ON THE DEFINITION OF REFERENCE SKELETONS FOR COMPARING THINNING ALGORITHMS

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ABSTRACT

This paper describes a method to define reference skeletons for binary images of hand-printed and typed characters. These reference models are used to compare visually the outputs of thinning algorithms. Three types of perception experiments using eleven thinning algorithms are reported.

RESUME

Cet article décrit une méthode pour définir des squelettes de référence à partir d'images binaires de caractères manuscrits ou typographiés. Ces modèles sont utilisés pour comparer visuellement les sorties de différents algorithmes d'amincissement. Trois expériences de perception utilisant onze algorithmes d'amincissement sont présentées.

Keywords: thinning algorithm, reference skeleton, handprinted and typed characters

INTRODUCTION

Thinning algorithms are used for the pre-processing of binary images into connected skeletons, generating a structure of unit thickness which can be analysed for its representation into primitives. These ideas were developed about 20 years ago [1] and since that time several algorithms have been found useful in numerous applications: inspection of printed circuit boards, counting asbestos fibres on air filters, analysis of chromosome shapes; examination of soils cracking patterns; classification of finger prints, recognition of characters etc. The major functions of thinning in image processing and pattern recognition are: to reduce data storage, to reduce transmission time and to facilitate the extraction of morphological features from digitized patterns.

Most existing algorithms produce a skeleton by successive stripping of the edge points of the binary pattern. Each algorithm has its own set of stripping rules. This results in different skeletons, each one having a different degree of distorsion.

Comparison of the algorithm performances is generally based on execution time and memory requirements. However the degree of distortion is difficult to analyse quantitatively and comparative studies are generally limited to the evaluation of the connectivity of the final output, its symmetry and the ability of the algorithm to retain end points [2,3].

The purpose of this study is to define reference skeletons for some binary images of handprinted and typed characters from which the outputs of thinning algorithm can be compared visually. In the first part of this paper, the method for defining reference skeletons is presented. Three types of visual comparison experiments are then described and discussed in the second part.

METHOD

Figure 1a shows the set of ten handwritten characters and two typed characters that were used for this experiment. These specimens were selected since they reflect the main structural properties of alphanumeric characters and also of other types of lines. The characters were digitized with an OCR scanner (Microtek Inc.) at 200 dpi. and the resulting images were then printed on large scale (see a few specimens in figure 1b)

Copies of these outputs were presented to a group of 33 human subjects. About one half of this group was already familiar with thinning algorithms. Each subject was given an instruction sheet describing the purpose of thinning algorithms and asking her/him to mark with a pencil the dots of the enlarged images that she/he considers as part of the character skeleton that is, dots that best represent the shape of the character.

After these manual thinning operations, the 33 sample skeletons of each character were input to a microcomputer with the help of a digitizer and an interactive software specifically developed for this purpose. Figure 2a shows the typical distributions of the skeletons for some characters.

Each distribution was then analysed visually to define the most probable reference skeleton for each character, according to the following rules:

1) The skeleton is continuous and composed of the pixels of highest relative frequency that is the pixels most often selected by human subjects.
2) The skeleton is of unit thickness. At the junction of segments, node of degree higher than 2 are accepted if the global shape of the character is preserved.
3) If two adjacent pixels are of equal relative frequency, only one is kept, according to the gradient analysis of the surrounding.
4) For end points, the skeleton is truncated as

soon as a 20% decrease in the maximum distribution is encountered.

Figure 2b shows the most probable skeletons that were kept as references for the distributions of figure 2a.

PERCEPTION EXPERIMENTS

To check the validity of the final reference models, three types of perceptual experiment were conducted. Eleven thinning algorithms [4,5,6,7,8, 9,10,11,12,13,14] were used for these experiments. Each character of the data set of figure 1 was thinned with the help of these algorithms and the final output were printed. Figure 3 shows a set of these outputs: skeleton points are black and all those outputs that have been deleted in the thinning process are left white. Each output is defined by two letters, corresponding to the initials of the authors of the algorithm, PS refers to the reference model for this character as defined by the previous experiments.

