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Combining Contour and Region Information for Perceptual Grouping

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Abstract. Both contour and region segmentation have their own advantages and drawbacks. In this work we propose to combine contour approximation and contour-based groupings with region segmentation to enhance both contour- and region-based interpretation of the image data. Contour segments and regions are matched based on the distance between contours and region boundary. This information is used to hypothesise alternative regions and to generate additional closed contours within the contour-based grouping process. Initial results for real images are presented.

1 Introduction

The human visual system uses different types of visual cues for perception. Regarding computer vision, Sanocki, Bowyer, Heath and Sarkar [SBHS98] discuss the question, "Are edges sufficient for object recognition?". Their conclusion is, that contour information alone is not sufficient and they propose to use other sources of information like regions, surfaces or intermediate-level structures beside edge information to constrain each other.

Several algorithms have been developed to combine region techniques and edge based techniques to improve image segmentation. Pavlidis and Liow [PL90] apply criteria regarding contrast, gradient variation, and artefacts along region boundaries to verify and eliminate boundaries obtained from an oversegmenting split-and-merge method. In a similar way, [XAW95] uses the results of edge detection to verify and correct region boundaries generated by region-growing. The approach of [XYJ92] integrates gradient information into a region growing process. In contrast, [PFV96] proposes a method to create a fully connected line-drawing from an edge segmentation using a stochastical region growing. Other approaches using similar combinations of region and edge segmentation can be found in [BB92] and [Koh95]. While these approaches employ different region and edge detection techniques, all of them rely on pixelbased combinations of segmentation results.

Our proposal is to combine contour and region segmentation, where contours are represented by parametric models like lines, circular or elliptical arcs, because

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contours contain more abstract information about the global structure of the image. We describe, how the combination of region and contour segmentation can resolve incorrect segmentation results of both techniques and therefore support and constrain each other.

2 Contour Segmentation and Grouping

In this section we give an overview of the contour-based segmentation and grouping we use as a basis for the combination with a region segmentation. For the initial contour segmentation we use a standard Sobel operator and subsequent thinning with non maximum suppression and hysteresis threshold. The resulting edge elements are approximated with straight line segments and elliptical arcs with the method of Leonardis (see [Leo93]).

To overcome fragmentation and to obtain more abstract image primitives these contour segments are subsequently organised within a hierarchy of grouping hypotheses (see fig. 1) using various Gestalt laws. In the lowest level contour segments are combined to form collinear and curvilinear groups which are again approximated with straight line segments or elliptical arcs. Theses groups as well as the initial contour segments are denoted as *linear groups* subsequently. In addition, pairs of contour segments or linear groups may form a proximity grouping if their endpoints are spatially close. The next 2×1D level which is not considered further in the rest of this article deals with pairs of symmetric or parallel linear groups. To generate hypotheses within the 1D and 2×1D level of the hierarchy we employ the concept of *Areas of Perceptual Attentiveness* which are derived from a hand labelled training set (see [MP95]).

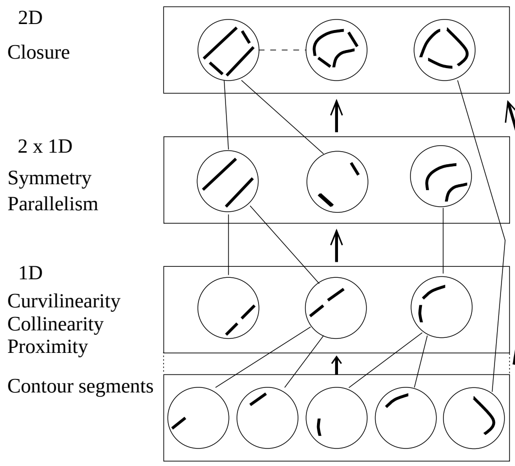
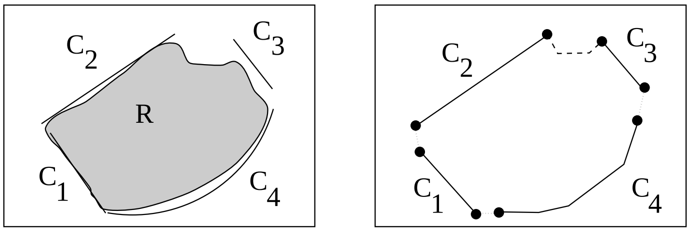


Fig. 1. Hierarchy of grouping hypotheses: Each group is depicted as a circle, some examples of part of relations are given as thin solid lines. Thick arrows show the data flow of the generation of hypotheses according to the hierarchy.

