DRAFT VERSION OF PAPER SUBMITTED TO DICTA'93: Morphology

Parallel Algorithm for Gray-scale Image Segmentation

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Abstract

One of the classic algorithms of mathematical morphology is the image segmentation algorithm of Rosenfeld-Pfaltz. This algorithm as presented was only applicable to binary images, although Cohen has previously presented an extaension to gray-scale. This algorithm in its "sequential" form, seeks to mark with a common label all connected pixels in an image, where the connectivity actually used in practice is 4-connectivity or 8-connectivity. The algorithm is not simple to parallelise in principle, as pixels in a subregion may be only connected via a chain of connected pixels in several other sub-regions. We present here a parallisable algorithm for segmenting into regions images of multiple gray-scale.

Introduction

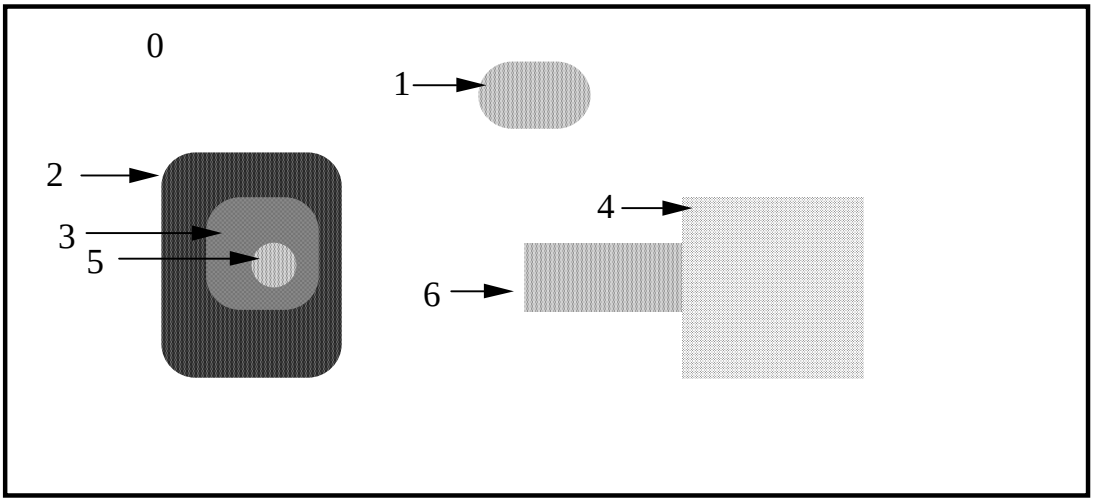
The segmentation of image raster data into connected regions of common gray-scale has long been seen as a basic operation in image analysis. In texture analysis, just this type of segmentation is possible after individual pixels in an image have been labelled with a numberic classifier. [4][5] In preparing images for used in geographic information systems (GIS) this segmenattion is usually followed by the production of a vector representation for each region.

The original algorithm for segmentation, developed by Rosenfeld-Pfaltz, [1][2] described a two pass 'sequential algorithm' for the segmentation of binary images. In this paper a one-pass algorithm is presented for the segmentation of gray-scale images. At the end of a single raster scan through the image each pixel is assigned a region index, the index being a pointer to a region table. A simplification of the same approach yields a one-pass version of the original Rosenfekd-Pfaltz algorithm.

Traditionally, in image analysis and computer vision, by segmentation is meant the LABELLING of pixels as belonging to the same region, where the classification criteria for a pixel to belong to a particular region are

- common colour or gray-scale (or near enough)
- membership of common texture region

To clarify concepts consider the following toy example;

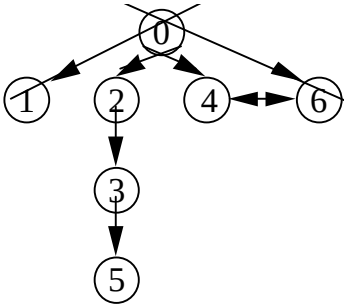


In this image the regions have been labelled. The segmentation task that we are concerned with are

- The labelling of each pixel with a region label.
- The determination of same start pixel for each region
- The specification of ADJACENCY and NESTING relationships.