Experiment 1

In the first perception experiment, the 33 subjects were given a set of outputs similar to those of figure 3. PS models output were not included in this experiment and the outputs of the eleven thinning algorithms were randomly distributed for each character. The subjects were instructed to select carefully the 3 outputs which they think best represent the skeleton of each input character and to rank them in descending order of preference.

Experiment 2

In the second experiment, the PS reference models were also included at random in the proper sets and the subjects were asked to perform the same task, among the twelve outputs for each character. Only 21 subjects "survived the first test" and participated in this experiment and the next one.

Experiment 3

In the last experiment, the subjects were given the same set of outputs as used in experiment 1 plus the reference models PS on separate data sheets. The participants were then asked to rank the outputs of the best three thinning algorithms with respect to PS models.

RESULTS

Figure 4 shows the global result obtained in these experiments. For each experiment, a histogram depicts in percentage the number of times a typical algorithm (identified in the abscissa by two initials listed in alphabetical order) was selected among the first three bests for the whole set of characters. In other words, for each experiment and for each algorithm i, F_i has been computed and plotted according to:

$$F_i = \frac{\sum_{j=1}^{N} \left[A_i + B_i + C_i \right]}{\sum_{i=1}^{n} \sum_{j=1}^{N} \left[A_i + B_i + C_i \right]} \times 100 \qquad (1)$$

where i = identifier of algorithm

N = number of thinned characters (12 in this study)

n = number of thinning algorithms (including PS in experiment #2)

A_i, B_i, C_i = number of times algorithnm i was selected as the first (A_i), second (B_i) or third (C_i) best position respectively.

Results of experiment #1, #2 and #3 are represented with continuous lines, dotted lines and discontinuous lines respectively.

DISCUSSION

Two important observations can be drawn from these results. First, as shown in the data of experiment #2, the reference models PS are always considered as the group of best skeletons for each character. A closer look at the results shows that they are mostly ranked as first or second (first in 62% of the cases). This is reflected in the histogram of figure 4 (dotted lines) by a peak which is more than two times higher than the others. Second, looking at the data from experiments #1 and #3, the relative ranking order of the thinning algorithms is conserved at least for the first four bests, that is HT [9], ED [8], CH [5], YC [13]. This observation is also true for experiment #2, if PS data are not considered.

This latter comment reflects the consistency of the human subjects throughout the experiments. However it must not be interpreted as an indication that PS models are useless for comparison. Indeed if one compares the results of experiment #2 with those of experiment #3, it is clearly observed that a greater discrimination between thinning algorithm performances has been achieved by the subjects when PS models were used as a reference. This fact was also confirmed verbally by a lot of subjects who found experiment #3 easier than the two previous ones.

CONCLUSION

Apart from their interest for qualitative evaluation of thinning algorithm outputs, the reference skeletons PS proposed in this paper are expected to be very useful in two other types of experiments.

First they might be of practical interest, at least for character recognition problems, for defining new "stripping rules" which are more oriented toward recognition processes. Indeed it has been observed throughout experiment #2 that none of the algorithms really challenges the human performances. Data analysis from experiment #1 suggests that thinning is performed by human as a function of a recognition goal. Since human never dissociates perfectly thinning and recognition processes, one might expect that a thinning algorithm that would produce outputs similar to those of figure 3, would lead to better performance in later stages of the recognition process.

Second, these reference models could be used in conjunction with the thinning algorithm outputs to quantify, with the help of a proper distance measure, the difference between the other algorithms. Studies on these distance measures might also reveal pertinent information about the human comparison process, in such a context. These latter studies are now under way.

