IDENTIFICATION OF BODIES IN A CONTOUR IMAGE OF A THREE-DIMENSIONAL SCENE

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A procedure for identification of body projections. Constraints on the class of images to which this proceduere is applicable are formulated.

Introduction

The problem of identifying bodies on a contour image of a three-dimensional scene is stated as follows (see, eg.g. I). A list of the contour image regions is given (each region is assumed to be associated with an surface or part of a surface of a three-dimensional body). The list should be decomposed into sublists each containing all regions of one and only one body.

There are a number of heuristic algorithms for body identification (2). To formulate the objective of this research two specific features of almost all these algorithms should be noted.

The first is that the source data is information on the neighborhood of the regions, on types of graphical tracing of the nodes and on properties of large segments of lines (parallelism coincidence of lines when the segments are extended, etc.). The need in data on large segments of lines imposes rather stringent constraints on the quality of the contour image that in real life follow from the half tone initial image of the scene.

The second specific feature is uncertainty of image classes to which these algorithms are applicable. An algorithm is often found to be applicable to very complex images but may not work in simpler cases. To identify and describe an image class is difficult because the correspondence between the image, e.g. types of the node tracing, and types of object combination in space is not univalent.

The objective of this paper is to enable a researcher to isolate a class of images associated with certain simple types of object combination in space and develop for this class a body identification procedure which would use only the information on which regions are neighboring and on the types of graphical tracing of nodes.

Jettisoning the data on properties of large segments of lines necesitates formulation of further constraints on the class of images to be analyzed. This constraints are caused by the possibility of essential shortage of local data for solution of the problem posed rather than by the above nonunlvalence of the space mapping on the plane.

It will be assumed hereinafter that the initial contour image corresponds to a configuration of convex bodies with flat surfaces. Each body can be represented in a projection of any form with the sole constraint that no pair of the image line segment associated with two edges of one body merge into one line. We will assume that the entire initial information is given as a list of regions with indication of their neighborhood and a list of nodes with indication of the type of graphical tracing of each node and its belonging to a certain region.

The paper consists of three sections, Sect. I describes the class of images to be discussed and lists the properties of nodes of these images. Sect. 2 describes a procedure for identification of separate bodies and Sect. 3 formulates conditions under which the procedure solves the problem posed.

Description of the Class of Images

Types of Graphical Tracing of Nodes, A node is the intersection point of two or more lines of the image. The regions which intersect in the node will be referred to as regions of this node.

The classification of node tracing types is based on the values of the angles α_i formed by node lines which limit each its region. The nodes are subdivided into three types, L, T and Y:

L: there is an i such that $\alpha_i > 180^\circ$;

T: there is an i such that $\alpha_i = 180^\circ$;

Y: $\alpha_i < 180^\circ$ at all $i = I, \ldots, n$,

where n is the number of node regions.

Note that the intersections of the image lines with the image frame are not regarded as nodes.

A region of the L- or T - type node with an angle larger than or equal to 180° will be termed external and all other regions of these angles, internal.

Using the convexity and the constraint on the nature of projection mentioned in the Introduction one can prove that the image of the visible part of one body can have nodes of two types

1) Y-type nodes all regions of which are associated with the surfaces of this body;

2) L-type nodes whose internal regions are associated with surfaces of the body and the external one is the background.

This statement is quite sufficient for construction of a body identification algorithm for a simplest class of images, or images for which projections of separate bodies are separated by background areas. For more complicated cases analogous asertions are needed on relation of the node tracing with the properties of mutual disposition of bodies. What follows will be an attempt to describe possible types of mutual disposition and identify a class of images corresponding to some of these types.

Types of mutual disposition of bodies. Assume that the image consists of flat sheets; on each a complete visible surface of one body is drawn and the sheet itself is cut precisely along the boundary lines of that drawing. Each such sheet will be termed a complete projection of the body. The lines and nodes at its margins will be termed boundary lines and nodes of that projections and all other lines and nodes, internal. Owing to this the mutual disposition of bodies as far as its reflection on the image is concerned can be judged in terms of relations on a plane rather then in a three-dimensional space.

