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THINNING ALGORITHMS FOR DOCUMENT PROCESSING SYSTEMS

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Abstract

The aim of this paper is to present the results of a study which was performed to assess the feasibility of thinning methods for document processing. As a result of these investigations, both theoretical and numerical, a new thinning method is described and some of its properties are given.

Introduction. When a document processing system is developed, special attention has to be paid to low level processing algorithms. Even the most fundamental and well-known methods need periodic reevaluation in order to adapt them to varying practical needs and to continuously developing computer architectures.
The aim of this paper is to communicate results of an investigation of thinning methods in the context of document processing and to present a method which exhibits some favourable properties while not sharing the disadvantages of other known approaches. The method was proposed by Ogawa and Taniguchi |7| and specifically by Xia |12|. Its theoretical bais was laid by one of the authors |2|.
In document processing systems, there are two different applications of thinning methods. First, if the content of a (black-and-white) document is thinned, the amount of data contained in it is reduced while the information content is (nearly) the same as before. Typically, a thinned document contains only 1/2 to 1/10 as much black points as the original. This data reduction is especially attractive when more complex methods for image analysis are considered. We mention here the Hough-transform which can be used e.g. for finding prominent directions in order to align a document. The efficiency of this transform severely depends on the number of black points in the image.
The second application for thinning methods is the segmentation of objects in the image. Thinning the background yields curves separating the objects from each other (the so-called exoskeleton of the image). Together with distance information one gets a large amount of structural knowledge about the document.

Properties of Thinning Methods. If a thinning method is intended for practical use, it should be implemented in parallel since computing times become prohibitive with sequential implementations even for documents of only moderate size (see e.g. |9|).
Any parallel thinning method consists of two parts, a topological criterion for finding candidates for removal from the set of black points and a mechanism for avoiding collisions when removing points in parallel.
Assume that the set of black points of a binary digital picture is equipped with the 8-connection topology and the set of white points with the 4-topology. The most general criterion for removing a black point (i.e. changing its color to white) was given by Rosenfeld |8|: A black point is a candidate for removal if its color neither influences the number of black (8-) connection components nor the number of white (4-) connection components of the image. It was shown by Rosenfeld that the question whether a point is a candidate for removal or not can be decided by inspection of its 3×3-neighborhood in the digital plane. Any point which meets this criterion is called a simple point |8|. Some authors (see e.g. |14|) prefer the so-called strict boundary points instead for thinning. These are simple points having the property that in addition also the number of black 4-connection components is preserved by eliminating them. Generally it is accepted that end points, i.e. black points having only one black (8-) neighbor, are not removed under thinning.
In order to avoid collisions in parallel elimination, a number of techniques was proposed. These techniques can be applied independently of the topological criterion used. All these methods have in common that among the candidates passing the topological test only a

fraction (typically one quarter or one half) is actually eliminated. The following approaches were published in the literature:

- Four phase ENWS method. In the first (second...) phase of this approach only candidates are removed having a white direct neighbor in east- (north-...) direction.
- Four phase method of Kreifelts |6|. All points in the digital plane are given numbers 1 to 4 according to the scheme

```
• • • • • •
• • 1 3 • •
• • 4 2 • •
• • • • • •
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In phase i only points having number i are allowed for deletion.

- Two phase checkerboard method. Here, all points in the digital plane are given colors - e.g. red and green - in a checkerboard-like manner. In the first phase only red points and in the second phase only green points are investigated.
- Two phase method of Rutovitz. This method can be formulated as follows |3|: In the first phase only points having a direct white neighbor in east or north direction are allowed for elimination, in the second phase points with white direct neighbors in west or south direction are considered.

All these methods are not invariant with respect to translations of the digital plane (Kreifelts' and the checkerbord methods) or with respect to 90°-rotations of the digital plane (ENWS and Rutovitz' methods).

Steinpreis |10| investigated eleven methods known from the literature. The result of Steinpreis' paper is that the main differences of the methods considered in his study were actually differences in the implementation of more or less the same algorithm. This agrees with Tamura's findings |11|.

<u>Definition of Requirements</u>. From the investigation of existing methods for thinning we arrive at a catalogue of requirements for an "ideal" thinning method. Here, the term "thinning method" is used for any combination of an elimination criterion together with a mechanism for avoiding collisions in parallel implementation. These requirements are:

- The method should be correct, i.e. the skeleton obtained by its application should have the same number of black and white connection components as the original picture. Indeed, some methods published in the literature are not correct (see e.g. |3|).
- The method should be well-defined, i.e. any two different implementations of it should yield identical results.
- The method should be invariant with respect to translations, rotations and reflections mapping the digital plane into itself. Whereas the topological criteria exhibit these invariances, the methods for collision avoidance usually are not completely invariant (see remarks above).
- Davies and Plummer |1| add the requirement that it should be possible to reconstruct the original image from the skeleton obtained by thinning if the points of the latter are labeled so that they carry distance information.

If a method is not well-defined or if it does not exhibit the fundamental invariances of the digital plane, the results of its application can only be understood and interpreted with respect to a specific implementation and a specific position of the binary image under consideration within the digital plane. So any practical comparison whith other methods is made difficult (if not impossible) by the side-effects of unknown magnitude caused by insufficient definition of the method under consideration.

The requirement of reconstructability has to be handled differently. On the one hand, any method with the property of being invertible at least causes no loss of information, and certainly no information essential for understanding the image content is destroyed by it. On the other hand, any method for image processing necessarily should reduce the raw image data by eliminating irrelevant information since usually the amount of data is very huge.

<u>An Ideal Method</u>. On the basis of the investigations mentioned and of a large number of numerical experiments a method was chosen having favourable properties and fulfilling the requirements mentioned above. This method was proposed by Ogawa and Taniguchi |7| and specifically by Xia |12|. It was reformulated and some properties of it were proved by the authors (|2|, |3|, |4|, |5|). The basic concept of the method is the notion of a perfect point. A black point P is termed D-perfect if it has a direct neighbor which is an interior point of the set of all black points (i.e. all its four direct neighbors are black) and if the direct neighbor opposite to the interior point is white:

