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Efficient decomposition of line drawings of connected manifolds without face identification ☆

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HIGHLIGHTS

- Decomposes a complex drawing into its constituting simple manifolds.
- Does not require face information to achieve the task.
- Basic two stage strategy: basic decomposition and subsequent repair.
- Reduces the time for subsequent face finding and 3D reconstruction greatly.

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ABSTRACT

This paper presents an algorithm for decomposing complex line drawings which depict connected 3D manifolds into multiple simpler drawings of individual manifolds. The decomposition process has three stages: decomposition at non-manifold vertices, along non-manifold edges and across internal faces. Once non-manifold vertices and/or edges are found, the decomposition can be performed straightforwardly. Thus the major task in this paper is decomposition across internal faces. This has two steps: basic decomposition and repair of incomplete parts. The decomposition process is performed before face identification which is computationally expensive. After decomposition, the time for face finding is much reduced and this, in turn, greatly improves the process for 3D reconstruction, which is the ultimate goal.

1. Introduction

3D reconstruction from 2D line drawings has been an active research topic for decades. An early general 3D recovery method, the optimization-based method, was first proposed by Marill [1], and improved by Leclerc and Fischler [2], Lipson and Shpitalni [3] and Liu et al. [4]. This method can recover 3D objects true to human perception, but the performance is inconsistent, as the experiments of Lee and Fang [5] show. Most algorithms have two major components: face finding and 3D recovery. There are a number of algorithms reported for face finding. The algorithms of Lipson and Shpitalni [6], Liu and Lee [7,8] and Liu and Tang [9] have an exponential complexity over the number of input vertices, n, while that of Varley and Company [10] has a complexity of $O(n^5)$. Leong et al. [11] developed a face finding algorithm that is an improvement over existing methods in general, but still has an exponential worst case complexity.

The complexity of the actual 3D recovery is $O(n^3)$ [3]. Lee and Fang [12] proposed a different recovery method exploiting cubic corners, which are trihedral vertices with mutually perpendicular edges. The method also requires face finding, with the same accompanying time complexity, but its complexity for 3D recovery is linear over n. Whether one uses the optimization-based method, the cubic corner method, or their hybrid [5], it is clear that the lower the value of n, the better the algorithms perform. If a drawing with n vertices can be partitioned into m components each with an average of n/m vertices, then the overall complexity for face finding using the algorithm by Varley and Company would be $O(m^*(n/m)^5) = O(n^5/m^4)$, which is a lot lower. Hence, drawing partition is a useful preprocess to actual face finding and 3D object recovery provided, of course, it is sufficiently efficient itself.

This paper proposes a novel method for decomposing complex line drawings without requiring face information. It is important to note that vertices exist explicitly when edges in the same plane intersect and the decomposition is made at existing vertices and edges, without introducing any new ones.

We introduce here the special terms that appear in the rest of the paper. Fig. 1 shows the decomposition of a line drawing and illustrates some of the terms.

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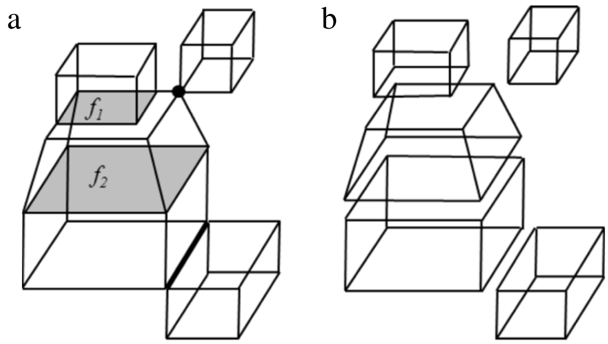

Fig. 1. Decomposition of a line drawing. (a) A line drawing of a non-manifold. The black dot is a non-manifold vertex; the bold black line is a non-manifold edge; the shaded polygons, f_1 and f_2, are internal faces. (b) Five simple manifolds are obtained by decomposing at the non-manifold vertex, non-manifold edge and internal faces.

Manifold: A manifold is a solid where every point in its surface has a neighborhood topologically equivalent to an open disk in the 2D Euclidean space [13].

Simple manifold: A simple manifold is a manifold that cannot be decomposed into simpler manifolds at existing vertices, along existing edges or across internal faces.

Complex manifold: A complex manifold is a manifold that can be decomposed into simpler manifolds at existing vertices, along existing edges or across internal faces.

