# HANDWRITING RECOGNITION OR READING? SITUATION AT THE DAWN OF THE 3rd MILLENNIUM

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During the last forty years, Human Handwriting Processing (HHP) has most often been investigated under the frameworks of Character (OCR) and Pattern Recognition. An evolution recently occurred and to date, HHP can be much more viewed as an automatic Handwriting Reading (HR) task for the machine. At the dawn of the 3rd millennium, we guess that HHP will be more considered as a perceptual and interpretation task closely connected with research into Human Language. This paper gives some guidelines and examples to design systems able to perceive and to interpret, i.e. to read the handwriting automatically.

## 1 Introduction

The ultimate goal of handwriting recognition should be to have systems able to understand any handwritten text. They must be able to read and understand any handwriting and the training phase should be minimum to automatically adapt themselves to a new user. They must be able to deal with a large size vocabulary, many different handwriting styles and they need to be multilingual [1]. Moreover, such systems must not impose any kind of constraint to the user, (i.e. they must accept spontaneous cursive handwriting). Besides, they must have a high degree of efficiency in the case of good quality handwriting and must be able to interpret difficult handwriting by making use of the maximum of available knowledge. Over the last forty years Human Handwriting Processing (HHP) has most often been investigated within the framework of Character (OCR) and Pattern Recognition [2, 3]. This situation has recently changed and, according to us, HHP can be seen as an automatic Handwriting Reading (HR) task for the machine. We guess that in the 3rd millennium, it is likely that HHP will be seen as a perceptual and interpretation task closely connected with research into Human Language [4].

In this paper, section 2 shows a brief history of the evolution of handwriting recognition approaches and systems. Section 3 is concerned with handwriting modeling. Section 4 presents a new general framework for *artificial* handwriting reading (i.e. done by a machine).

## 2 History

The earliest work on handwriting recognition was carried out in the sixties [5, 6, 7] and seventies [8, 9, 10]. Due to the poor performance achieved by these systems at that time, less research on handwriting recognition took place during the eighties [11].
The first research works dealt with the recognition of isolated handprinted characters [12]. These works followed on the works carried out on OCR, i.e. printed character recognition [13]. Later on, researchers began to study the recognition of on-line (dynamic) cursive handwriting [14, 15] and even more recently those of off-line (static) cursive handwriting [16].
A renew of interest [17] occured with the rise of new needs (postal and banking applications [18], portable computers [19]), new and more suitable acquisition systems (scanners, pen-pads, electronic papers, etc.) and more efficient recognition algorithms: Dynamic Programming Matching (DPM) [20], Hidden Markov Models (HMM) [21], Neural Networks (NN) [22], etc.
More recently, the combination or cooperation of several independent recognizers [23, 24], the use of lexicons or dictionaries [25] and of language models [26] as post-processings have been suggested to improve the overall efficiency of the system.
At the beginning of the nineties some products were available on the market, but their performance was not good enough to lead to a generalized use and to be able to recognize several pages of text.

As in many other research domains, the problem of handwriting recognition was initially considered as being very easy to solve, but has later proved to be very difficult. This evolution characterizes the fact that HHP which was initially considered as a well-defined problem, is now considered as an *ill-posed problem*.
Although some existing handwriting recognition systems run quite well for specific applications (e.g. addresses, bank check legal and courtesy amount recognition), multilingual, multistyles *Handwriting Reading System (HRS)* are not yet available on the market. Most of them are *black-box systems* e.g. HMM, NN, etc. able to absorb most handwriting variabilities and able to run with efficiency. But these systems have still some drawbacks: it is difficult to analyze how they work, it is impossible to precisely locate the origin of the errors that they make and to correct them in order to improve their general performance. They are also time-consuming and they need very large databases for training. To date, most of the existing systems are sequential processes without any backtracking, i.e. consisting of several levels or several modules connected

together in serial mode. In the electronic domain, it is well known that the overall performance of such systems is mainly determined by the performance of the worst module.

