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ScienceDirect
Computers & Graphics 31 (2007) 568–579
COMPUTERS & GRAPHICS
www.elsevier.com/locate/cag

Calligraphic Interfaces

Reconstructing the frontal geometry of drawings of arbitrary surfaces

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Abstract

We present a method for creating $2\frac{1}{2}$D models from line drawings of opaque solid objects. As input, we use a single drawing composed of strokes indicative of surface geometry, but not of texture, color or shading. We attempt to allow the artist to draw naturally, differing from many previous approaches. Our system allows both perspective and orthographic projection to be used and we make no *a priori* assumptions about the type of model to be produced (i.e. planar, curved, normalon). The frontal geometry of the input drawing is reconstructed by placing constraints at the contours and solving a 2D variational system for the smoothest piecewise smooth surface. An analysis of line labelling allows us to determine what constraints are possible and/or required for each input line. However, because line labelling produces a combinatorial explosion of valid output geometries, we allow the user to guide the constraint selection and optimization with a simple user interface that abstracts the technical details away from the user. The system produces candidate reconstructions using different constraint values, from which the user selects the one that most closely approximates the model represented by the drawing. These choices allow the system to determine the constraints and reconstruct the model. The system runs at interactive speeds.

Keywords: Artificial intelligence; Perceptual reasoning; Computer graphics; Computational geometry and object modelling; Document and text processing; Graphics recognition and interpretation

1. Introduction

Despite great advances in CAD modelling, designers overwhelmingly prefer to design with a pencil instead of a computer. In many professions, sketching is used exclusively in the early stages of design. Despite this, there are few sketch based modelling systems that allow the artist to draw naturally. They are typically forced to learn a set of drawing operators that are used as an interface to an underlying CAD system. Alternatively, previous methods that analyze existing drawings typically limit the type of drawings/models that are reconstructible to a very limited range of output models useful in manufacturing and CAD environments.

The principal goal of this work is to allow the artist to draw as naturally as possible, placing as few restrictions as possible on the structure and process of the input drawing and the form of the output model. The reconstructed model should be a close approximation of the artists intent. We briefly review how our system differs from previous work.

We allow the user to draw interactively, without having to learn any special rules, although we do limit the contours in our system to being representative of either the normal or depth discontinuities (and not, say, shading, color or texture) of an opaque solid object. Contours can be of any form, straight or curved. Because of this, we make no assumption about the type of model to be produced; most previous research limited the type of models that could be represented to either (1) polyhedral or normalon (all object faces parallel to one of the three coordinate axes), or (2) CSG-tree style construction of curved models. Allowing strokes to be drawn in any order yields an implicit construction method. This means that we place no limitation on the process by which the drawing is created, whereas the CSG-tree process requires an explicit construction sequence.

We relax the orthographic projection requirement that most previous research in this area imposes. While

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0097-8493/$ - see front matter © 2007 Published by Elsevier Ltd.
doi:10.1016/j.cag.2007.04.006

requiring orthographic projection is a simplifying assumption that eases certain computations concerning parallelism and angle determination it does not correspond with how artists actually draw. We reconstruct using a single view, as opposed to allowing sketches from multiple viewpoints as input, for the same reason.

Our system works as follows: the user draws into the screen buffer using a mouse or tablet/stylus. A piecewise smooth surface is created by applying constraints to a $2\frac{1}{2}$D mesh that lies over the domain of the drawing plane. The constraints are located along the input contours. We analyze line labelling techniques to determine the constraints that are possible for each contour. Because line labelling yields a combinatorial explosion of valid constraints (and, therefore, output models), we attempt to coopt the user's perception to find the correct constraint set. The system iteratively produces candidate reconstructions, testing different constraint options. From among these choices, the user selects the reconstruction that best approximates the desired output model. Successive user choices help to define a gradient through the space of constraints that the system searches through to find the correct set of constraints. The constraint selection mechanism is abstracted away from the user, in order to minimize the extra knowledge required to use the system. We attempt to demonstrate that a simple selection mechanism based on user perception is sufficient to find the correct constraints.

In addition to the benefits discussed above, here we outline our principal contributions. First, we present a new method for labelling line drawings based on the constraints each line defines for a surface. This allows for a more precise specification of the undetermined data at a line. Second, we present a method for determining the constraints for a line drawing using user guidance. We allow the user to make perceptual choices about tentative reconstructions to indicate constraint validity. We present a user interface that allows the user to interact with the program at a very high level, minimizing the details the user needs to understand about the system. We present a method of efficiently searching the space of all constraints by grouping constraints and using heuristics where possible. We present several novel heuristics that can be applied. Finally, we present a complete system demonstrating these techniques running at interactive speeds.

2. Related work

Inferring models from sketches has been extensively studied, therefore, we only present the work most closely related to this research. The reader should be familiar with the background material in [1–3], especially line labelling, in order to fully appreciate this paper.

2.1. Reconstruction methods

Reconstruction methods construct a model from an existing drawing. Most research in this area falls in the category of line labelling. See Company et al. [4] for a comprehensive overview.

Huffman [5] and Clowes [6] made the first successful attempt to catalogue the type of labels that could occur. They exhaustively catalogued all the vertices that could arise in line drawings of trihedral objects and then used this catalogue to derive labels for each line. Since only certain types of line labels may occur between specific junction types, global consistency in the labelling is forced by propagating requirements along adjacent edges. This yields all possible labellings for a drawing, using the assumption that only one label is possible for each stroke along its length. The Huffman–Clowes trihedral catalogue is well established but the limitation to trihedral surfaces is overly restrictive.

Mackworth [7] developed the concept of gradient space which allowed the labelling of drawings as polyhedral scenes. This method had the property of producing an excessively large number of labellings, many of which correspond to counterintuitive geometries.

Turner [8] presented the first method for producing labelling for curved line drawings but his catalogue of possible labellings at each junction was enormous. One junction type had 1905 possible labellings. Shapira and Freeman [9] considered cases where three faces meet at a vertex leading to a smaller junction catalogue. Malik [1] developed the first full theory of line labellings for piecewise smooth curved surfaces.

More recently, Lamb and Bandopadhay [10] and Varley et al. [11–13] have shown that normalons and regular objects composed of planar faces can be interpreted under certain restrictions. Orthographic projection is used to aid in line parallelism determination. In many instances, surfaces are assumed to be normalon. They have argued strongly that the assumption of regular angles can be used to reconstruct objects useful for engineers. The tradeoff is that they restrict the class of output models to those particular to a sub-domain of engineering.

Varley et al. [14] also demonstrated a method for reconstructing drawings of curved objects. First a user would create a line drawing of a polyhedral template corresponding to the curved drawing. Then the polyhedral template drawing would be inflated. The inflation was then used to guide reconstruction of the curved model. This method works well but requires a great deal of extra effort beyond the initial drawing creation.

Lipson and Shpitalni [15–17] presented a correlation based approach that was highly successful for polygonal objects. This approach established probabilities of the correct geometric interpretation of lines in a scene by analyzing actual drawings of simple geometric objects. This established a "dictionary" of probable interpretations which was consulted to establish the closest probable correlation of angles for all the lines and junctions in the scene. A linear optimization was performed to yield the depth inflation with the best cost determined using the lookup table. Shesh and Chen extended this paradigm with additional operators in [18].