The last level organises linear groups into closed contours. To this end we construct an undirected marked graph from all linear groups hypothesised. This so-called *proximity graph* for a synthetic example is depicted in figure 2. Both endpoints of each linear group yield a node of the graph and both are connected by a *contour edge* representing the underlying contour. In addition, for each proximity grouping the two appropriate endpoints of both linear groups are connected by a *proximity edge*. In this graph a closed contour corresponds to a simple cycle with an alternating sequence of contour and proximity edges. In addition the underlying contour segments as well as the gaps between endpoints bridged by proximity edges may not intersect. To check for intersections, proximity edges are modelled as straight line segments between the endpoints and elliptical arcs are approximated with a polygon. In [HW91] and [UE96] contour segments are also represented in a graph to search for closed or longest paths. However, they model each contour segments as one node and therefore have to distinguish different types of edges for each node.



(a) (b)

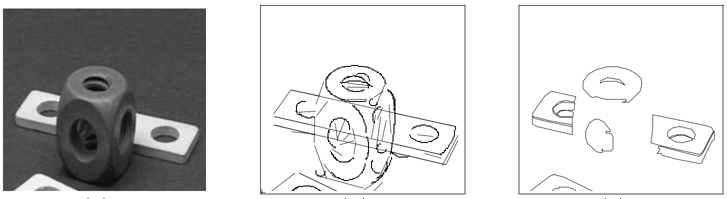
Fig. 2. (a) Synthetic region and contour segmentation; (b) Sample proximity graph: nodes are displayed as black circles, contour edges corresponding to contour segments with solid lines; for C_4 the polygonal approximation used to check against intersection is depicted; proximity edges from contour based grouping are shown with dotted lines, while the proximity edge connecting C_2 and C_3 derived from region information is shown as a dashed line (cf. section 3).

The generation of these grouping hypotheses within the hierarchy relies on local evidence of the image data only. Therefore, all hypotheses are subsequently judged in a more global context using a Markov Random Field. For details on this global judgement and the generation as well see [MPSS97].

The approach to combine contour and region information proposed in this work is based as well on grouping hypotheses and as on judged groups and will be described in the following section.

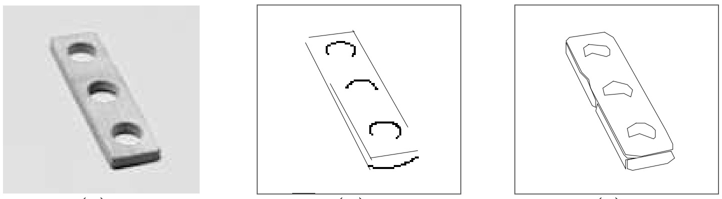
3 Approach

The aim of our approach is to resolve the drawbacks inherent in both segmentations by combining them. A typical drawback of region segmentation is depicted in figure 3. The region segmentation fails to segment the wooden bar as one region, because it is partially occluded by the cube: the segmentation produces two disconnected regions for the upper surface (fig. 3(c)). The collinear groupings connect the fragmented contour into linear groups (fig. 3(b)) and a closed path of linear groups for the surface of the bar is found within the proximity graph. Based on this closed contour and information, that the contours are nearby the underlying region boundaries, an alternative region can be hypothesised merging both regions of the surface. Another situation occurs if two wooden bars do overlap. Region segmentation techniques inherently tend to generate one region for both bars, because their projection in the image is of homogeneous colour



(a) (b) (c)

Fig. 3. (a) Image with parts of BAUFIX toys (cube and wooden bar), (b) contour segmentation and linear groups, (c) region segmentation depicted as closed polygons: some regions of the cube have been deleted to focus on the regions of the bar



(a) (b) (c)