If the sheets are superimposed on each other then we will say that one complete projection overlaps another. The visible part of the overlaped complete projection of a body will be termed a projection. If the sheets merely touch by their boundaries we speak of projection attachment. If there is no such contact then the projections are referred to as isolated.

Let us consider versions of mutual diposition of complete projections only within a sufficiently small vicinity of nodes of a composite image. Let one complete projection (first) overlaps the other (second). Then all possible versions of overlapping can be classified into such versions (see Fig.I):

1) The boundary line of the first projection crosses the lines or touches the nodes of the second projection.

2) The boundary node of the first projection does not touch the lines or nodes of the second projection.

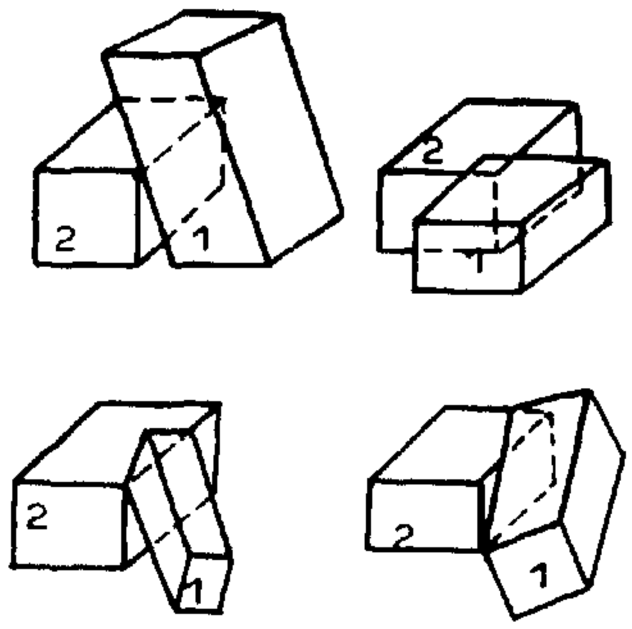

Figure 1

3) The boundary node of the first projection touches the internal lines or nodes of the second projection.

4) The boundary node of the first projection touches the boundary lines or nodes of the second projection.

This way of listing the versions can be extended to the case of any finite number N of the projections. To do this it is sufficient that the first projection be substituted with a totality of N-I projections (assuming they are drawn on one sheet) and second one, with the N-th projection .

<u>The Image class PI</u>

We will deal only with the first two versions of overlapping and with the case of isolated projections. These define a class of images which will be referred to as the cluss Pj. To be more exact, we will assume that the image, belongs to the class Py if it consists of isolated or mutually overlapping projections and in the vicinity of each node any overlapped projection is correlated with all projections covering it, according to the first two versions of overlapping.

An example of an inage of the class Pj is given in Fig.2.

By induction over the number of projection one can show that the images of the class P_T can have nodes of the types L, T and Y with the following properties:

