puter Vision and Pattern Recognition, Seattle, Wash., pp. 84-91, June 1994.

[15] J. Ponce, D. Forsyth, L. Shapiro, R. Bajcsy, D. Metaxas, M. Hebert, K. Ikeuchi, S. Sclaroff, A. Pentland, T. Binford, A. Kak, and G. Stockman, "Object representation for object recognition," *Proc. IEEE Conf. Computer Vision and Pattern Recognition*, Seattle, Wash., pp. 147-152, June 1994.

[16] G. Taubin, "Estimation of planar curves, surfaces, and nonplanar surface curves defined by implicit equations with applications to edge and range image segmentation," *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 13 no. 11, pp. 1115-1138, 1991.

[17] S. Ullman, "An approach to object recognition: aligning pictorial descriptions," Technical Report AI Memo No. 931, M.I.T. AI Laboratory, 1986.

Comments on "Efficiently Computing and Representing Aspect Graphs of Polyhedral Objects"

Aldo Laurentini

Abstract—This correspondence is originated by the definition of aspect given in a recent paper [1] on the computation of aspect graphs of polyhedra. Simple examples are presented which show that the data stored according to this definition can be unsuitable for identifying an object or its attitude through a topological match. A definition is suggested which does not incur the problems pointed out.

Index Terms—Aspect graphs, polyhedra, topological definition of aspect.

1 Introduction

In a recent paper, Gigus, Canny and Seidel define the aspect of a viewpoint as the topological graph structure of the image structure graph ISG(Section 2, The viewing data of a polyhedron). The ISG is defined as a labeled planar graph that corresponds to the line drawing of an object as seen from a viewpoint. The labels of this graph are related to the names of the edges of the polyhedron. It is also stated that two different viewpoints have the same aspect if and only if the corresponding ISGs are isomorphic.

A main point of the paper is to efficiently compute a partition of the viewing space into open regions such that the aspects of all the points of a region are the same. The above definition of aspect is suitable for this purpose.

Also the viewing data are stored by the authors in the aspect graph according to the same definition. The aspect graph is the dual graph of the partition of the viewing space; to each of its vertices is associated a description of a representative view. The description chosen by Gigus, Canny and Seidel is the ISG, and their paper presents an efficient algorithm for computing and storing these data(Section 9, Computing and storing the views).

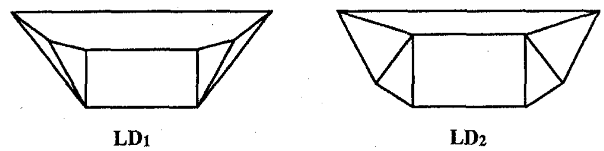


Fig. 1. The line drawings LD1 and LD2, whose corresponding graphs are isomorphic, are views relative to different attitudes of the same object.

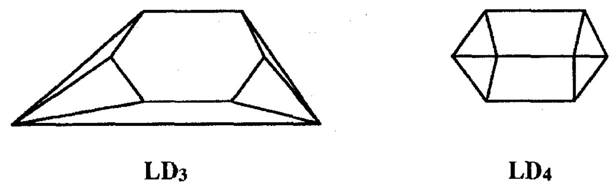
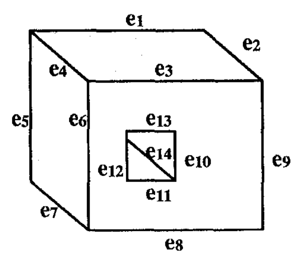


Fig. 2. The line drawings LD3 and LD4, whose corresponding graphs are isomorphic, are views of different objects.



$(e_3,((e_{12},-e_{14},e_{11}),(e_{14}-,e_{12},e_{13},e_{10})),e_9,e_8,e_6),(e_4,e_6,e_7,e_5),(e_1,e_2,e_3,e_4)$

Fig. 3. An aspect and its topological description.

The main utility ascribed to the aspect graphs, according to this and other papers [2] [3], is to provide a set of stored views of an object, actually all the topologically different views. The line drawing extracted from an image should be topologically matched against this set for identifying a polyhedron or its attitude. It is clear that the choice of the data stored determines which matches are possible. The purpose of this note is twofold: 1) to show with simple examples that the data stored according to the ISG definition can be unsuitable for topological identification; 2) to suggest a definition of aspect more effective for this purpose.

Let us observe first that the stored ISG data do not allow identification of one line drawing from another if the corresponding graphs are isomorphic (of course the labels are of no use for this purpose). Let us inspect the two line drawings LD1 and LD2 of Fig.1. The corresponding graphs are isomorphic, and therefore cannot be distinguished, but it is clear that LD1 and LD2 cannot be considered equivalent views. Actually, if we suppose that all the edges are visible in both views, it is easy to understand that LD1 and LD2 are views of the same object relative to different viewing regions. Let us consider now the line drawings LD3 and LD4 of Fig.2.