In the above image, adjacency relationships can be expressed by the adjacency matrix of traditional graph theory: Alternatively an adjacnecy graph can be drawn, which is easily coded as a linked list:

Fig(i)



Fig(ii)

Region	0	1	2	3	4	5	6
0	0	1	1	0	1	0	1
1	1	0	0	0	0	0	0
2	1	0	0	1	0	0	0
3	0	0	1	0	0	1	0
4	1	0	0	0	0	0	1
5	0	0	0	1	0	0	0
6	1	0	0	0	1	0	0

Fig (ii) Adjacency Relations for the seven regions of Fig (i) expressed as Adjacency Table (left) and as adjacency graph (right). Note that Region 0 is the background. Note how the graph representation clearly indicates region 5 is nested within region 3 that is nested in region 2, regions 4 and 6 touch, while region 0 is the common background.

Segmentation

Harvey A. Cohen, *One Pass Gray-scale Image Segmentation*, Proceedings of Digital Image Computing: Techniques and Applications, DICTA'93, Sydney, 8-10 December, 1993, Australian Pattern Recognition Society, pp 572 -578.
[This is pre-Publication Version]

For binary images, a one-pass region labelling algorithm was presented in a highly historic paper by Rosenfeld and Pfaltz (1966). [This is Azrael Rosenfeld, long-time editor of Computer Vision, Graphics, and Image Processing, chairman of the First International Conference of Computer Vision etc] Although not originally presented in that form, the Rosenfeld Pfaltz is most cogently stated in terms of mathematical morphology using the following forward sequence masks [3]:

- 0 -	0 0 0	- ignored neighbour
0 *	0 *	* current pixel
City Block	ChessBoard	

Here the two different masks refer to two different notions of connectivity, City Block (Manhattan), and Chess-board Connectivity:

New One Pass Segmentation Algorithm for a Binary Image

Using the forward sequence masks as above:

The mask scans the image left to right, top to bottom. At each pixel location * the set of values

M(*) = {mask element + overlaid pixel}

is determined. If the pixel at * is background, then it is unchanged. . Elsewise the pixel is given a grey scale value m :

m = max {v, v1 M(*) } ; If m=0, then m= Next available

If m= Next available, then LUT(m) := m else LUT(m) := minimum { LUT(v) : v1 M(*) }

Upon completion of the pass, the LUT is used so that, for each Σ-pixel property Q all Q[m] corresponding to a unique region label are summed.

Pascal code for the segmentation algorithm executed on a single TV scan pass at each pixel:

```
if  E(i,j)  <>  background

then
        begin
                test :=  max (E(i,j-1) ,  E(i-1,j)) ;  {City Block Connectivity}

                if test = background then
                        begin
                                test := next_available;
                                next_available:= next_available+1;
                                Look_up_table[test] := test;
                        end
                else            Look_up_table[test] :=  min_valid (E(i,j-1) ,  E(i-1,j))
                E(i,j):= test;
`       end
```

Here max is an ordinary maximum procedure, while min_valid returns the least value in its argument list, but excluding background.

Harvey A. Cohen, *One Pass Gray-scale Image Segmentation,* Proceedings of Digital Image Computing: Techniques and Applications, DICTA'93, Sydney, 8-10 December, 1993, Australian Pattern Recognition Society, pp 572 -578.
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The One-Pass Segmentation Algorithm for Gray scale Images

As before it is assumed that the background has gray scale 0, achieved through thresholding and inversion as necessary. In addition to the image E these is an identically sized segmented image array called here F.

The gray scale of the image E at * is p. If p= 0, then a 0 is loaded into E at *.
Else determine which pixels under the mask on E also have gray scale p. Find m the minimum value of region number ascribed to the corresponding pixels in F. If m = 0, then m = Next Available region.

```
        if  E(i,j)  <>  background
        then
                begin
                        {City Block Connectivity}

                        test :=  0;

                        if  E(i,j-1)  =  E(i,j)   then test:= max(test,F(i,j-1));
                        if   E(i-1,j) =  E(i,j)   then test :=  max(test,F(i-1,j);
                        Look_up_table[test] :=  min_valid (E(i,j-1) ,  E(i-1,j))
                        if test = background then
                                        begin
                                                test := next_available;
                                                next_available:= next_available+1;
                                                Look_up_table[test] := test;
                                        end
                        F(i,j):= test;
`       end
```

This is the basic segmentation algorithm (using City Block Connectivity).