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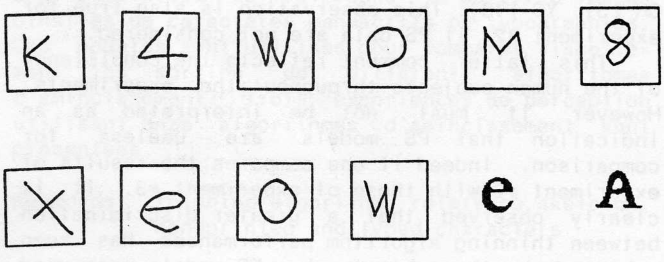

Figure 1a

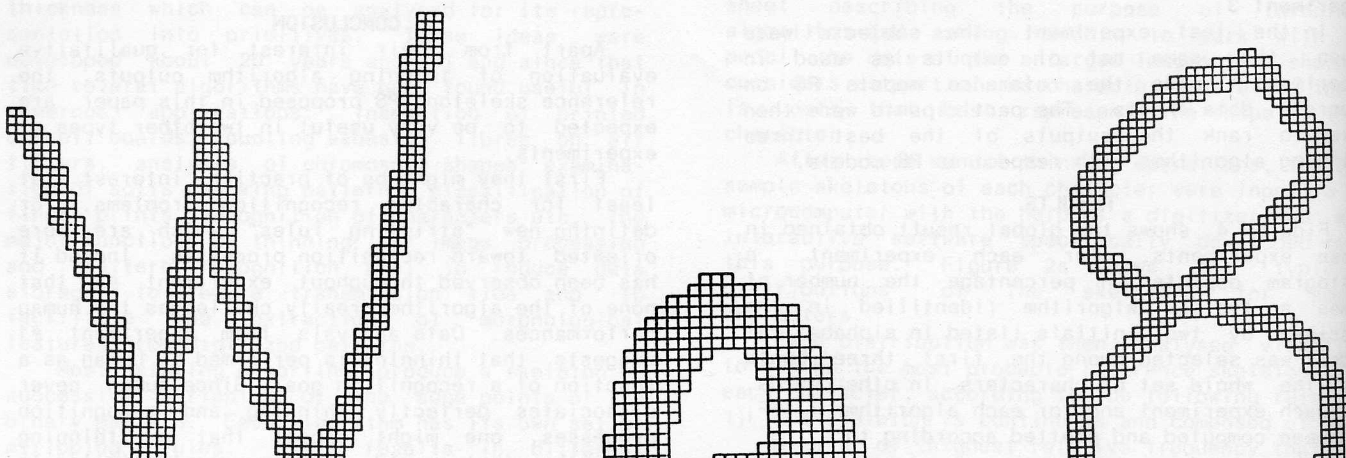