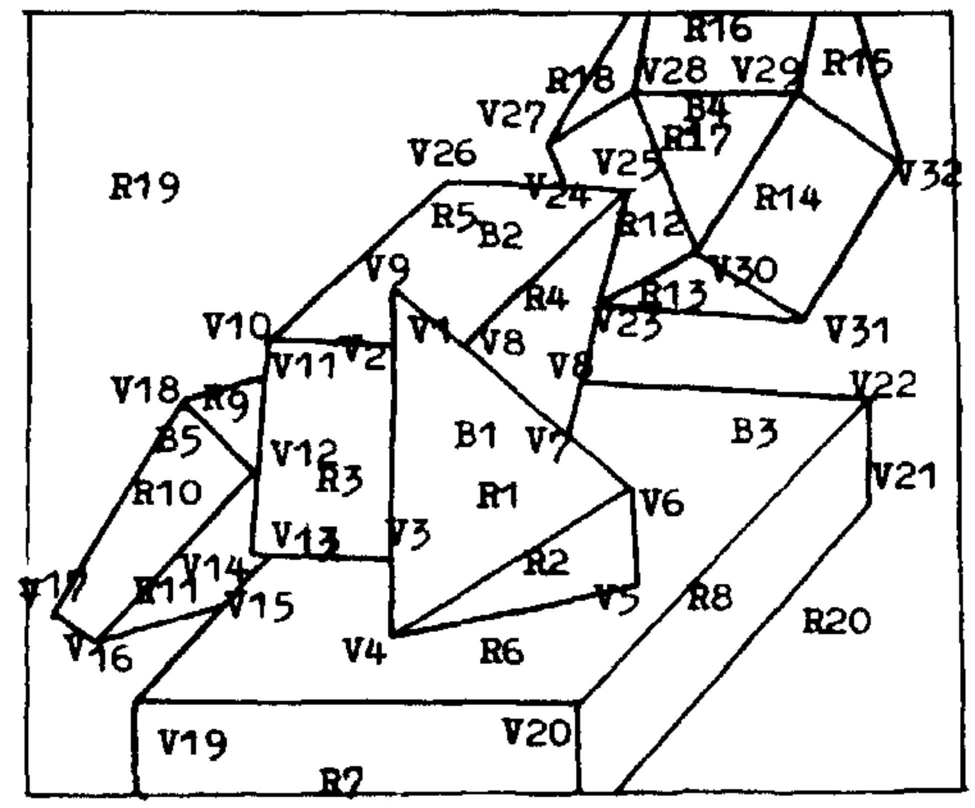

Figure 2

1) All internal regions of on L-type node belong to one (over-lapping) projection and the external regions belongs either to another (overlapped) projection or to the background.

2) All regions of the Y-type node belong to one projection,

3) The external region of a T-type node belongs to the overlapping projection whereas all internal regions, to overlapped projections (there be no more than two of these, one possibly being the background). These assertions are the core of the body projection identification procedure described in the subsequent Section.

<u>A body projection Identification procedure</u>

Let us assume that it is not known in advance whether the i.aage regions belong to the body projection or what regions belong to the background.

The procedure which will be described below is reduced to looking up all image nodes and to declaring that certain regions of each node belong to the background. Ti.is operation has been defined through a system of rules each being applicable to nodes of only one type of graphical tracing. The procedure includes cyclic application of this operation. At each of the subsequent cycles all projections are identified that can be assumed uncovered if the projections already identified are disregarded.

The procedure consists of five rules. These are ordered in the sense that each is applicable only if all preceding rules are inapplicable.

R.1. Declare the external region of an L-type node a temporary background.

R.2. Declare all internal regions of the T-type node temporary background.

R.3. If one of the internal regions of an L-type node has been declared temporary background, declare all remaining internal regions of that node temporary background.

R.4. If one of the regions of an Y-type node has been declared temporary background, declare all remaining regions of that node temporary background.

R.5. (cycle rule). Regard the totality of neighboring regions surrounded on all sides by the background (temporary or permanent) as body projection. Declare the regions of all identified projections permanent background. Eliminate the temporary background in all remaining regions and return to R.1.

The procedure ends when all regions of the image are declared permanent background.

As an example consider again the image of Fig.2. The course of the procedure is given in the Table.

Cycle	Rule	Nodes	Temporary background (regions)
I	I	4-6,9,10,14, 16-19,21,22, 25-27,31,32	5,6,11,12, 19,20
	2	1-3,7,8,11-13, 15,23,24	3,4,9,10,13
	3	19,22,27,31, 32	7,8,14,15,18
	4	28-30	16,17
	5		
Projections identified /R_I, R_2/			
2	1	10,14,16-19, 21,22,25-27, 31,32	11,12,19,20
	2	8,11-13,15, 23,24	6,9,10,13
	3	19,22,27,31, 32	7,8,14,15,18
	4	28-30	16,17
	5		
Projections identified /R_3,R_4,R_5/			
3	1	16-19,21,22, 27,31,32	19,20
	2	15	11
	3	16,18	9,10
	5		
Projections identified /R_6-R_8/, /R_{12}-R_{18}/			
4	1	16-18	19
	5		
Projections identified /R_9-R_{11}/,/R_{20}/			
5	5		
Projections identified /R_{19}/			