In this paper, we consider the following questions: is there only the PR as possible framework? Is it possible to design systems using less information on the drawing but using much more a priori knowledge? Is the serial or hiearchical organization the only one approach? Is it possible to organize modules in a different way? Is it possible to design *transparent or crystal systems*, i.e. systems whose work mode would be more explainable and improvable. In the sequel of this paper, some guidelines and examples will be given to design systems able to *perceive, recognize* and *interpret*, i.e. to read cursive handwriting. Most of the topics considered in this paper concern western handwriting but some of them (downstroke invariance, perceptual points, etc.), could be extended to oriental language for reading Chinese, Japanese (Hiragana, Katakana, Kanji) or Korean (Hangul).

## 3 Handwriting Modeling

Handwriting, as speech, is one form of expression used by the human language[4]. As it results from a human activity, it is frequently vague, ambiguous, uncertain and incomplete. In these conditions, handwriting reading is an *ill-posed problem.* Cursive handwriting is a continuous process, but most of the time, it is modelled as a discrete process which can be either statistic (HMM) or structural.

### *3.1 Handwriting Basic Invariant Primitives*

The need to be able to deal with a large vocabulary favors *analytical* approaches rather than *holistic* approaches (global word approaches) and also requires the use of linguistic knowledge sources. Omni-handwriting reading systems can be defined as systems which are able to read any handwriting, even a handwriting that has never been seen previously. The design of these systems can be based only on general knowledge of the handwriting skills learned in primary school and about the linguistic knowledge of the language considered. In primary schools pupils are taught to draw elementary strokes (linear, curved or circular), loops, spirals, etc. and a lot of habits are acquired at primary school.

We may ask ourselves wether it exists or not in the handwriting drawing some general invariants common to a large set of personal handwriting styles?

- *Clues from Paleography*
  The study of the shapes of the oldest handwritten characters, of their different styles and of their corresponding ***ductus*** (the order of the sequence of movements) as well as the study of the art of writing during the Middle-Ages, reveal that most of the characters were initially derived from ROMAN CAPITAL letters previously drawn in stone or clay tablets and that, for this reason, they were drawn by ***descending movements*** of the fingers.
  But, as there is also an aesthetic parameter, handwriting was also often embellished (illuminations found in the incunabula, Gothic manuscripts). The invention of cursive handwriting in the Middle-Ages, handwriting with a running hand, was done to speed-up the work of the monks copying religious books. This led to the creation of new alphabets with new letter shapes such as uncial, Caroline script, etc.

- *Clues from Tools*
  The old writing instruments (calamus, quill pens, pen nibs, brushes) were designed in such a way that they had to be ***pulled*** and not pushed. This is no longuer the case with modern writing instruments which do not imply movement in a privileged direction, but there is a long tradition of teaching and learning such movements e.g. those which are still found in the calligraphic art.

- *Clues from Biomechanics*
  Biomechanics shows that there are very difficult or impossible combined movements of the wrist and of the hand. This explains the fact that, for western handwriting, movements in the NE or SE directions are the easiest ones, that movements in the SW are a little bit more difficult and that movements in the NW direction are very infrequent.

- *Clues from Forensic Sciences*
  Signature verification studies have highlighted the fact that in European signatures the rectilinear parts of the signature drawing correspond to the parts drawn at the highest speed. They are also the most stable parts of the signatures and have a certain degree of invariance. For example, they can be transposed from the signature of a single woman into her new signature once married and among these stable parts of drawings are the downstrokes.

- *Clues from Injuries and Disabilities*
  The observation of the handwriting of injured or disabled people shows the existence of a ***stroke basis*** of the handwriting because it has been

observed that strokes are omitted or extraneous strokes are added in the handwriting of these people.

- *Clues from Handwriting Generation Modeling*
  The studies on handwriting generation modeling have pointed out the fact that there are some balistic movements in handwriting movements and that the cursive characteristics result from the superimposition of the successive biomechanical orders [27]. Besides, the shapes of links are variable. This comes from the lead or the lag in time between the vertical and the horizontal movements [28].

All this clues are a piece of evidence and point out the fact that the most, but not totally invariant and robust parts of the handwriting are probably the *downstrokes*. Downstrokes are done with the maximum strength, thickness and precision while the links are much more variable. This can be confirmed by experimentation [29]. Downstrokes have already been frequently used in existing handwriting recognition systems.