Fig. 4. (a) Image of a wooden bar, (b) contour segmentation and linear groups, (c) region segmentation (depicted as closed polygons)

and the inhomogeneities at the boundary between both surfaces are usually insufficient for separating them. In this case the linear groups and detected closed contour paths for the surfaces of the two bars support a separation of the region into the correct surface projections of the bars. For contour segmentation, a characteristic disadvantage is shown in figure 4. The contour segmentation fails in situations where the gradient magnitude is not sufficient to locally support a discontinuity in the image (see lower right corner of the bar in fig. 4(a,b)). However, the region segmentation detects the boundary of the surface of the bar (fig. 4(c)). This is due to fact, that region segmentation tries to detect homogeneous areas in an image using more global information to segment the image, whereas the contour segmentation uses only local image data to detect discontinuities in an image. In this situation the region boundary can help to close a path of linear groups in the proximity graph traversing the boundary to find the next linear group near the region boundary (see figure 2 for a similar example, where region information can be used to close a path between C_2 and C_3).

These two example show how we use a combination of region and contour segmentation including linear groups to support and constrain each other. Our focus is on the latter case and will be described in detail in section 3.3. Some initial results concerning the former case are presented in section 4.

3.1 Notation

The combination of the two different segmentation techniques requires an appropriate representation. For both results, we use a polygonal representation, since this uniformity gives an efficient means to calculate various measures.

A linear contour groups is denoted as C and represented by open polygons $poly(C)$. To this end, elliptical arcs are approximated with appropriate polygons. The results of region segmentation are represented by closed polygons $poly(R)$ for each region R, approximating the region boundary.

3.2 Matching linear groups to regions

In the following we assign each linear group to one region if both probably belong to the projection of the same 3D-surface. Therefore each linear group is tested against all regions to find the region with minimum distance between its boundary and the linear group. To find the best matching region R for a given linear group C the sum of the minimum euclidean distance $d(v, poly(R))$ of each vertex v in the contour polygon $poly(C)$ to the region polygon $poly(R)$ is calculated[1].

$$d_{sum}(R, C) = \sum_{\forall v \in poly(C)} d(v, poly(R))$$

To enhance the efficiency of the calculation, the test is only applied to regions intersecting a neighbourhood around the linear group. The region R with minimum $d_{sum}(R, C)$ is established to match the linear group C. This selection only establishes a relation between a linear group and a region, where linear groups must not approximate the region boundary but can also be based on structure inside or nearby the region.

The correctness of each match is judged by three measures. The first and second measures are the euclidean distances $d_{start}(R, C)$ and $d_{end}(R, C)$ of the endpoints of the linear group to the region boundary. To compute an estimate of the average distance between the linear group and the region boundary, the polygon of the linear group $poly(C)$ is projected onto the polygon of the region $poly(R)$. The area A between the projection and the contour polygon is calculated. The third measure is then defined by: $d_{avg}(R, C) = \frac{A}{length(C)}$, where $length(C)$ is the length of the contour segment (see figure 5). This gives an estimate for the average distance between both polygons.

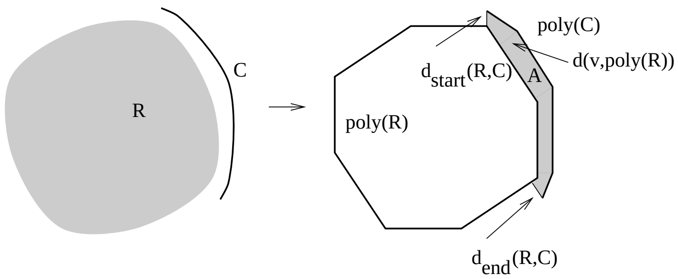


Fig. 5. Matching of contour C to region R

[1] We do not have to normalise the sum, since the number of vertices in $poly(C)$ is constant for the test against all regions R_i.

3.3 Using matches to detect closed paths of contours

We now describe how these matches can be used to generate cycles of linear groups even if the proximity information of the grouping process is not sufficient.

The search for closed paths of linear groups may fail in situations, where a proximity relation between two linear groups is missing to close a path. These situations can be resolved using the information which linear group match a region: In figure 2, the path $C_1 - C_2$ can not be closed to $C_3 - C_4 - C_1$, due to the missing contour based proximity information between C_2 and C_3. However, we can use the matching of C_2 and C_3 to the same region R to complete the path along the region boundary. We call this a *region based proximity* between the endpoints of C_2 and C_3. The following describes this idea in detail.