Figure 1b

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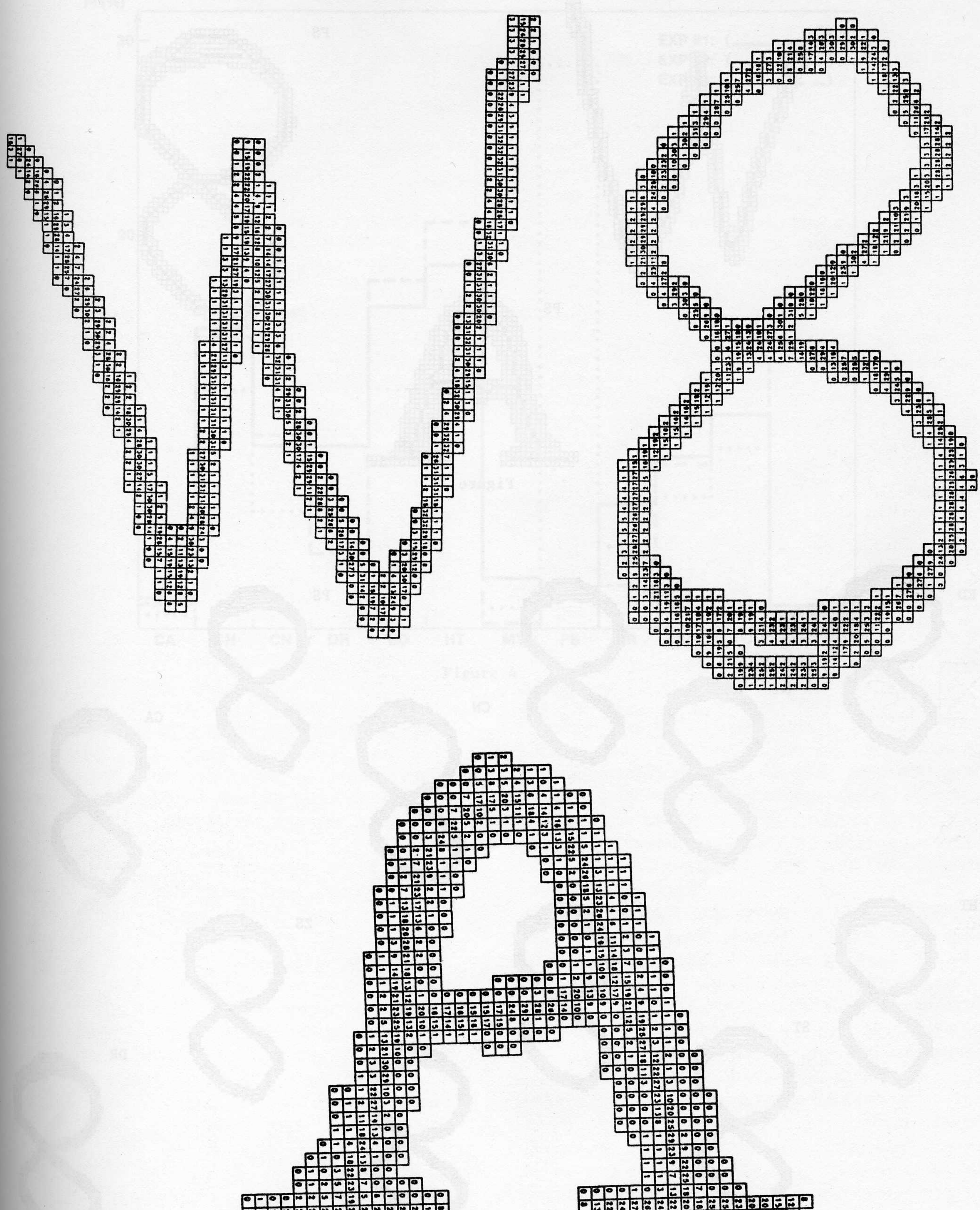
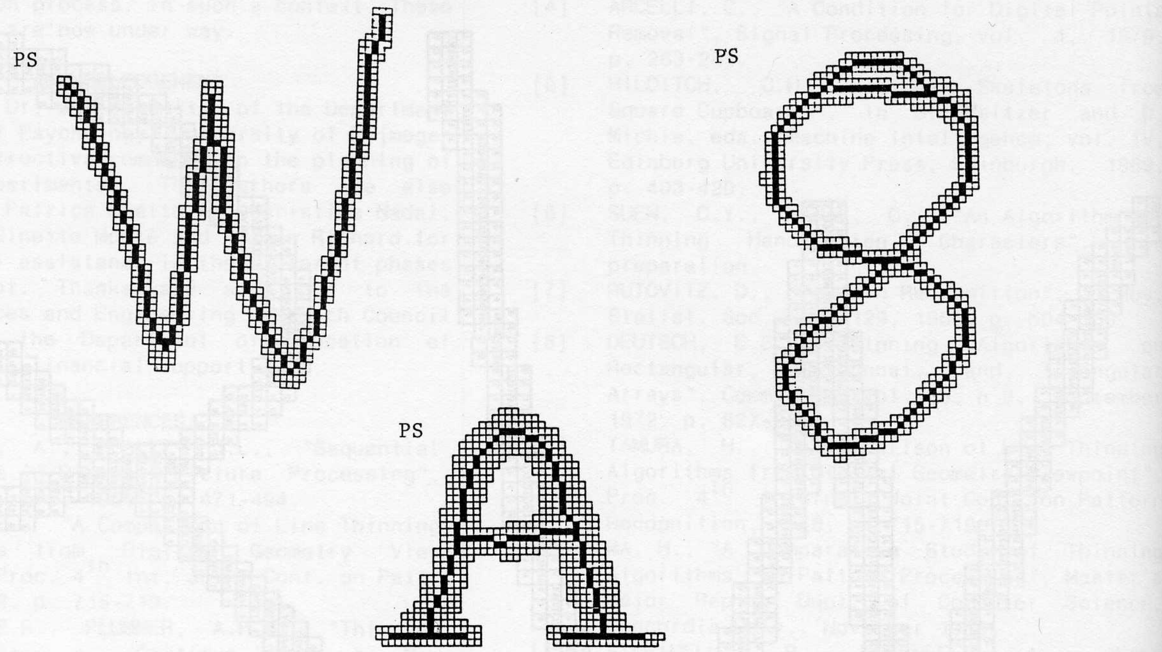


