# Vectorization of Cartoon Drawings

**Ju Jia Zou**[†] **Hong Yan**[†‡]

[†]School of Electrical and Information Engineering, University of Sydney, NSW 2006, Australia.
[‡]Department of Electronic Engineering, City University of Hong Kong, Kowloon, Hong Kong
Email: {jjzou,yan}@ee.usyd.edu.au

**Abstract**

This paper presents a non-pixel-based skeletonization method for vectorizing cartoon drawings. The constrained Delaunay triangulation technique is applied to subdivide a shape into a set of non-overlapping triangles. Then, certain triangles in the triangulation are merged to remove artifacts. The skeleton of a shape is obtained from the skeletons of its constituent parts. Experiment results show that the proposed method is more accurate and efficient than a typical thinning method.
*Keywords:* Skeleton, thinning, constrained Delaunay triangulation, cartoon, animation.

## 1 Introduction

The traditional cartoon film production is a labor-intensive operation. Thousands of frames need to be generated to produce a cartoon film. Traditional cartooning can be accelerated by introducing computer-support to the image-related stages, such as drawing, painting and in-betweening [Xie, 1995]. Automatic painting and in-betweening are often based on techniques of shape matching and interpolation. However, these techniques cannot be directly used in raster images, but are more suitable for processing vector-based graphics. Thus, a vectorization process is required to convert a raster-based cartoon image into a vector form.

An artist often uses pencils to make a cartoon drawing. Such a drawing is in essence composed of a set of elongated or line-like patterns which can be suitably represented by their skeletons. Skeletonization is a popular vectorization scheme for line-like drawings [Jimenez and Navalon, 1982]. In-between frames can be generated via interpolation by matching the skeletons of two key frames [Xie, 1995].

This paper is aimed at efficiently computing accurate skeletons from cartoon drawings. The method proposed in the paper is non-pixel-based. Specifically, the skeleton of a shape is computed by subdividing the shape into a set of non-overlapping triangles using the contour information. Skeletonization artifacts can be removed by merging certain triangles.

## 2 Triangulation

A shape is triangulated using the constrained Delaunay triangulation technique to obtain its skeleton. Assume that shape contours are approximated by polygons which can then be described by a planar straight-line graph (PSLG) $G = (V, E)$, where every vertex is a contour pixel, and every edge represents a contour segment. Given a PSLG $G = (V, E)$, a *constrained triangulation* of $G$ is a PSLG $G' = (V, E')$, where $E \subseteq E'$, such that no edge connecting two vertices of $V$ can be added to $G'$ without crossing an existing edge. Given a PSLG $G = (V, E)$, the *constrained Delaunay triangulation (CDT)* of $G$ is a constrained triangulation of $G$ where the circumcircle of each triangle does not contain in its interior any other vertex of $G$ which is visible from all vertices of the triangle. Two vertices of $G$ are *visible* from each other if a straight-line segment connecting them does not intersect an edge of $G$ at an interior point.

The CDT of an image consists of *internal* and *external* triangles. The interior of an internal triangle lies entirely inside the foreground of the image while the interior of an external triangle stays inside the background. An edge of an internal triangle is an *external edge* if it is a contour segment. Otherwise, it is an *internal edge*. Each internal edge of an internal triangle indicates that another internal triangle lies on the other side of the edge. There are four types of internal triangles (Figure 1). Different types of internal triangles represent different local structural information. An internal triangle without any internal edge is an isolated 'island'. It is called an *Isolated-Triangle (I-T)*. An internal triangle with one internal edge symbolizes an end of a branch because it is adjacent to only one internal triangle. Hence, it is called an *End-Triangle (E-T)*. A *Normal-Triangle (N-T)* is an internal triangle which has two internal edges. An N-T is adjacent to two other internal triangles. An internal triangle with three internal edges indicates that it is a confluence of three branches. It is called a *Junction-Triangle (J-T)*.

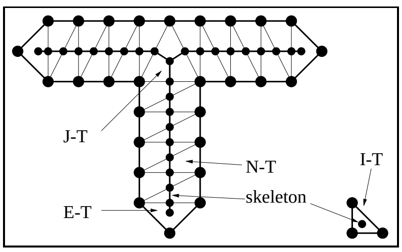


Figure 1: Internal triangles and their skeletons.

## 3 Skeletonization

A shape is partitioned into a set of non-overlapping triangles after triangulation. Thus, the skeleton of a shape can be obtained from the skeletons of the internal triangles of the shape (Figure 1). The skeleton of an E-T is a straight-line segment which connects the centroid of the triangle with the mid-point of the internal edge of the triangle. The skeleton of an N-T is

---

This paper appeared at the Pan-Sydney Area Workshop on Visual Information Processing 2000 (VIP2000), Sydney, Australia. 

a straight-line segment which connects the mid-points of two internal edges of the triangle. The skeleton of a J-T is a set of three straight-line segments where each connects the centroid of the triangle with the mid-point of one of the internal edges of the triangle. The skeleton of an I-T is the centroid of the triangle.

## 4 Artifact Removal

The skeleton of a shape obtained from CDT may contain artifacts. Skeletonization artifacts can be divided into two groups: periphery artifacts and intersection artifacts [Zou and Yan, 1999].

