quantities of images, requiring a great deal of human and financial resources;
- the research proposed purely theoretical models without any certainty about their effective ability of working on digital databases;
- no prototype really uses automatic or semi-automatic recognition: all prototypes need a preliminary planning of complex algorithms to extract information and create the models by which performing the matching with digital images, but their output is nearly always incomplete and unsatisfactory.

Unlike the systems and prototypes described above, the ICRPad graphic matching algorithm proposes a different way for creating the shape model, based on contour shape recognition without a preliminary segmentation process. It is based on a pyramidal model, and exploits the pixels that do or do not cover the shape that makes up the model.

- **Use of the ICRPad System**

ICRPad provides scholars with the following advantages/functionalities:

1. connecting in real time to several existing databases, using the “repository selection” funcionality of the “system setting” interface;
2. exploring the images stored in the connected databases to evaluate which items are to be selected to create shape models to be used as search keys;
3. changing at any moment the parameter settings in order to customize the searches and fine-tune the quantity and quality of the results, depending on how much data the user expects to find in the search (deformation thresholds, etc.): the higher the

thresholds combined with the deformation parameters, the more exact the search for shape model occurrences;
4. creating in real time shape models tailored on the user's needs: after displaying one or many images, the user can select, by pointing and zooming directly in the images, the regions he is interested in and create the shape model according to his needs (one graph, many graphs, one word, etc.); an image noise detection tool allows him to check the "dirt" levels that might somehow compromise the reliability of the search;
5. customizing the search by saving selected regions to be used as shape models.

A user-friendly and highly usable interface allows the user to exploit intuitively several tools.

Using the system, first the user selects the "Setting" functionality, that allows him to customize the search parameter settings in order to get results fitting his expectations, or the kind of contents represented in the database(s) of interest, or the graphic item he intends to use as a shape model.

Once the parameter settings have been defined, the user selects from the database(s) he connected for consultation the image(s) from which he wants to create the sample(s).

Then, using the "Create model" functionality, he selects the ROI from the image. It can be any portion of a page image for which he is interested in searching for further occurrences in one or many available database(s) of images: a grapheme, or a glyph, or part of a lemma or a whole lemma, a single line or even a set of lines, images, illuminations or parts thereof. By the ROI, an automatic and zoom inclusive process creates the models and allows him to define the shape contour in real time. In case he believes that those models can be exploited again in future researches, he can save them in a customizable system repository.

Finally, the user moves to the "Find" functionality, and runs his search on the entire set of databases previously selected.

3 A Technical View of the System

The matching algorithm of ICRPad is based on shape contours, even of different size. As a starting point of the process, it extracts a graphic region (an image or a part of it) and creates a shape model to be used for searching similar patterns in one or more target images. After defining the model, in order to obtain satisfactory results, the system must return:

- the position within the document on which the search is performed;
- the angle;
- the scale of the image part found with respect to the specimen given in input;
- a score indicating how much (a percentage) the result is similar to the starting model.

It is possible to handle settings using both a well-rounded set of *primitives* and graphic features as basic parameters for searching portions of the graphic regions in digital images. Some main graphic features managed by the algorithm are: angle, rotation, scale, overlay, contrast, brightness, color, transparency, focus, distortion, occlusion, deformation.

The system embeds a shape-based pattern matching algorithm which recognizes and represents objects by their shape, ignoring their size and the gray-scale values of pixels and their neighborhood in the model. It can be classified as a *spotting* algorithm, since it does not need a preliminary segmentation of the document pages.

There are several ways to determine or describe the shape of an object. ICRPad extracts the shape by selecting all pixels whose contrast with neighboring pixels exceeds a threshold set by the user. Typically, such pixels belong to the object contour. So, given a shape model, the main task of the matching process is to try and find into the target image its occurrences (all of them, or a maximum number thereof, if initially specified).

In particular, the algorithm allows to specify which pixels belong to the model, to speed up the search by using subsampling, to specify a range of orientations, to specify a range of scale and so on.

Finally, the system allows to search many models at the same time within each image, and to parallelize all of the processing for one or more models, in order to optimize the search times by a computational point of view.

Depending on the parameter settings, the process can provide the following features for each model found:

– position, skew angle and score of the found model(s);
– position, skew angle, a uniform resolution factor and the score of the model(s) found;
– position, skew angle, different (horizontal/vertical) resolution factors and score of the fitted model.