Figure 2a



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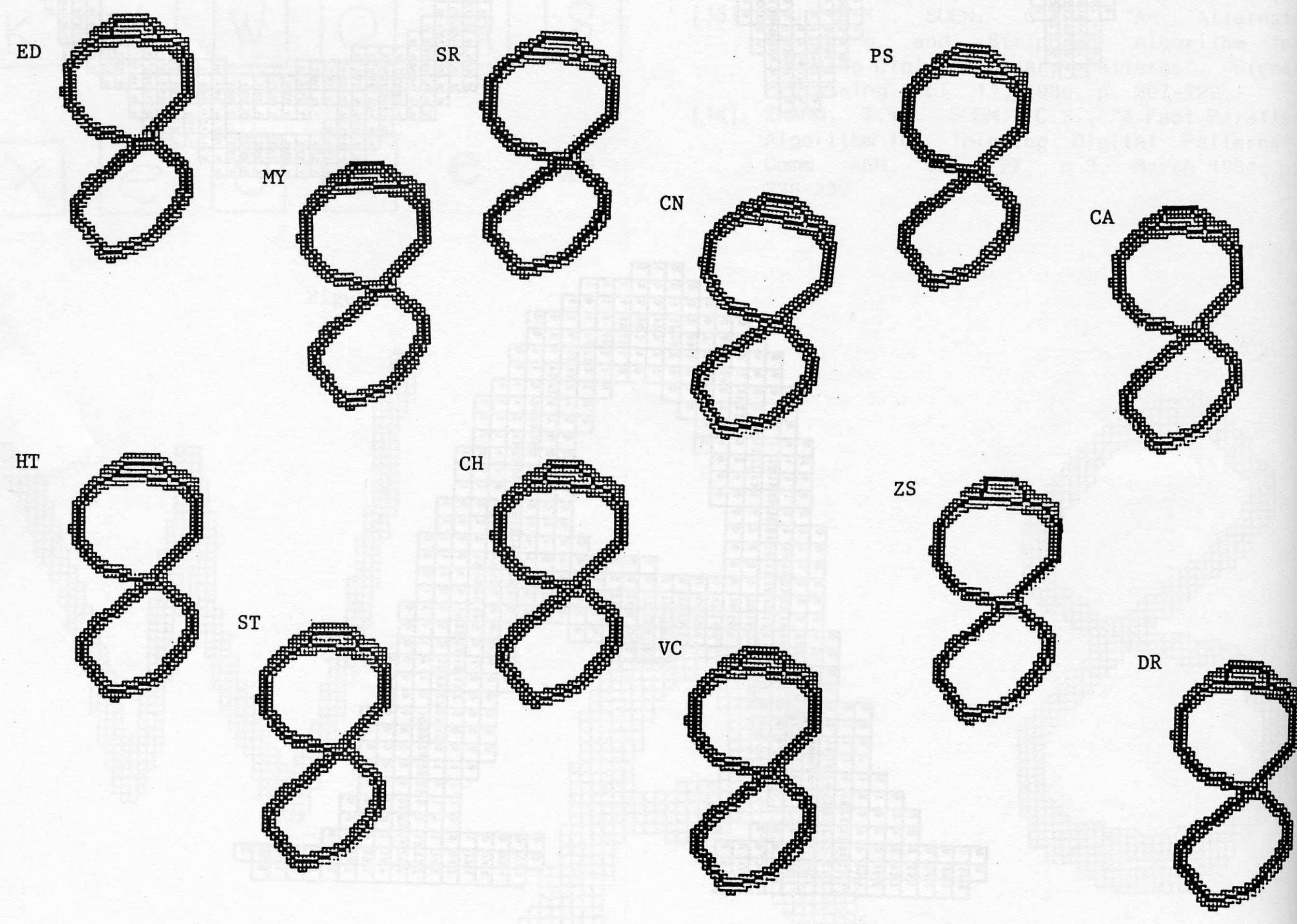