Degree of vertex: The degree of a vertex is the number of edges meeting at the vertex.

Rank of edge: The rank of an edge is the number of faces sharing the edge.

Non-manifold vertex: A non-manifold vertex is a vertex where a non-manifold can be decomposed to produce multiple simpler manifolds.

Non-manifold edge: A non-manifold edge is an edge along which a non-manifold can be decomposed to produce multiple simpler manifolds.

Internal face: An internal face could be thought of as the face formed by gluing two faces of two manifolds together to form one manifold, and is thus internal to the combined manifold and is not a true face.

Isolated vertex: A vertex that belongs to only one simple manifold after the decomposition of a complex manifold.

Complete part: A complete part is a decomposed part that contains vertices with degree 3 or more.

Incomplete part: An incomplete part is a decomposed part that contains vertices with degree 2 or less.

The decomposition of a complex manifold or non-manifold must result in a collection of simpler manifolds and, in the best case, a collection of simple manifolds. There should not be any dangling edges containing vertices with degree 1 or faces containing vertices with degree 2. This is a condition that we use to check for the correctness of the decomposition, because a drawing with all its vertices having degree 3 or more can be considered as a manifold topologically [14,11].

2. Related work

There are four works in the literature on the partition of line drawings. Sun and Lee [14] analyzed the topology of a line drawing that may contain manifold and non-manifold entities. Manifolds may be joined at vertices or edges to form non-manifolds. Sun and Lee provided algorithms to determine the existence of such non-manifolds without actually partitioning them into simpler manifolds. Manifolds may be joined at faces, either fully or partly, resulting in internal faces. They also defined an internal face as a face with all its edges ranked higher than 2, and proposed that a line drawing may be decomposed along an internal face. But their definition is not complete; for example, the internal face f_1 in Fig. 1(a) will not be identified by their definition.

Chen et al. [15] proposed a divide-and-conquer method to recover 3D objects from line drawings. This method first decomposes a complex line drawing into multiple simple manifolds by using internal faces, which are identified in the face finding process. The decomposition of a manifold across an internal face produces two simpler manifolds. The decomposed line drawings are then recovered separately and the results are merged together to form the complete object depicted in the original line drawing. This method can handle complex objects more efficiently than other known methods. Even though the computation time for 3D reconstruction is much reduced in [15], face finding is still required, with its ensuing high computational cost.

Liu et al. proposed several properties that are used to identify an internal face in a line drawing [16]. The line drawing can be decomposed easily across the internal faces once they are identified. Xue et al. [17] proposed that a complex line drawing can be decomposed across "cuts". A cut is a planar cycle consisting of some edges of the line drawing and/or new edges. An internal face is a special case of a cut.

These two decomposition methods require knowing the faces beforehand. Therefore, the partitioning can reduce the time for 3D reconstruction but not for face finding, since the decomposition requires the faces to be found first.

In this paper, we further the work in [14] by providing improved algorithms for line drawing decomposing at non-manifold vertices and edges. The authors of [14] proposed that not only a complex manifold can be decomposed into multiple simple manifolds, but also a non-manifold can be divided into simple manifolds and dangling entities. In our paper, we focus only on the decomposition of line drawings of complex manifolds and non-manifolds formed by manifolds joined together. This is because the identification and removal of dangling edges and faces can be done straightforwardly, as Sun and Lee reported [14].

We also decompose a line drawing of manifolds across internal faces to obtain multiple drawings of simpler manifolds, all directly from the line drawing itself without finding faces first.

3. Decomposition

The inputs are line drawings which represent the projections of the wireframes of planar 3D objects in a generic view, in which all the edges and vertices are visible, no edges overlap and no edge is projected into a point.

There may be non-manifolds connected at a vertex or an edge, or a manifold connected at a face, as shown in Fig. 2. When the connection is at a vertex, the vertex is a non-manifold vertex, and has a degree of at least 6 [14]. When the connection is at an edge, the edge is a non-manifold edge, and each of its end vertices normally has a degree of at least 5 [14]. In the special situation when the non-manifold edge is collinear with another incident edge, an end vertex may have degree 4. When the connection is at a face, the face is called internal face [16].

The decomposition aims to produce a collection of simple manifolds, and the process has three stages according to the type of connection: decomposition at non-manifold vertices, non-manifold edges and internal faces. These stages are carried out sequentially. The decomposition here is along existing vertices and edges; it does not create or delete either. Therefore, the vertices and edges in each separated component are inherited from the original line drawing.