[1] A. Rosenfeld and D. Pfaltz, *Sequential Operations in Digital Picture Processing* J.A.C.M. (1966) **13** No 4 pp 471-494.

[2] A. Rosenfled and J. Pfaltz, *Distance Transformson Digital Pictures,* CVGIP *(*Computer Graphics, Vision and Image Processing) Vol 34, 1968, pp 33-61.

[3] G. Borgefors, "Distance Transforms in Digital Image " in CGVIP 34 (1986) pp 344-371.

[4] J. You and Harvey A. Cohen, *Classification and Segmentation of Rotated and Scaled Textured Images Using Texture Tuned Masks*, International Journal of Pattern Recognition, Vol 26, No 2, pp 245-258, 1993.

[5] Harvey A. Cohen and You Jia, *A multi-scale texture classifier based on multi-resolution "tuned" masks,* Pattern Recognition Letters, Vol 13 No 8 August 1992, 599-603.

Harvey A. Cohen, *One Pass Gray-scale Image Segmentation*, Proceedings of Digital Image Computing: Techniques and Applications, DICTA'93, Sydney, 8-10 December, 1993, Australian Pattern Recognition Society, pp 572 -578.
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GRAY SCALE IMAGE INPUT TO ONE PASS LABELLING ALGORITHM

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```

Director's Cut -- from end of file:

Not included in DICTA-93 paper
but may be useful.

LUT

n	LUT[n]
1	1
2	2
3	3
4	4
5	1
6	6
7	1

ADJACENCY TABLE

	0	1	2	3	4	5	6	7
0	1	1	1	0	0	1	1	1
1	1	1	0	0	0	1	0	1
2	1	0	1	1	0	0	0	0
3	0	0	1	1	1	0	0	0
4	0	0	0	1	1	0	0	0
5	1	1	0	0	0	1	0	1
6	1	0	0	0	0	0	1	1
7	1	1	0	0	0	1	1	1

In 1990 the writer and a student, Chris Karadaglis, showed that the Rosenfeld-Pfaltz algorithm could be both

- performed on a single pass
- simultaneously summable region properties could be determined, where summable properties include region areas, perimeters first and second moments. This work dealt purely with binary images.During the algorithm the mask indicated is passed through the has been developed based on mathematical morphology that labels the pixels of each connected region of a binary image on a single (forward only) pass. During the pass through the image a look up table (LUT) is constructed. At the same time, each pixel's contribution to various Σ -pixel properties is added to a labelled bucket. Although the numeric labels applied during the single pass may be different for certain pixels within a single region, the LUT gives unique region labels corresponding to each applied label. Upon completion of the pass, all buckets corresponding to a unique label on the LUT are summed.

During 1991 I extended the segmentation algorithm to gray scale images - a major upgrade. (In the 1990 implementation of the segmentation of binary image, the displayed image itself was marked with image segment labels during the pass of the morphological transform. However, for gray scale images it was necessary to have a separate large array to hold the segmented image, and devise a scheme for display.) However I also determined that the adjacency relations could also be determined during the same single pass. A Turbo Pascal program (written by HAC) illustrates the implementation of the extended algorithm. The code, together with input and output 64*64 gray-scale images is presented as Appendix C. The code uses the City Block (or Manhattan) concept of connectivity .

[Note LUT(0) = /] If the current pixel contributes an amount q to a (summable) property Q, then Q[m] = Q[m] + q

0	1	1	0	0	1	1	0
0	1	1	0	0	1	1	0
0	0	0	1	0	0	0	0
0	0	0	0	1	0	0	0
0	0	0	0	0	1	1	0
0	0	0	0	0	1	1	0

Fig (iii) Binary Image with background pixels 0, region pixels 1.

0	1	1	0	0	2	2	0
0	1	1	0	0	2	2	0
0	0	0	3	0	0	0	0
0	0	0	0	4	0	0	0
0	0	0	0	0	5	5	0
0	0	0	0	0	5	5	0

Image segmented into five regions 1,2,3,4,5 via City Block Connectivity

0	1	1	0	0	2	2	0
0	1	1	0	0	2	2	0
0	0	0	1	0	0	0	0
0	0	0	0	1	0	0	0
0	0	0	0	0	1	1	0
0	0	0	0	0	1	1	0

Image segmented into two regions 1,2 via ChessBoard Connectivity