If the search concerns several models, information about which model each found instance refers to is also provided.

3.1 Model Creation

The shape model characterizes and defines an internal representation of the portion of image that should be used as a search criterion. This image should be shown in its ideal form, i.e., the sharpest possible, without occlusions and possibly aligned with the horizontal axis.

The source image format to define the model can be any of the common electronic formats, such as TIFF, BMP, GIF, JPEG, PPM, PGM, PNG, PBM, and so on. The image for creating the model may be of any shape (elliptical, circular, polygonal or even outlined freehand) and have arbitrary angle.

Figure 1 shows how models are created. The region surrounding the model is the ROI. The search process optimization starts from the definition of a good model. After defining the portion of image to be used as a model, some of its parameters for the search process may be changed; also, a model can be stored on disk, in order to retrieve and modify it later for future use.

To obtain a suitable model, the contrast must be chosen so that the pixels that are *significant* to the object are included in the model. By *significant pixels* we mean those pixels that characterize the object and allow to clearly discriminate the shape to be searched from other objects and from the background. The model must have minimum noise or a low number of non-interesting regions (i.e., regions not belonging to the object

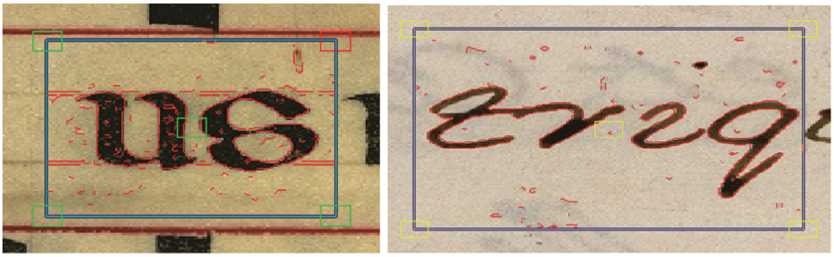

Fig. 1. Creation of models

to be searched). In some cases there is no single contrast threshold that allows to both discriminate the noise and, at the same time, remove non-interesting parts from the graphic region.

3.2 Search Parameters

The most important parameters for searching a model are:

- *contrast:* through the definition of a threshold (low-high) it allows to discriminate the pixels belonging to dirty or irrelevant portions of the image;
- *number of pyramid levels* that make up the model, i.e., the image set consisting of a number of graphic models having different resolution, as shown in Fig. 2: if the original image has a resolution of 600 × 400 dpi, the pyramid will consist of a first-level image at 600 × 400 dpi, a second-level image at 300 × 200 dpi, a third-level image at 150 × 100 dpi, and so on; this is a crucial factor for performance and accuracy of the results; as general rule, it's a good result if a region of interest has a width of $2^{\text{LevelNumber}} - 1$ pixels (e.g. 8 pixels width allows one to use four pyramid levels); then, after an appropriate region has been set, the reduced image may be used as a model for creating the reference shape;

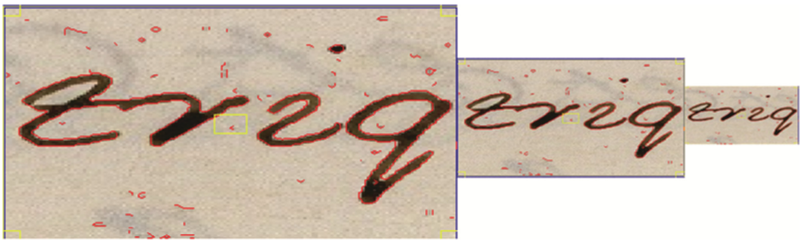

Fig. 2. Number of pyramid levels

- *rotation angle and extension of the model:* e.g., setting the angle to 5° and the extension to 10°, the search could be performed using images with a rotation tolerance of about ±5°;

- *scale parameter for factors x, y:* this allows to define the pair min/max for each axle in order to run a stretch of the model;
- *timeout parameter:* this allows to speed the search process up to 10%; this is useful when one wants processing to stay within a certain amount of time for each image-destination.

3.3 Configuration Parameters

The various configuration parameters were tested on a dataset of different images, and were calibrated on some test cases by varying gradually the percentage of recognition, in order to improve the steps of the algorithm.