A peripheral skeleton branch is delimited by an end point and a junction point. A peripheral skeleton branch is a *periphery artifact* if it does not represent a perceptually significant branch of the underlying shape. The perceptual significance of a protrusion can be measured by the ratio $\gamma$ of the length $l$ of the protrusion to its width $w$: $\gamma = \frac{l}{w}$. If $\gamma < \gamma_{th}$, the peripheral skeleton branch is deleted and the internal triangles of the protrusion are merged. Otherwise, the skeleton branch is retained. $\gamma_{th} = 0.5$ usually gives satisfactory results.

An intersection of a shape is often split into two or more junction triangles after triangulation. A false skeleton branch is created between the centroids of two split junction triangles. Such false skeleton branches are called *intersection artifacts*. These artifacts are detected by comparing the orientation of joining branches, and removed by merging related triangles.

## 5 Experiment Results

The proposed skeletonization algorithm consists of the following steps: (1) Input a binary image; (2) Estimate the median width of each object; (3) Extract contours; (4) Approximate the contours by polygons; (5) Compute the CDT of the contours; (6) Remove artifacts; (7) Extract skeleton.

Each contour of a shape $S$ is approximated by a polygon whose edges except one have an equal length $l = 0.3\omega$ where $\omega$ is the median width of $S$. The exceptional edge has a shorter length. To estimate $\omega$, a shape is scanned horizontally and vertically. Then, a run-length histogram, which gives the probability of occurrence of the lengths of different black runs, is constructed. $\omega$ is a run length corresponding to the maximum value of the histogram.

Figure 2 shows a typical example of using the proposed skeletonization method. The thinning result using a much-cited method proposed by Zhang and Suen's [Zhang and Suen, 1984] is also included in the figure for comparison. It can be seen that the proposed method produces clean skeletons where artifacts have been removed effectively. However, Zhang and Suen's result contains a number of artifacts. Furthermore, the proposed method is much faster than Zhang and Suen's. Table 1 shows a comparison of the proposed method with Zhang and Suen's in terms of computation time. A Pentium II MMX processor with a clock frequency of 233MHz was used in the experiment.

| Image | Size (pixels) | Time (sec.) A | Time (sec.) B |
|---|---|---|---|
| Fig. 2(a) | 3860 × 2624 | 21.8 | 88.9 |

Table 1: Computation time. A: the proposed method. B: Zhang and Suen's method [Zhang and Suen, 1984].

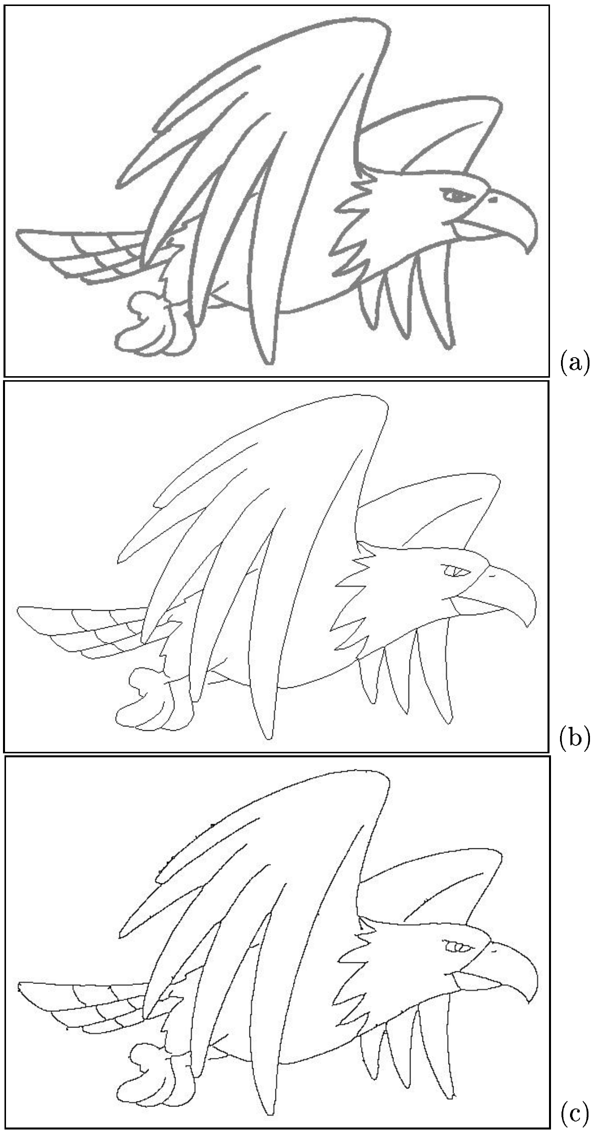


Figure 2: (a) A cartoon frame. (b) Skeletonization result using the proposed method. (c) Thinning result [Zhang and Suen, 1984].

## 6 Conclusion

Experiment results show that the proposed method can produce clean skeletons where artifacts are removed effectively. The method is fast when compared to a much-cited thinning method.

## References


[Jimenez and Navalon, 1982] Jimenez, J. and Navalon, J. (1982). Some experiments in image vectorization. *IBM J. Res. Develop.*, 26:724–734.

[Xie, 1995] Xie, M. (1995). Feature matching and affine transformation for 2D cell animation. *The Visual Comput.*, 11:419–428.

[Zhang and Suen, 1984] Zhang, T. and Suen, C. (1984). A fast parallel algorithm for thinning digital patterns. *Comm. ACM*, 27:236–239.

[Zou and Yan, 1999] Zou, J. and Yan, H. (1999). Extracting strokes from static line images based on selective searching. *Pattern Recognition*, 32:935–946.