### *3.2 Handwriting Models*

- *Physical Model*
  The physical model which is proposed here relies upon a mathematical model for plane curves. According to Thom's theory [30], every change in shape is a *morphogenesis* (i.e. the generation of a new shape) corresponding to a *catastrophe* which is an abrupt change in one of the properties of this shape. Handwriting is a 2-D plane curve for which the main geometrical features are: continuity, differentiability and curvature. Therefore, we define as *catastrophe points* the subset comprising points where the curve is disrupted, angular points and cusps. Some other singularities are the points of inflection, the extrema and the multiple points. All these points are the set of *singularities* in the handwriting drawing. We suggest describing a plane curve by two subsets of primitives: a subset of singularities or *perceptual anchorage points* and a subset of ordinary arcs i.e. regular geometric arcs, or *regularities*, each of them consisting of the set of regular points.

- *Logical Model*

  - *Fundamental Primitive Shapes and their Combination Rules*
    These fundamental primitive shapes can also be based on a mathematical model, namely the curvature sign and its magnitude, the direction of the half-tangent and of the normal to the curve at the

characteristic point(s) attached to this part of the drawing. They are connected together by logical operations which include: *concatenation* i.e. juxtaposition, *linkage* or coarticulation which modify their shapes mostly at their beginning and their end, *fusion* which is at the origin of the ligatures (i.e a personal handwriting style or new shape for a subset of characters e.g. th) and *splitting* of one stroke into two others.

– *Basic Allograph Models*
Allographs are different drawings of a same character according to different handwriting styles (capital, small, handprinted, script, etc.). For alphabetical western languages, characters have only one, two, or three downstrokes which are the basic primitives or the fundamental letter strokes (i.e. a kind of kernel for each letter). These downstrokes are partially connected together depending on the vertical position of the pen tip (up or down).

From the different kinds of primitives, of basic strokes and of their combination rules, a generic model of handwriting has been deduced[31].

### *3.3 Fundamental Equation of Handwriting*

Based on several paleographic clues (the study of medevial texts, litterary author drafts, etc.) and on the basis of the logical model described above we suggest a more compact and synthetic handwriting model:

$$\begin{aligned} Handwriting = & PertinentInformation \\ & +(Beginnings + Links + Ends) \\ & +Embellishments \end{aligned} \tag{1}$$

or

$$Handwriting = PertinentInformation + StyleVariations \tag{2}$$

which may be summarized into :

$$Handwriting = PertinentInformation + \text{“}Noise\text{''} \tag{3}$$

### *3.4 Characteristics of Handwriting*

- *Speed vs Legibility*
The faster is the handwriting, the less legible it is and the less information it contains. At one extreme, we may have a calligraphic, very legible , but

slowly drawn handwriting and at the other extreme, either a long stroke drawn very quickly but without any information in it, or a handwriting with a lot of missing information (e.g. a physician's prescription).

- *Polysemy*
  At each level (stroke or graphemic level, letter or lexical level, word or syntactic level) each graphic symbol or sign may have a different meaning depending on its local context.

## 4 Reading: Perceiving, Recognizing and Interprating Handwriting

### *4.1 Handwriting and Reading*

Handwriting is a coding of mental ideas into physical visual shapes. A more synthetic (idiosyncratic) handwritten coding of oral text is shorthand[32]. Handwritten text reading is the decoding of the message. This might be a more or less difficult task according to the ratio of information perceived from the text to the ambiguous or missing information part. Intelligent human reading of a handwritten text can be defined as the combination of three activities: fisrt, perceiving the handwritten signs or some visual clues of the text (i.e. keystrokes, keyletters, keywords) second, using a lot of knowledge to finally reach a coherent interpretation of the text and third, making some backtrackings and focusings on some details if misunderstandings or contradictions occur. This could also serve as a new general framework for designing a new kind of reading machine.

### *4.2 Perceiving*

Recent new insights into handwriting recognition and perceptual reading models, indicate that some elements seem to be more perceptually significant.

- *Perception of the ductus*
  Perceiving a ductus is in fact detecting the order of primitives derived from the handwriting signals [X(t), Y(t)] or extracted from the image [F(x,y)]. It is not absolutely necessary to reconstruct the exact sequence in which the strokes have been drawn initially, but only to converge on one possible coherent and stable sequence of primitives. This type of perception corresponds in some way to the trajectory of someone following a magnified version of the handwriting drawing with his finger. This characterizes some *dynamic characteristics* of the handwriting signal. In on-line handwriting reading, this process overcomes the problem of the

stroke order sequence variability. Moreover, this unifies the on-line and off-line approaches.