For this process matches between linear groups C and regions R are only considered, if the following condition is valid:

$$d_{avg}(R, C) < \theta_{err} \quad \wedge \quad d_{start}(R, C) < \theta_{dist} \quad \wedge \quad d_{end}(R, C) < \theta_{dist}$$

This insures a sufficiently small distance between the matching linear group and the region boundary. For each region all assigned linear groups are linearly ordered around the region. This order is defined by the projected start- and endpoints of the linear group onto the region polygon. Thus, for the endpoint of one matching linear group, the start of the next matching linear group $\tilde{C}$ can be found along the region boundary of the same matched region R. Adding region based proximities to the proximity graph for perceptual grouping of contour segments is controlled by the distance of the endpoints of C and $\tilde{C}$. Only if the distance between the endpoints of C and $\tilde{C}$ along the region boundary of R is smaller than the length of both segments and there is not already a proximity edge in the graph between them, a new region based proximity edge is inserted. These edges are used in the same way as proximity edges are used in the proximity graph as described in section 2.

4 Results

In this section we give results for using region information to enhance the quality of closed contours detected within the proximity graph and first results using this approach to generate alternative regions.

Figure 6(a) shows a typical scene of our domain, a wooden toy construction kit. The initial contour segmentation including the linear groups is displayed in figure 6(b), the region segmentation using Island-Growing and subsequent Sequence-Region-Growing for one frame (see [BP97]) in figure 6(c). Closed contours generated from the proximity graph without region information are shown in 6(d). Figure 6(e) shows in addition the closed contours generated using region information. Important structures for one of the bars and one of the cubes as well as for the tyre are generated combining contour information with region based proximities. Similar results have been detected for other images. Table 1 summarises runtimes for segmentation, grouping, and combining both segmentations. The main difference in the runtime of 2D-grouping is due to the

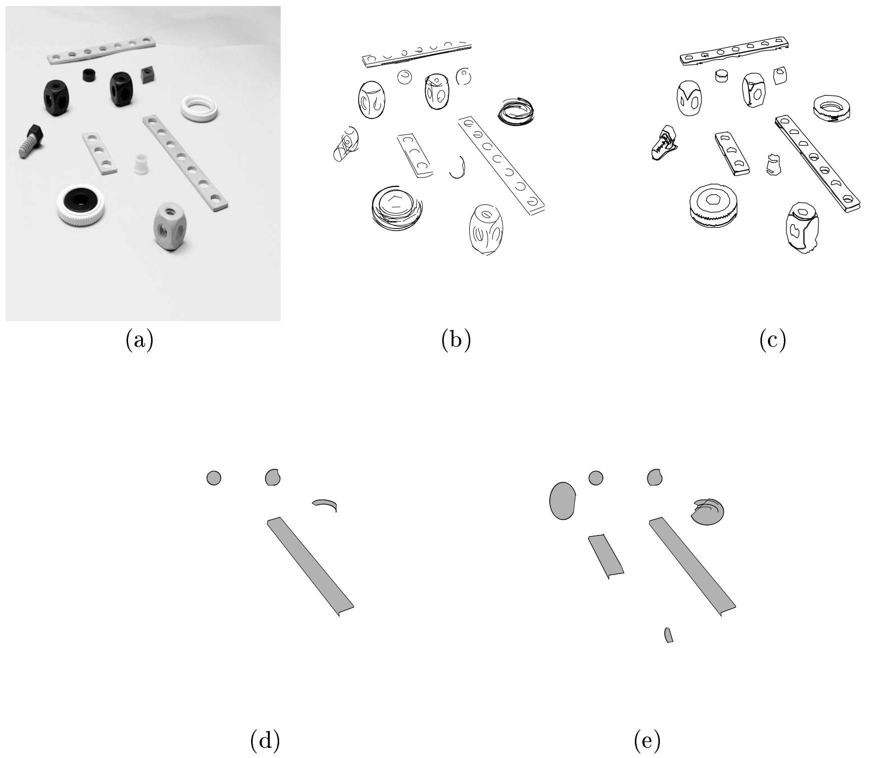


Fig. 6. (a) Image of a wooden toy construction kit; (b) initial segmentation and linear groups; (c) region segmentation; (d) hypotheses of closed contours without using region information and (e) with region information

