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# Three-dimensional shape rendering from multiple images

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**Abstract**

A paradigm for automatic three-dimensional shape and geometry rendering from multiple images is introduced in this paper. In particular, non-photorealistic rendering (NPR) techniques in the style of pen-and-ink illustrations are addressed, while the underlying presented ideas can be used in other modalities, such as halftoning, as well. Existing NPR approaches can be categorized in two groups depending on the type of input they use: image based and object based. Using multiple images as input to the NPR scheme, we propose a novel hybrid model that simultaneously uses information from the image and object domains. The benefit not only comes from combining the features of each approach, it also minimizes the need for manual or user assisted tasks in extracting scene features and geometry, as employed in virtually all state-of-the-art NPR approaches. As particular examples we use input images from binocular stereo and multiple-light photometric stereo systems. From the image domain we extract the tonal information to be mimicked by the NPR synthesis algorithm, and from the object domain we extract the geometry, mainly principal directions, obtained from the image set without explicitly using 3D models, to convey shape to the drawings. We describe a particular implementation of such an hybrid system and present a number of automatically generated pen-and-ink style drawings. This work then shows how to use and extend

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well-developed techniques in computer vision to address fundamental problems in shape representation and rendering.
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## 1. Introduction

One of the strengths of non-photorealistic rendering (NPR) is that it can represent complex scenes using simple schematic drawings. A sketch-like picture obtained with NPR techniques emphasizes high level or salient perceptual features and at the same time effectively communicates shape and geometry. In producing computer generated NPR [11,37], principles of traditional drawing can be established and a number of these implemented as part of automatic rendering systems. From the rich variety of NPR depiction styles, we restrict the discussion to pen-and-ink style illustration (although the concepts here introduced are general and apply to other rendering styles as well). Pen-and-ink drawings can be reproduced by adequately placing individual strokes over the image. It is the combination of two basic illustration principles: *density* and *orientation* of strokes that conveys the desired appearance to the drawings. Changing stroke density we can represent different textures/lighting conditions, and strokes oriented along principal directions of objects in the scene effectively represent shape [10]. Producing a stroke-based representation of a scene has then two separate stages:

- *Feature and geometry extraction*—extract from the available input data the density and orientation values required to adequately represent the underlying scene.
- *Rendering*—draw a configuration of single strokes that achieves the density-orientation combinations specified in the previous stage.

The emphasis of this work is on the first stage. Stroke density information can naturally be obtained from images (as done here), while orientation information is traditionally obtained from 3D shape models. We propose to use computer vision techniques so that all the information relevant to the rendering process can be extracted from multiple images without the explicit availability of 3D models. This follows the tradition in computer vision of inferring critical 3D information without 3D reconstruction [8,14]. This has also been very influential in the graphics community (e.g., in the area of *image based rendering*) and it is starting to be used for NPR as well, e.g., [24].[1]

[1] We should note that this paper on multiple flashes is posterior to the work presented in this paper, see for example http://www.ima.umn.edu/preprints/nov2002/nov2002.html for early versions of this work.

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