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# Using scale space filtering to make thinning algorithms robust against noise in sketch images ☆

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ABSTRACT

We apply scale space filtering to thinning of binary sketch images by introducing a framework for making thinning algorithms robust against noise. Our framework derives multiple representations of an input image within multiple scales of filtering. Then, the filtering scale that gives the best trade-off between noise removal and shape distortion is selected. The scale selection is done using a performance measure that detects extra artifacts (redundant branches and lines) caused by noise and shape distortions introduced by high amount of filtering. In other words, our contribution is an adaptive preprocessing, in which various thinning algorithms can be used, and which task is to estimate automatically the optimal amount of filtering to deliver a neat thinning result. Experiments using five state-of-the-art thinning algorithms, as the framework's thinning stage, show that robustness against various types of noise was achieved. They are mainly contour noise, scratch, and dithers. In addition, application of the framework in sketch matching shows its usefulness as a preprocessing and normalization step that improves matching performances.



## 1. Introduction

Thinning algorithms are classic in digital image processing and used to extract a pattern's *skeleton*, that is a thin or nearly thin representation of the pattern [1]. Thinning algorithms have been used in many applications such as OCR [2,3], document image analysis [4,5], fingerprint identification [6,7,8], biometric authentication using retinal images [9,10], signature verification [11–13], sketch matching and sketch-based image retrieval [14–17], etc. In OCR, thinning is used as a normalization step to insure invariance to pen thickness and handwriting styles. In fingerprint identification, thinning is used as a key preprocessing step essential before feature extraction. In authentication systems using retinal images, thinning is applied in order to produce a one-pixel-wide vascular tree of blood vessels, whose geometrical and topological properties are used in the identification process. In document analysis, signature verification and sketch-based image retrieval, thinning is used as a preprocessing and normalization step.

A thinning algorithm is considered desirable if it meets the following properties [1,18]:

- produce a thin or nearly thin skeleton;
- preserve the connectivity of the original pattern, which means that connected parts in the original pattern should stay connected in the skeleton;
- preserve the visual topology of the original pattern, which means that although the skeleton is a compact representation of the original pattern, it should deliver the same visual information;
- be robust against noise.

Although many thinning algorithms have been presented, the criteria above are rarely met altogether. Usually, choosing a particular thinning algorithm is an application dependent issue motivated by the ability of the algorithm to fulfill a particular criterion among the mentioned above. For instance, the necessity of producing one-pixel-wide skeletons is a priority in some applications [19], however it is sacrificed in other applications in order to preserve the topology of the pattern [18].

While many thinning algorithms have satisfying performances regarding connectivity and topology preservation, most of the algorithms are sensitive to noise [11,20]. Using a state-of-the-art thinning algorithm [21] to thin the noisy patterns in Fig. 3(a) gave the results in Fig. 3(b). Such noisy skeletons are a challenge for applications such as OCR [22], Content-Based Image Retrieval [19], and fingerprint recognition [7].

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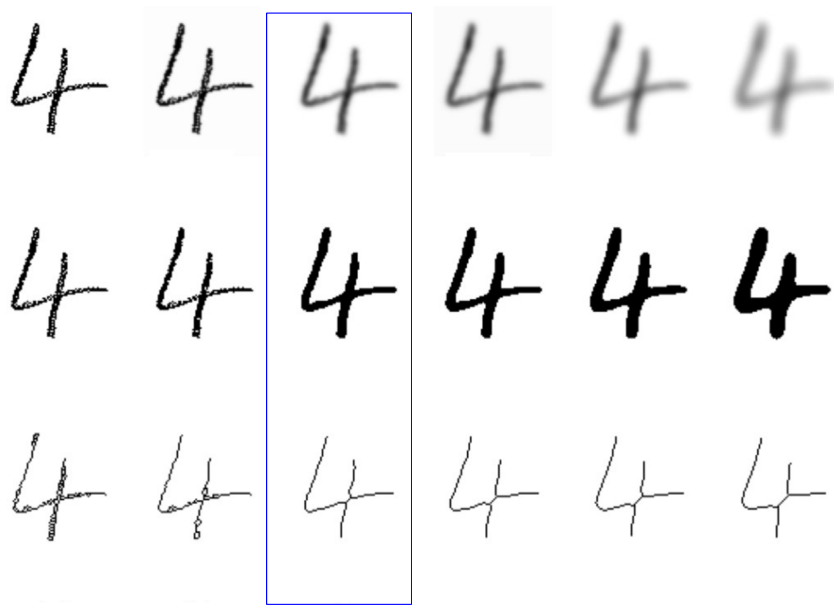