The parameters used during this trial and in the subsequent final definition of the steps of the algorithm are:

- basic:
  - minimum score: a similarity measure between the model to be searched for and a candidate occurrence; the larger the score value, the faster the search, because candidates are discarded earlier; experiments lets us conclude that, given a positive sample, i.e. documents certainly containing the shape model to find, the percentage of recognition required to define the optimal score for a uniform image type are about 90%: such condition means that the parameters defining the model and those for the algorithm execution ensure the expected result;
  - maximum number of items found per image: this is the value to retrieve all potential models from each image.
- advanced (these are essential for the search):
  - completeness: determines the trade-off between efficiency and effectiveness of the search results. A low value determines a complete, but quite slow search; the higher the value, the faster the search, but at the expenses of completeness (i.e., an occurrence of the model might not be found even if it is visible in the image);
  - overlap: specifies how two graphic regions may overlap an image; in case of symmetry, the allowed overlap should be reduced to prevent multiple matches on the same object;
  - sub-pixel: determines accuracy by selecting the precision in calculating the position, orientation and scale; default definitions may be provided for these features, such as calculation of position, which can be determined with precision ‘pixels’ only, while accuracy of orientation and scale is respectively equal to values of angle and of scale size specified during the construction of the model; in this way, the position is estimated with accuracy at pixel level, and the size of the object determines the accuracy of estimated scale and orientation: the larger the size, the more precise the orientation and scale;
  - deformation: sometimes, the objects are either not found at all or found with a low precision degree only, because they are slightly deformed compared to the model. In these cases, it is possible to use a deformation parameter that expresses how many pixels of deviation are tolerated from the edges found in the image to those of the model shape. The value of this parameter should be set as small as possible,

using a high value only for targeted searches. Indeed, the higher this value, the greater the risk of finding wrong model instances; moreover, a high value for this parameter often produces an increase in processing time; both problems mainly stem from the search of small/fine/thin structured objects, because these kind of objects, when undergoing further deformation, lose their characteristic shape, which is important for an effective search.

3.4 Searching Shape Model

The position and rotation of the found instances are returned as *row*, *column* and *angle* values. Moreover, each instance found is marked by a *score*. Additional information is returned, such as *scale*: if the shape model is creating, the resolution ratio between the model and the found image is parameterized.

Downsampling can be enabled to speed up the matching process, i.e., images at lower resolution can be used. The set of images at different resolutions representing the same source image, ordered by decreasing resolution, is called a *pyramid*, and the images in a pyramid are the pyramid *levels*, where the top of the pyramid is the image at the lowest resolution. When defining a model, a set of images having different resolution is created. So, the model is created and searched on multiple pyramid levels (images). The number of levels of the pyramid to be used can be specified: it is a good practice to choose the highest level of the pyramid with models containing at least 10 to 15 pixels and such that the shape model still resembles the shape of the object.

However, the system provides primitives that allow the user to automatically set these parameters by an internal analysis of the region covered by the model.

4 Experimental Results

The full matching process of ICRPad was tested on about 3500 images belonging to 7 medioeval latin manuscripts dated between the XI and XIII Centuries, all of unknown – but seemingly different – authors and scriptoria.

The graph "&" was used as a sample of this first experiment, because it was distinctive of all researched manuscripts.

Before starting the matching process, we created the shape model. Then we set the deformation parameter and the different resize and minimum score parameters by which searching the patterns within the set of images.

By varying the ratio between deformation, minimum score and resize we got different results for each sample image and thus we could evaluate the effectiveness of each performed pattern.

We had best result with deformation 3, resize 40% and minimum score between 60% and 80%. By setting these parameters we had a high level of True Positives in four manuscripts (numbered 1, 2, 4 and 5): about 80%, with few False Positives in manuscript 5 setting minimum score at 60% (weak/low parameter). Surprisingly, we knew that really these were written either by the same hand or by the same scriptorium. Furthermore, we noticed that some False Positives were to be considered as further evidence of omography of the four manuscripts, because by overlapping them with some similar True Positives (e.g. C and O, S and F) we saw that some graph curves were identical.

The above parameters can be changed and set either before the search by looking at the shape model that has been created, or during search if the result is not as expected.