<table>
<tr><td rowspan="3"></td><td colspan="2">Contour</td><td colspan="3">Grouping</td><td>Region</td></tr>
<tr><td>Sobel +</td><td>Approxi-</td><td>1D</td><td colspan="2">2D</td><td rowspan="2">Segmentation</td></tr>
<tr><td>Thinning</td><td>mation</td><td>contour</td><td>contour-based</td><td>contour+region-based</td></tr>
<tr><td>Time</td><td>748 ms</td><td>9164 ms</td><td>916 ms</td><td>50 ms</td><td>332 ms</td><td>1410 ms</td></tr>
</table>

Table 1. Runtime on Alpha 500/400MHz for image in figure 6(a)

matching of linear groups to regions ($\sim 80\%$). The contour-based approach uses 135 proximities to generate 4 closed path of linear groups, while the contour- and region-based approach uses 39 additionally region-based proximities to generate a total of 9 closed paths (3 overlapping closed paths for the tyre). As parameters we use $\theta_{dist} = 5$ and $\theta_{err} = 10$.

Figure 7 shows a typical situation in which region segmentation fails to generate separate regions for the surfaces of the two overlapping wooden bars (see fig. 7(c)). Using significant, i.e. well judged, linear groups and closed contour paths (see [MPSS97]), and the information about matching regions with contours (fig. 7(d)) we get evidence to separate the underlying region. Therefore we propose alternative regions from closed contour paths, in which most of the constituting linear groups match to the same region. Figures 7(e), (f) show only a subset of alternative regions. There were also some for the projection of the

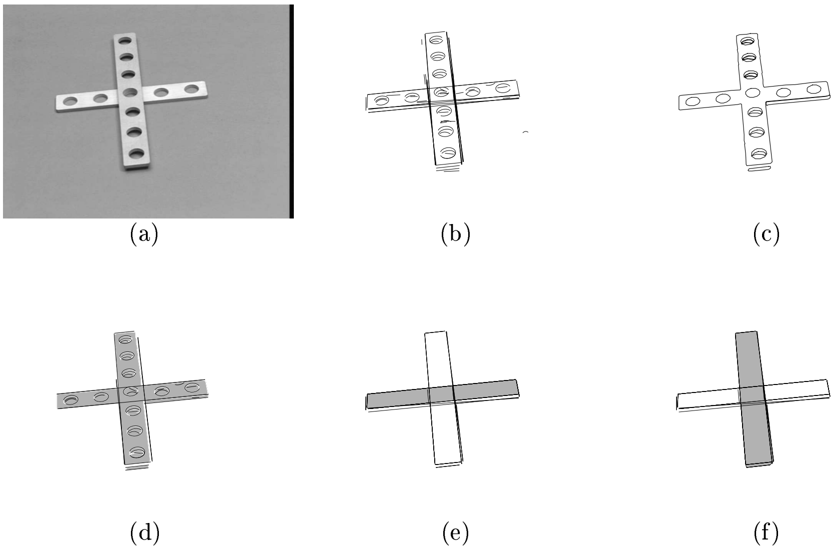


Fig. 7. (a) Image of a wooden toy construction kit; (b) initial segmentation and linear groups; (c) region segmentation; (d) region segmentation and matched linear groups; (e) , (f) subset of alternative contour-based regions generated in the proximity graph

3D-surfaces, e.g. two regions for the projection of the lower bar, and some incorrect ones, grouping the lower bar with the bottom part of the upper bar into a T-region. To generate the matches in this context we use $\theta_{dist} = 7$ and $\theta_{err} = 30$.

5 Conclusion

In this paper we propose to combine region- and contour based segmentation at a level, where contour segments have been approximated with straight lines and elliptical arcs and are already organised into more abstract linear groups and closed paths. Each linear group is matched to one region based on minimum distance of the underlying polygons. These matches are used to generate alternative region hypotheses in cases where the projection of one 3D surface decomposes into several regions or where projections of different 3D surface are merged because of homogeneous pixel values. Alternatively, the matches are employed to insert edges into the proximity graph of linear groups to add proximity information which is missing due to low local contrast during edge detection. Results for real images show significant improvements of the generated closed contours with only small computation overhead. Current work is concerned with realization of the former case and parameter selection.

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