Also the graphs corresponding to LD3 and LD4 are isomorphic, but also in this case LD3 and LD4 cannot be considered equivalent views. Actually, if all the edges are visible in both views, LD3 and LD4 are views of two objects S1 and S2 with quite different shapes.

In conclusion, the inability of telling one isomorphic graph from another when they correspond to different views could prevent us from identifying the attitude of an object, as shown by the first example, or telling one object from an other, as shown in the second. It is worth observing that in many other papers on the aspect graphs the focus is on

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the computation of the partition of the viewing space, and the aspects are more or less loosely defined as topological descriptions of representative views.

It is not difficult to find purely topological definitions more suited for a topological match. For instance, we suggest the following definition, which also includes the information given in the ISG.

An aspect of a polyhedon S is specified as a set of polygons SP. The polygons of SP are all the polygons which can be extracted from a line drawing of S and do not enclose any other polygon of this line drawing, except for polygons belonging to not connected sub-drawings (which could represent polyhedral "holes" or "protrusions" in a face of S). Each polygon is identified by a set of edges, given in clockwise sequence starting from any vertex of the polygon. The edges are labeled as the corresponding edges of S. A minus sign before or after an edge of the sequence indicates that the edge is occluded by the previous edge or by the following edge respectively. The description of not connected sub-drawings will be enclosed in brackets and inserted into the sequence of edges representing the polygon containing the sub-drawing.

An example of description of an aspect according to this definition is shown in Fig. 3.

There is immediate verification that this topological description does not incur the problems outlined before. It allows the reader to tell LD1 from LD2, and therefore to recognize the two attitudes of the object. Also the descriptions of LD3 and LD4 result to be different. Since it can be easily verified that the set of aspects of S1 does not contains LD4, and that the set of aspects of S2 does not contains LD3, both LD3 and LD4 identify uniquely one of the two polyhedra.

Finally, let us remark that the algorithm of Gigus, Canny and Seidel is also able to efficiently compute and store aspects according the definition that we have suggested.

REFERENCES

[1] Z. Gigus, J. Canny, and R. Seidel,"Efficiently computing and representing aspect graphs of polyhedral objects," *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol.13, no.6, pp. 542-551, June 1991.

[2] H. Plantinga and R. Dyer, "Visibility, occlusion and the aspect drawing," *J. Computer Vision*, vol. 5, no. 2, pp.137-160, Nov. 1990.

[3] J. Stewman and K. Bowyer, "Creating the perspective projection aspect drawing of polyhedral objects," *IEEE Proc. Second Int'l Conf. Computer Vision*, New York, pp. 494-500, Dec. 1988.

MDL-Based Segmentation and Motion Modeling in a Long Image Sequence of Scene with Multiple Independently Moving Objects

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Abstract—This paper presents a method for spatiotemporal segmentation of long image sequences of scenes which include multiple independently moving objects, based on the minimum description length (MDL) principle. First, a family of motion models is constructed, each of which corresponds to a physically meaningful motion such as translation with constant velocity or a combination of translation and rotation. Then, the motion description length is formulated. When an object changes the type of the motion or a new part of an object appears, the corresponding temporal or spatial segmentation is carried out. Ambiguous segmentation of two consecutive images can be resolved by minimizing the motion description length in a long sequence of images. Experiments on several real image sequences show the validity of our method.

Index Terms—Long image sequence, spatiotemporal segmentation, motion estimation, MDL principle.

1 INTRODUCTION

SPATIOTEMPORAL segmentation is vital in order to analyze long image sequences of dynamic scenes. Spatial segmentation aims to extract differently moving objects from complex scenes. Temporal segmentation is to divide a complicated motion stream into temporal intervals of simple and stable motions. So far many methods of spatial segmentation have been proposed, which are based on the optical flow from two consecutive images (e.g., [1], [11]). However, the motion only from two views is not sufficient to obtain stable segmentation for complex scenes. The use of a long sequence has been studied. Generally, approaches to long sequence analysis can be divided into two categories. One is to consider the properties of the spatiotemporal pattern as a whole and to analyze the motion in the spatiotemporal space [6], [8]. The other is to process a motion sequence progressively, in which the previous result is well integrated for analysis at the current moment [5], [7], [2]. In [5], with the estimated motion parameters the image is registered so that the motion of the tracked object can be canceled. In [7], the intensity change of object in an image sequence is modeled by a spatiotemporal Markov-random-field. The spatial segmentation at each moment is performed based on the maximum a posteriori criterion. However, this method requires prior optical flow fields which are difficult to obtain. In [2], the extraction of the optical flow is avoided by representing the flow vector of each point with a 2D linear model. The progressive approach has the advantage of prompt processing so that it provides the possibility of real-time implementation. In this paper we adopt this approach and propose an MDL-based method.

The minimum description length (MDL) principle can be traced back to Occam's words in the 14th century, "*Entities should not be multi-*

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