- *Perception of the visual shape*
  Perceiving the visual shape is perceiving the 2-D display of the handwriting as an image. This characterizes some *static characteristics* of the handwriting. It is necessary to detect regularities and singularities of the handwriting drawing, to recognize the fundamental shapes of the primitives and of the strokes, to detect the relative positions and sizes of the primitives, of the letters, of the diacritics, etc. The perception of the visual shape is also able to unify the on-line and the off-line approaches since it is generally easier to detect intersections and relative positions using a small image matrix than directly on the signal. It is noticeable that some on-line handwriting recognition systems already work in this manner [33].

  - *Perception of singularities and regularities*
    In the perception of the visual shapes, it was pointed out that the *dominant points* of the object contours are very important elements [34]. We assume that singularities of plane curves or of handwriting are also pertinent "perceptual points".
  - *Perception of the shapes of the basic primitive and of the fundamental downstrokes*
    According to the previous modeling of the handwriting the shapes of the basic primitives or of the fundamental downstrokes can be perceived according to their different geometrical features. This might overcome some of the variabilities of the allograph shapes.
  - *Perception of the local relative positions*
    These relative positions can be perceived for example by only examining the characterics of position of the surrounding rectangles of the primitives, of the strokes, of the letters or of the diacritics. This is done in order to decide if a stroke or a letter is on the left or on the right side, above or under another one or if it has an extension over or under the median zone, etc. (e.g. as for "d", "b", "q" and "p"; "e" and "l"). This perceptual technique, which only acts locally, might overcome some of the difficulties of determining the two lines closest to the handwriting body (i.e. the median zone) of a whole line of text or of a whole word.
  - *Perception of the relative sizes of primitives and letters*
    The perception of the relative sizes of primitives is important to

recognize different letters having the same subset of basic primitives, (i.e. the same fundamental strokes and placed in the same relative positions). For example, "a" and "d" differ only by the size of the elongate stroke on their right side, "e" and "l " are only distinguished by the length of their loop. The perception of the relative sizes of letters is also an evidence to distinguish the capital style from the small style of a letter. The perception of the relative position of a letter in a word is also an evidence of the fact that a character may be a capital letter if it is situated at the beginning of a word or may be a small letter if it is situated in the middle or at the end of a word.

- *Perception of discriminative signs*
  This occurs when we face very similar shapes (e.g. "O" and "Q"; "1", "i" and "l"; "b" and "l", "l" ant "t", "c" and "ç", etc.). The human visual system focuses on the small part of the drawing i.e. the *discriminating sign* which makes the essential difference and leads to different interpretations. It will therefore be important for a handwriting reading system to be able to automatically detect the minimum amount of pertinent information needed to discriminate between very similar shapes.

- *Perception of the global visual shape*
  According to the Gestalt theory a shape is perceived globally. It is not only the result of its constitutive elements. For handwriting perception, the result will be variable according to the relative positions and sizes of the elements (primitives, strokes, characters, etc.). For example, the couple of strokes $(C, |)$ can be interpreted as an "a" of small script style or the couple "c i", depending on the relative position of both strokes.

All the information issued from this set of perceptions (i.e. relative sizes, positions, etc.) varies in a continuous manner and is *intrinsically fuzzy* in nature. This is an important characteristic because it can be a source of confusion errors. Moreover, it can explain all the possible confusions which are observed.

### *4.3 Recognizing*

According to the previous equation (3), to date, when classical recognizers are used for handwriting recognition, what takes place is a comparison between an unknown "noisy" handwriting and a handwriting model which may also itself

include “noise”. Therefore, it is not at all surprising that the recognition result can be somewhat erratic and that the recognizer makes errors depending on whether the comparison is mostly made on the pertinent information or on the “noise”, i.e. the variable part of the handwriting.
What is suggested in this paper is to use only an *optimal* number of primitives representing only the *pertinent information* and the *discriminating information*. In other words, to use only few primitives in order to avoid recognition errors and unstable results. But, on reverse side, not to use too few primitives otherwise there would be a risk of several confusions. The recognition might include the following steps: firstly suppress all the flourishes, hooks at the beginnings, long ends, etc. and, base the recognition on the pertinent information only (i.e the recognition of the basic downstrokes without considering any part of the “noise'), secondly, consider the links to overcome ambiguities on stroke shapes. This is equivalent to inhibiting the perception of the unstable part of the handwriting. We have already suggested such a method elsewhere[31, 35].