Consider the image of Fig.3. If the data on the properties of large segments of lines are not uded, then the projections B1 and B2 cannot evidently be identified. Hence it is necessary to formulate additional constraints on the class R1 so that the projections be separable. The nature of these constraints that will be formulated in the next Section is such that the linkage of regions through their boundaries should be completed with the linkage through nodes, Thus the projections Bj and B_2 In Pig.3 would be separable if there was no pyramids 1,2,3.

The condition for separability of body projections

Let us consider only the case where body projections can be ordered only in terms of "overlapping". A projection which is not overlapped by any other will be termed a first-order projection. By definition, a projection is of order i if it is not overlapped by any other projections except projections of order i - 1 and possibly by projections of orders from 1 through i - 2. The order r_j, of the region R_j will be the order of the projection to which it belongs. The order of a node will be the number equal to the least value of the order of its regions. ,

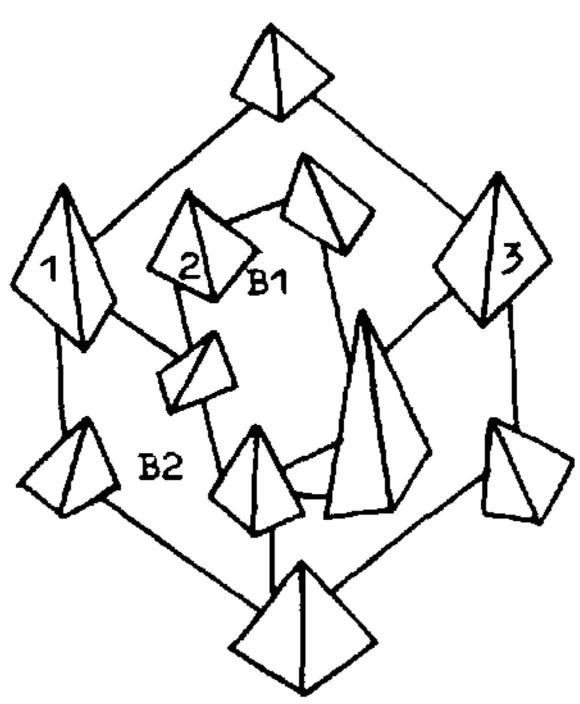

Figure 3

The set of neighbors W_j of the projection B . of order r_j will be a total!-ty of regions of order at least r_j+I neighboring with the regions of B_j. For instance, a set of neighbors of the projection B_2 in Pig.4 formed by regions R_6, R_7, R_8 and R_9.