5 A Data Science Perspective on Scholarly Research on Data Humanities

We use ICRPad to envision a method that allows scholars to search different types of digital libraries, querying them according to an "assumption-free" approach. It means that the system does not deal with a single, specific, pre-defined database, but it can be connected in real time to several databases available on-line. The user will select one of them as relevant to his research objectives. After selecting the databases, the user chooses the image(s) that will provide the models to be searched. Then, he creates the shape models for his search and, by using them, he queries the connected databases. In the classical setting, he starts from a search hypothesis and checks whether the query results may confirm it. In the new setting we envisage, he may also issue a random search, i.e., without any expectation on the results, and draw inspiration to build new research hypotheses from the very search results. Finally, he might query the databases with a research hypothesis in mind, but in addition to the True Positive outcomes, he may also carefully analyze False Positive outcomes: the latter, in facts, may be of great interest, because some of them, albeit different than the model, may nevertheless reveal similarities that suggest the scholar interesting hypotheses to be investigated. This is a data science approach to the consultation of databases, and opens new frontiers to the study of data humanities.

We show this with the following sample scenario. We tested ICRPad working with a scholar involved in paleographic and historical studies on handwritten codices. He aims at exploring new research hypotheses concerning his domain of interest. To this purpose, he chooses to query some existing on-line databases in order to collect useful hints for his research inspired by the results of his queries. Using ICRPad, he connects to a registered on-line database (e.g., the digital library of The British Library), because he wants to explore two manuscripts included in a famous codex (let us call them "*ms A*" and "*ms B*"), that are generally considered in the literature as written by different writers. He aims at checking whether there is some chance that, using the matching algorithm, the alternate graphs, on which the claim that the two writers are different is based, have in fact sufficient similarity to be considered as written by the same writer. In real time, he connects to the repository in which the codex is stored, chooses at random a page image from one of the two manuscripts under consideration (say, *ms A*), and from this image he selects the greek alphabet glyph ψ as Region of Interest (ROI). Then, he proceeds by creating from the ROI the shape model to search using the "create model" tool. He saves the shape model just created in his personal system repository, then he runs the "find" functionality. The system scans the whole codex and returns all occurrences that fulfil the parameters, and thus are considered equal or similar to the shape models he created. He gets the following results:

- ms A, glyph ψ:
  - True Positives (homograph of psi): 75% (50% in ms A, 25% in ms B)
  - False Positives: 25% (10% in ms A, 15% in ms B); among which:
    glyphs nearly homograph of ψ: 20% (5% in ms A, 15% in ms B), all referred to glyph ψ, whose strokes perfectly overlap the corresponding traits of ψ;
    glyphs approximately homograph: 5% (all in ms B), all glyphs υ, some traits of whose curved lines can be overlapped to the corresponding traits of ψ.

The True Positive results, albeit uncertain, could be somewhat expected by the user when issuing his search, but might also have been insufficient, alone, to back the hypothesis that the same writer wrote both manuscripts. On the other hand, False Positive results, albeit unexpected, may be even more important, because they turn out to be in many traits totally homograph to the model. In such a case, an item that would normally be considered as a noisy result, may be interpreted as a further confirmation that both manuscripts were made by the same writer. In turn, this stimulates additional investigation on both the digital and the physical artifact, and becomes the starting point for a new hypothesis about the authorship of the two manuscripts. E.g., contrary to what was claimed and believed along many years of literature, it suggests that the two manuscripts were actually manufactured by the same person, operating in one scriptorium or, in different moments, in several scriptoria that used exactly the same "canone". Another possibility is that the "canone" stayed unchanged during one or two centuries in the same scriptorium or in different scriptoria in the same geographic area, and that it was used according to strict, precise rules by different writers.

6 Conclusion

In this paper we outlined the features of ICRPad, a patented graphic matching system for the digital recognition of manuscripts, and proposed a new approach to searching and retrieving information in digital libraries. This approach is based on applying data science, the fourth paradigm of knowledge development in the scientific field, that is at the basis of science informatics, to studies of data humanities.

The training process is based on the outlined matching algorithm, which uses the recognition of contours shape without any segmentation process. It does not use the gray-scale values of the image. It is based on a pyramidal model, and exploits the pixels that do or do not cover the shape that makes up the model: i.e., the set of images is composed by models at different graphic resolution. This factor is crucial for performance and accuracy of the results because, after setting an appropriate region, the reduced image can be used as image-model for the creation of the shape-model.

The latest system version that we have implemented processes about 240.000 images/h with 60%–90% of positive matches, starting the search from four base minimum score parameters of 60% (weak), 70% (low), 80% (medium), 85–90% (high).

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