### *4.4 Interpreting with Contextual Knowledge Sources*

What are needed are systems which can take into account the cognitive and semantic characterization of the handwritten expression mode. Moreover, handwriting reading is not only a problem of recognition but also a problem of understanding the semantic meaning of handwritten texts which require from time to time some interpretation using all the available knowledge:
- *knowledge from paleography,*
- *knowledge about the physical instruments,*
- *knowledge about biomechanical constraints,*
- *knowledge about handwriting morphology* (different styles, etc.),
- *pragmatic knowledge* (direction of handwriting, speed, legibility, etc.) ,
- *knowledge about education* (teaching of handwriting and reading at elementary school),
- *linguistic knowledge* (lexical, syntactic, semantic).

### *4.5 Managing the Knowledge Sources*

In this new framework, researchers will have to deal on the one hand, with several knowledge sources (K.S.) and on the other hand with vagueness, fuzziness, uncertainty and missing data. This can be done with existing techniques, (e.g. data fusion, numeric and symbolic knowledge sources integration, fuzzy set and possibilistic theories, studies derived from cognitive sciences, etc.) and we propose to use a paradigm of verification of a global criterion of simultaneous *coherence* between all available information. The originality of this new approach consists in designing systems based on data fusion issued from different K.S. instead of having systems having a classical sequential organization, in using higher level K.S. to try to overcome ambiguous or missing information encountered at a lower level and, in using any available *redundancy* to improve the system performance.

## 5 Conclusion, Future Trends and Outlook

The approach suggested might be summarized as follows: use the optimal information amount to solve the problem (i.e suppress all the unnecessary information); use the local visual context to overcome the question of relative sizes and positions; focus only on the discriminative information to overcome possible confusions; use more general contexts and knowledge to deal with vague ambiguous or missing information; take only soft decisions at each level and take only the final decision on a criterion of coherence of all the available information.
At the dawn of the 3rd millennium, Human Handwriting Processing (HHP) is emerging from its infancy and set to become a mature technique. We shall probably see in the near future a number of mixed systems able to read both on-line and off-line handwriting. We would also like to see a second generation of Handwriting Reading Systems (HRS) consuming less memory and time but, fitted with some perceptual faculties [36] and with the ability to interprete ambiguous data entries.
More generally, there is a clear need for methods designing Perceptual and Interpretative Systems (PIS) which will lead to efficient and easy to use multimodal and multi-lingual interfaces. This paper has suggested some guidelines and has given a few examples to move in that direction.

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## References

1. J.J. Lee and J.H. Kim, "A unified network-based approach for on-line recognition of multi-lingual cursive handwritings", in *Progress in Handwriting Recognition*, World Scientific Publ., pp. 81-86.