```
• x • •        x  black point
x # P o        o  white point
• x • •        #  interior point.
```

A black point P is termed I-perfect if it has an indirect neighbor which is an interior point and if the indirect neighbor of P which is opposite to the interior point is white together with the direct neighbors of it being also direct neighbors of P:

```
• • o o
• x P o
x # x •
• x • •
```

A point is perfect if it is either D-perfect or I-perfect |2|. The method proposed here consists in eliminating only points which are perfect and simple. We list some properties of the method, details can be found in the references cited:

- The method for parallel thinning consisting in elimination of all simple and perfect points from a set simultaneously is correct (see Xia |12|, Eckhardt |2|, |4|).
- Application of this parallel method to a binary picture leads to a well-defined result |2|.
- The method is invariant with respect to all translations, rotations and reflections leaving the digital plane invariant |2|.
- A simple and perfect point is a strict boundary point |2|.
- End points are never perfect, hence they are preserved by the method. Moreover, certain critical configurations discussed by several authors (see e.g. Tamura |11|) are not changed by the method:

```
x x
  x x
    x x
      .
       .
```

- It is possible to organize the elimination of simple and perfect points in such a way that only boundary information is used. Simple and perfect points can be characterized by the fact that they belong to regular pieces of the boundary of a set |4|.
- If a point is simple but not perfect then it is not eliminated by the method proposed here. It can be shown that in this situation two cases are possible |4|: Either such a point remains simple and not perfect until the end of the elimination. Then the decision whether the given point should be eliminated or not can be postponed to a postprocessing phase (see below). Otherwise the point becomes simple and perfect at some stage of the elimination process. Then there exists a neighbor Q of the given point P such that Q is simple and P is no longer simple if Q is eliminated and vice versa. Hence P and Q cannot be removed simultaneously (collision). In this situation an arbitrary decision whether P or Q should be eliminated is necessary. This decision is made automatically by our method when P becomes perfect. Hence, when the situation arises that any other method for thinning causes a point P to be eliminated which is not eliminated by our method, then either this decision can as well be postponed or else the elimination is made arbitrarily and especially it cannot be justified by information taken from the neighborhood of P.
- The connection number of a point is the number of 8-connection components contained in its neighborhood. The connection number of a set is the sum over the connection numbers of all points contained in the set. When the method described here is applied to a digital set, the connection number is strictly increased. This is not necessarily the case with other thinning methods |4|.
- The skeleton obtained from a set by any thinning method can contain interior points. Under a very simple and natural condition it can be guaranteed that in the skeletons obtained by the method described here the maximal size for a cluster of interior points connected together is 12 |5|.

Implementation. The method can easily be implemented by applying a suitable labeling scheme for keeping track of interior points during thinning (see Xia |12|). The so-called pseudo-skeletons obtained by application of the method do contain simple points. Hence they can be further reduced by any conventional thinning method. This, however, will destroy the properties of the method mentioned above. Since the number of remaining simple points is usually not very high, it is not necessary to use a fast method for postprocessing, instead a thorough investigation of each simple point is possible. Even if a naive method for postprocessing is applied, the error imposed by it can be easily controlled. It is, however, also possible to take the pseudo-skeleton without any further postprocessing. The additional data reduction achieved by postprocessing is comparatively small so that it does not outweigh the additional effort and the loss of favourable properties mentioned above.
The method was implemented in an experimental version in PASCAL on the VAX 7800 of the Siemens Research Laboratories in München-Perlach and on the SIEMENS 7.882 at the University of Hamburg. A very large number of tests was performed and statistical data were gathered for judging the properties of the method under different contexts. The method now runs in a stable way and a large number of theoretical results exists to assess their properties under practical conditions.

Open Questions. In spite of the theoretical and numerical results known and published in the literature cited there remain some open questions. We give a list of some of them:

- There does not exist a variant of the method for the foreground-4-topology. Such a variant would be very desirable for calculating exoskeletons (i.e. skeletons of the set of white points). These can be used very efficiently for segmentation of objects in the image.
- Thinning procedures are known to be unstable, i.e. small disturbances in

the original picture will cause large changes in the associated skeletons. This phenomenon is certainly not desirable since it can cause difficulties in the recognition process. Yu |13| gave a method for regularization of the medial axis transform. In the present context, it would be desirable to have a similar regularization concept also for thinning.

- The method described here can be formulated as a labeling procedure which is related to the distance transform in the 4-metric. This formulation is very attractive as well from the theoretical as from the practical point of view. Details of it will be given elsewhere. We only mention here that the requirement of reconstructability formulated by Davies and Plummer |1| can be fulfilled by our method.
- The skeletons obtained from a set by any thinning method do not always exhibit a "graph-like" structure as required e.g. by Davies and Plummer |1|. Even if it can be guaranteed that large clusters of interior points do not occur in the skeleton (|5|, see above), this does not imply that the latter is indeed graph-like, i.e. that it consists of digital curves which can be represented by a chain-code and are connected together by only few points having a connection number higher than two. A theoretical analysis of the skeletons obtained by our method is necessary to clarify the situation.
- A theoretical investigation of the postprocessing process seems necessary in order to get a clearer picture of what can be achieved and to what extent postprocessing will retain the invariance properties mentioned.

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