**Fig. 1.** Using scale space filtering in ATF: Images in the first row are results of different amount of filtering. Images in the second row are binarized images corresponding to the ones of the first row. Images in the third row are skeletons corresponding to binary images of the second row. ATF should be able to select the amount of filtering producing the best trade-off between noise removal and shape alterations, as shown in the blue box. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this article.)

In this work, we introduce a framework for making thinning algorithms robust against noise, using scale space filtering. Inputs of our method are hand-drawn binary images that are scanned or introduced using a computer graphics software or a tablet. We refer to this class of images as sketch images. Our method produces multiple representations of an input image within multiple scales of filtering. Then, the filtering scale that gives the best trade-off between noise removal and shape distortion is selected. For optimal scale selection, we introduce a performance measure that detects irrelevant artifacts caused by noise and shape distortions introduced by high amounts of filtering. The selection is automatic and done adaptively to each input image. Hence, we call our method Adaptive Thinning Framework (ATF). ATF is aimed to deal with the typical types of noise which exist in sketch images. They are contour noise, scratch and dithers.

The remainder of this paper is as follows: Section 2 is a state-of-the-art review. ATF is explained in detail in Section 3, and evaluated in Section 4. Section 5 concludes the paper.

## 2. Related work

Thinning algorithms received considerable attention with the emergence of pattern recognition applications requiring to transform an image to a compact form that preserves geometrical and topological properties.

Thinning algorithms for binary images can be categorized into sequential algorithms, parallel algorithms, and medial axis algorithms [1]. Sequential algorithms proceed by deleting iteratively contour points in a predetermined order, and hence are non-isotropic. Parallel algorithms deal with this limitation by making points deletion based on the result of only the previous iteration.

Medial axis algorithms produce a medial or central line of the pattern by line following methods or distance transform.

The parallel paradigm received more attention than the two other categories and many parallel algorithms have satisfying performances in preserving connectivity and topology [1]. In a typical parallel thinning algorithm, the image pixels are checked from top-left to bottom-right, and those satisfying certain conditions or matching specific templates are flagged. Then, when all pixels are checked, the flagged ones are removed.

We refer the reader to [1] for a comprehensive survey on thinning algorithms.

Most algorithms require a binary image as input [1,18–26]. In case of grayscale images, a binarization step is needed before applying the algorithm. Alternatively, several thinning algorithms that work directly on grayscale images without binarization have been introduced [27–31].

Despite the vast repository of thinning algorithms, sensitivity to noise remains an open issue [11,20]. Some attempts for making thinning algorithms robust against noise have been presented. In [23], Chen and Yu presented an entropy-based method for thinning noisy images inspired from the human vision process. Their method computes the circular range containing the maximal information for each pixel. A symmetry score of the pixels distribution in the circular range in then computed. The symmetry information is treated as a grayscale image which is then thinned to obtain the skeleton.

Chen and Yu's method has been reported to maintain good performances under reasonable noise levels [24]. However, it becomes vulnerable once the amount of noise is significant [25], and it is time-consuming [26].

Hoffman and Wong presented an algorithm for thinning both binary and grayscale images using scale space filtering [27]. Their algorithm generates filtered versions of an image, then it extracts the skeleton by finding the peak, ridge and saddle points in the grayscale filtered image. The extracted pixels are called "The Most Prominent Ridge-Line pixels (MPRL)" and used to form the skeleton. A MPRL pixel in the image scale space pyramid is a pixel such that all ridge-line pixels in its sub-pyramid have greater second derivatives. The quality of the skeleton in regards to noise depends strongly on a parameter that determines the minimum amount of smoothing to be applied on the image. This parameter has to be set manually by the user.

In a recent work [28], Cai introduced a thinning algorithm for thinning noisy patterns based on Oriented Gaussian Filters. The author dealt with contour noise present in handwriting and fingerprints, caused by pen perturbations and scanning documents and