2. C.H. Chen *et al.*, "Handbbok of Pattern Recognition and Computer Vision", World Scientific Publ., 1997.
3. H. Bunke and P.S.P. Wang, " Character Recognition and Document Analysis", World Scientific Publ., 1996.
4. R.A. Cole *et al.*, "Survey on the State of the Art in Human Language Technology", pp. 1-590, Nov. 1995. http://www.cse.ogi.edu/CSLU/HLTsurvey/HLTsurvey.html
5. P. Mermelstein and M. Eden, "A system for automatic recognition of handwritten words", *Proc. FJCC (AFIPS)*, pp. 333-342, 1964.
6. L.D. Earnest "Machine reading of cursive script", *IFIP Congress*, Amsterdam, pp. 462-466, 1963.
7. N. Lindgren, "Cursive script Recognition", *IEEE Spectrum*, **2**, 5, pp. 104-116, May 1965.
8. R.W. Ehrich and K.J. Koehler, " Experiments in the contextual recognition of cursive script", *IEEE Trans. Comp.*, **C24**, pp. 182-194, Feb. 1975.
9. G.M. Miller, "Real Time classification of handwritten script words", *IFIP Congress*, Amsterdam, pp. 218-223, 1972.
10. M. Sayre, "Machine Recognition of Handwritten words. A project report", *Pattern Recognition*, **5**, pp. 213-228, Sept. 1973.
11. K.C. Hayes, "Reading handwritten words using hierarchical Relaxation", *CGIP*, **14**, pp. 344-364, 1980.
12. C.Y. Suen *et al.*, "Automatic Recognition of Hand Printed Characters - The State of the Art", *Proc. of IEEE*, **68**, 4, pp. 469-487, Apr. 1980.
13. T. Pavlidis and S. Mori, "Special Issue on Optical Character Recognition ", *Proc. of IEEE*, **80**, 7, 1992.
14. C.C. Tappert *et al.*, "The state of the Art in On-Line Handwriting Recognition", *IEEE Trans. on PAMI*, **PAMI12**, 8, pp. 787-807, 1990.
15. R. Plamondon Ed., "Handwriting processing and application", *Pattern Recognition*, **26**, 3, March 1993.
16. P.S.P. Wang Ed., "Character and Handwriting Recognition: Expanding Frontiers", *IJPRAI*, **5**, 1-2, June 1991.
17. R. Plamondon Ed., *MVA*, **8**, 4, 1995.
18. S. Impedovo Ed.,"Special Issue on Automatic Bankcheck Processing", *IJPRAI*, Jan. 1997.
19. A. Meyer, "Pen Computing", *SIGCHI Bulletin*, **27**, 3, pp. 46-90, 1995.
20. D.J. Burr, "Designing a Handwriting Reader", *IEEE Trans. on PAMI*, **PAMI5**, pp.554-559, 1983.
21. L.R. Rabiner, "A Tutorial on Hidden Markov Models", *IEEE ASSP Magazine*, **3**, 1, pp. 4-16, 1986.

22. I. Guyon and P.S.P. Wang Eds., "Advances in Pattern Recognition Systems using Neural Networks", *IJPRAI*, **7**, 4, 1993.
23. T.K. Powalka *et al.*, "Multiple Recognizer Combination Topologies", in *Handwriting and Drawing Research: Basic and Applied Issues*, IOS Press, pp. 329-342, 1996.
24. J. Kittler *et al.*, "On Combining Classifiers", *IEEE Trans on PAMI*, **PAMI20**,3, pp.226-239, 1998.
25. C.J. Wells *et al.*, "Fast dictionary look-up for contextual word recognition", *Pattern Recognition*, **23**, pp. 501-508, 1990.
26. I. Guyon anf F. Pereira. "Design of a linguistic postprocessor using variable memory length", *ICDAR*, Montreal, pp. 454-457, Aug. 1995.
27. R. Plamondon, "A kinematic theory of rapid human movements, Part I and Part II", *Biological Cybernetics*, **72**, 4, pp. 295-320, 1995.
28. L.R.B. Schomaker *et al.*, "A Computational model of cursive handwriting", in *Computer Recognition and Human Production of Handwriting*, World Scientific Publ. pp. 153-177, 1989.
29. G. Menier *et al.*, "A new Modeling Method for On-line Handwriting Recognition", *ICDAR*, Montreal, pp. 499-503, Aug. 1995.
30. R. Thom, "Structural stability and morphogenesis", W.A. Benjamin Inc., 1975.
31. É. Anquetil and G. Lorette, "Perceptual Model of Handwriting Drawing Application to the Handwriting Segmentation Problem", *ICDAR*, Ulm, pp. 112-117, Aug. 1997.
32. G. Leedham, "Automatic Recognition and Transcription of Pitman's Shorthand", in *Computer Processing of Handwriting*, World Scientific Publ. pp.235-269, 1990.
33. S. Manke *et al.*, "Npen$^{+}$.$^{+}$ A writer Independent, Large Vocabulary On-Line Cursive Handwriting Recognition System", *ICDAR*, Montreal, pp. 403-408, Aug. 1995.
34. F. Attneave "Some Informational Aspects of Visual Perception", Psychological Review, Vol. 61, n 3, 1954, pp. 183-193.
35. É.Anquetil and G. Lorette, "On-line handwriting character recognition system based on hierarchical quality fuzzy modelling", in *Progress in Handwriting Recognition*, World Scientific Publ., pp. 109-116.
36. M. Côté *et al.*, "Automatic reading of cursive scripts using a reading model and perceptual concepts. The PERCEPTO system., *IJDAR*, **1**, 1, pp.3-17, 1998.