Figure 3

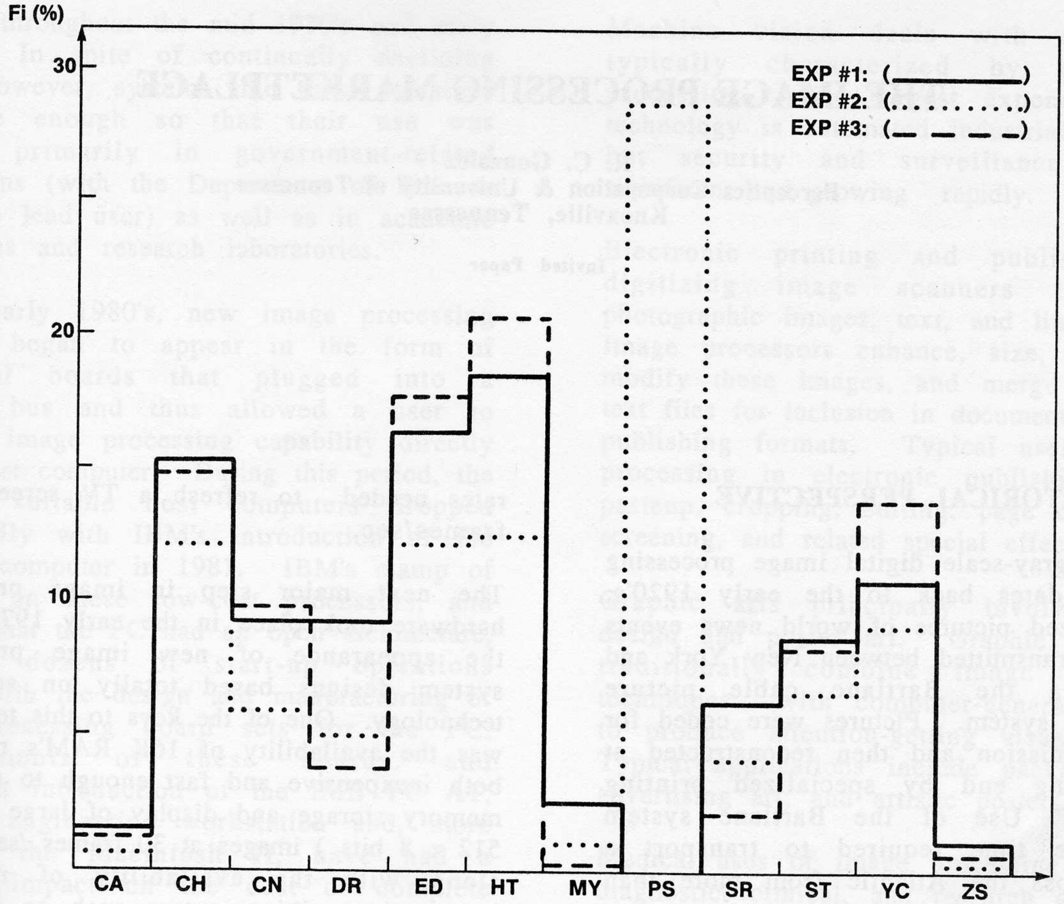

Figure 4