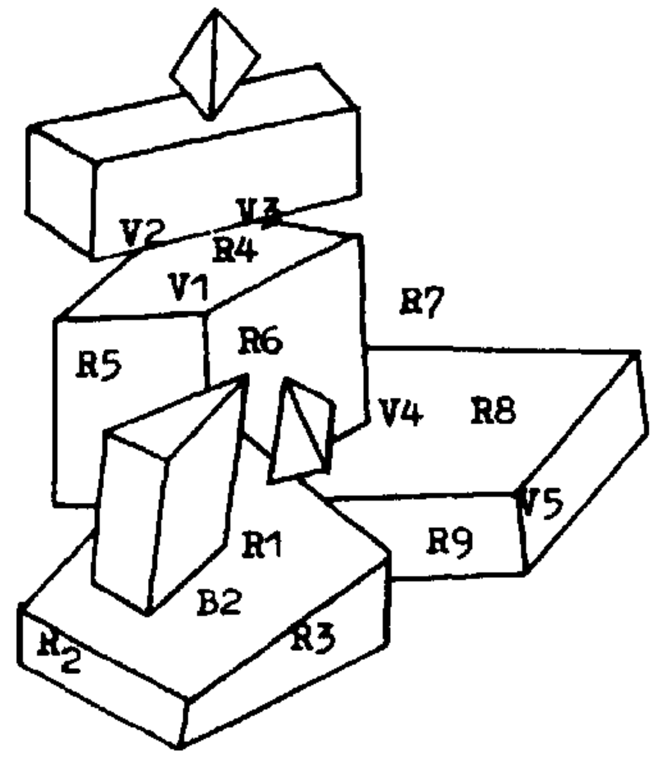

Figure 4

The projection separability condition is formulated through the concept of regions linkage. This concept is defined below.

Let the regions R_j and R_k be of order r_j and r_k respectively with $r_j \leq r_k$.

Definition I.

The regions R_j and R_k have linkage of order r if they are regions of the same node V of order r(V)=r. The linkage is belateral if $r_j = r_k$ or $r_j < r_k$ and $r < r_j$. The linkage is unilateral and directed from R_j to R_k, if $r_j < r_k$ and $r = r_j$.

For instance, in Fig.4 the pairs of regions $/R_4, R_5/$ and $/R_5, R_6/$ have belateral third order linkages (see node V_1). The region R_7 has a belateral linkage with the region R_4. This is a second-order linkage since $r_4=3$, $r_7=5$ and $r(V_2)=2$. The region R_6 has unilateral linkage wuth the region R_8. This is a third-order linkage since $r(V_4)=3$.

Definition 2.

We will say that the regions R_j and R_k are r-linked if there is a sequence of regions $R_1, \dots, R_n$ such that between each pair of regions $/R_j, R_1/$, $/R_1, R_2/ \dots /R_{n-1}, R_n/$ $/R_n, R_k/$ there is at least one belateral linkage of order r and higher.

The region R_j is r-linked with the region R_k if, in addition to this condition there is at least one pair with a unilateral linkage and orders of the linkages are the same.

For instance the region R_4 in Fig.4 is unilateral three-linked with the region R_9 (see the sequence R_4, R_6, R_8, R_9).

Definition 3.

The set of regions $/R_1/, ..R_n/$ fcrm an assembly of order r if there is a subset Z of these regions that is called the kernel and is such that any region of Z is r-linked with each of the regions $/R_1 ..., R$ /. The kernel is called eigen-kernel if it coincides with $/R_1 ..., R_n/$. The nuber n is the assembly size.

Definition 4.

A set of assemblies is called the coverage of a set of regions $/R_1 ... R_n$ / if each region R_j is contained in at least one assembly and each assembly contains at least one region from $/R_1 ..., R_n/$.

In Fig.4 the regions $/R_7, R_5, R_4, R_6$, RQ,RQ/ form a second-order assembly with the kernel /RrnRctR*. ?**£/• This assembly is the coverage of the set of neighbors of the projection B-.

Let a projection B_j of order r_j and a set of its neighbors be given.

The projection B. is said to satisfy the separability^condition if there is a coverage S.K/S- f...,S, / of a set of neighbors W. by assemblies of order at least r_j such that for each assembly there is a pair of regions R'£B. and R"CS^ (where S, is the kernel of the assembly S.) such that R' is unilaterally r.-linked with R".

Let N be the maximal order of projection in the image . If each projection of order i is an assembly of order i or i-1 with eigen kernel and satisfies the separability condition, the above procedure will identify all projections in the order of their coverage. Note that first-order projections always meet the separability condition and are first-order assemblies. Therefore these projections will be necessarily identified.

References

1. Gasman A. Decomposition of a visual scene into there-dimensional bodies. In "Automatic interpretation and classification of images". A.Grasselli (ed.), Academic Press, New York, London, 1969, pp.243-276.

2. Vainstein G.G., Zavalishin N.V., Muchnic I.B., Processing of visual information by robots (survey). Automation and Remote Control, N 6, 1974.