1.1 Image modeling

Well established models [1] - [4] postulate that any natural image can be decomposed into several disjoint spatial regions, each one covered by a certain texture. An example of such decomposition is illustrated in Fig. 1. Despite of its widespread use, modeling an image as the union of disjoint areas, each one of which has constant texture inside, is too simplistic for at least two reasons:

- Slow texture changes are not taken into account. For example, the synthetic image of Fig. 2 has two different types of texture on its left and right sides, but it is not possible to trace a line that sharply separates them. Such gradual texture changes are very often present in natural images. For instance, the river in Fig. 1 presents several types of texture, but there is no obvious way to define boundaries between them.

- Texture boundaries bring poor semantic information. For example, if the boundaries of Fig. 1 (right) are presented to a human observer who has not seen the original image, he will hardly be able to understand the content of the image (namely, that there is a river with an island in the middle and a bridge that crosses it).

For these reasons, in this thesis we define contours as the set of all lines that a human observer would regard as essential in order to represent the seen objects. An example of defining

![Fig. 1. Left: a natural image taken from the Berkeley dataset [5]. Right: regions, drawn by a human observer, which are judged to contain the same texture.](image-url)
contours in such a way, rather than as simply texture boundaries is given in Fig. 3: human observers will judge the wires on the boat as «essential in order to represent the seen objects», though they are not being boundaries between textures. Another example is given in Fig. 4, which shows a contour map for the image of Fig. 1 (left). Differently from Fig. 1 (right), the binary map of Fig. 4 has been drawn without constraining contours to be texture boundaries. As we see, the contour map of Fig. 4 is much more informative than the one of Fig. 1 (right). Specifically, five observers, who have not seen the image represented in Fig. 1 (left), have been asked to identify the objects that should be present in the original image, by only looking at the contour maps. As a result, 100% of the observers identified correctly a larger number of objects for the contour map of Fig. 4 with respect to the one shown in Fig. 1.

Fig. 2. A synthetic image showing a gradual change in texture.

Fig. 3. A natural image. The wires of the boat do not separate different textures, yet they would be regarded as contours.
1.2. Scope of this thesis

From the above discussion it is clear that contours and texture play key roles in the interpretation of an image. However, people are able to understand the content of an image even when either contours or texture are partially missing. For example, the apple of Fig. 5 (left) is easily identifiable even though the contours are incomplete. Similarly, the scene represented in the watercolor painting of Fig. 5 (right) is clearly recognizable, though texture is missing or different from a photographic rendering of the same scene. Therefore, it is interesting to explore how far a computer can perform the same task, i.e., to preserve the content of an image while removing totally or partially its texture information.

In this thesis, this is done in two application fields: contour detection and artistic imaging. Concerning the former, contour detector algorithms are developed, which are inspired by several aspects of the both low and high level of the human perception, such as contour integra-

**Fig. 4.** A contour set for the image of Fig. 1 (left), for which contours are not constrained to be texture boundaries. This contour set is much more informative than the one of Fig. 1 (right). Unlike the one of Fig. 1, it allows to recognize and interpret the scene without the necessity to see the original image.

**Fig. 5.** Left: incomplete contours of an apple. Though the contours are not complete, people clearly recognize the object. Right: A watercolor painting (“Suzhou Canal”, from E. Taylor). Though texture is strongly reduced with respect to photographical images, people still recognize the content of the scene.
tion and edge grouping, rather than simply seeking for discontinuities in the texture attributes. As for the latter, algorithms for the automatic generation of painterly images are proposed, by removing texture while preserving edges, or by replacing the natural texture of the input image with a synthetic one.

1.3. Thesis outline

The rest of this thesis is organized as follows: in chapter 2, a survey of the state of the art in contour detection is presented. Specifically, contour detectors are divided in local and global operators. The former are mainly based on differential analysis, statistical approaches, phase congruency, rank order filters, and combinations thereof. The latter include computation of contour saliency, perceptual grouping, relaxation labeling and active contours. Important aspects are covered, such as preprocessing aimed to suppress texture and noise, multiresolution techniques, and connections between computational models and properties of the human visual system. An overview of metrics and procedures for quantitative performance evaluation is also presented.

In chapter 3, a biologically motivated multiresolution contour detector with Bayesian denoising and surround inhibition is proposed. Specifically, the proposed approach deploys computation of the gradient at different resolutions, followed by Bayesian denoising of the edge image. Then, a biologically motivated surround inhibition step is applied in order to suppress texture edges. We propose an improvement of the surround suppression used in previous works. Finally, a contour-oriented binarization algorithm is used, relying on the observation that object contours lead to long connected components rather than to short rods obtained from textures.

In chapters 4 and 5 Gestalt laws of proximity and good continuation are taken into account in order to further improve the contour detection process. Specifically, in chapter 4 a simple model for the gestalt law of proximity is proposed, which results in a totally unsupervised algorithm that groups points similarly to how human observers do. Groups are identified as the connected components of a Reduced Delaunay Graph (RDG) that we define in this chapter. A measure of dissimilarity between two different groupings of a given point set is introduced and used to compare the proposed algorithm with human visual perception and the k-means clustering algorithm.

This model is then extended in chapter 5 to the gestalt law of good continuation. Specifically, a new morphological operator, called adaptive pseudo-dilation (APD), is introduced, which uses context dependent structuring elements in order to identify long curvilinear structure in the edge map. The novelty of this operator is that dilation is limited to the Voronoi cell
of each edge pixel. An efficient implementation of APD is presented. The grouping algorithm is then embedded in a multi-threshold contour detector. At each threshold level, small groups of edges are removed, and contours are completed by means of a generalized reconstruction from markers.

In Chapters 6 and 7, links of edge detection and texture analysis with artistic imaging are explored. In particular, in Chapter 6 a simple and mathematically well-posed edge and corner preserving smoothing operator is presented. Unlike many existing approaches for edge preserving smoothing, the concerned operator is able to add an interesting artistic effect to the input image. In Chapter 7, a simple texture manipulation algorithm based on the theory of Glass Patterns is introduced for the purpose of painterly rendering. Specifically, a two-steps painterly rendering algorithm has been developed: first, natural texture is removed from the input image by means of an evolution of the edge preserving smoother developed in Chapter 6. Then, synthetic texture which simulates long curvilinear brushstrokes is added to the input image. Such synthetic texture is the result of extending to the continuous case the mathematical formalism related to Glass patterns, which originally are binary discontinuous 2D functions, while maintaining the same geometrical structure as in the discrete case.

Finally, conclusions are drawn in Chapter 8.

Bibliography


