

Parallel Algorithm for Gray-scale Image Segmentation

Harvey A. Cohen
Computer Science and Computer Engineering
La Trobe University
Bundoora 3083

Email: H.Cohen@latrobe.edu.au FAX: 03 9479 3060

Abstract

One of the classic algorithms of mathematical morphology is the image segmentation algorithm of Rosenfeld-Pfaltz. 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 sequential Rosenfeld-Pfaltz algorithm (RS Algorithm) algorithm was presented for binary images; Cohen has previously presented a one-pass modification to the RS algorithm, and extended the algorithm to gray-scale. The RS algorithm is not simple to parallelise in principle, as pixels in a connected subregion may be connected only via a chain of connected pixels in several other sub-regions. We present here a parallelisable algorithm for segmenting into regions images of multiple gray-scale, based on the one-pass algorithm.

Introduction

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 via quantization)
- membership of common texture region

Traditionally segmentation involves the labelling of each pixel with a region label. However, in this paper we have the perspective that segmentation is complete when assigned pixel labels, used in conjunction with a look-up-table, will assign a unique region label to all pixels in a connected region.

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 numeric classifier, [4][5]. In preparing images for used in geographic information systems (GIS) this segmentation 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. The key feature of the Rosenfeld-Pfaltz algorithm is that the image is raster-scanned, first the forward direction, from top left to bottom right, then backwards. During the forward pass, each pixel is located a region label, based on information scanned through; the regions so demarcated may have pixels with more than one label therein. During the backwards pass, a unique label is assigned to each pixel. Hence this classic algorithm can be described as a two-pass algorithm. In a previous paper Cohen [6] presented a one-pass algorithm was presented for the segmentation of gray-scale images. Cohen's single pass algorithm proceeds to label pixels on a forward pass, exactly as in Rosenfeld-Pfaltz, except that during the same forward pass, a look-up-table is prepared, that reveals the connectivity of pixels that have different labels. For most purposes, the labelling of the pixels from the first pass, combined with the look-up-table, provides a complete segmentation, but to actually output an

image with unique pixel labels in each region, a pass through the image using the look-up table is required.

In this paper a new parallel region segmenting and labelling algorithm is introduced, that is applicable to gray-scale images, and is appropriate to coarse-scale parallel programming as with PVM or DSM. The key feature of this algorithm is the geometric splitting of the image into rectangular blocks, with one pixel overlap at joins. Then using Cohen's one pass algorithm, each region is separately labelled. Then by examination of the overlap regions, the connectivity of different region labels is determined, through connectivity tables, and finally the overall image is completely segmented into connected domains of common gray-scale.

The scheme of this paper is to first represent a reformulation of the classic Rosenfeld-Pfaltz algorithm, then present the one pass algorithm for binary and gray-scale images. In Section 3 the new parallel algorithm is described. General conclusions are presented in section 4.

2 - Image Segmentation by Modified (one-pass) Sequential Algorithm

For binary images, a two-pass region labelling algorithm was presented in a classic paper by Rosenfeld and Pfaltz (1966). Although not originally presented in that form, the RS (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 4- and 8- connectivity respectively. To apply the RS Algorithm, foreground pixels are labelled 0, while background pixels are labelled - or notionally ∞ .

2.1 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

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

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

$$m = \max \{v, v \vee M(*)\} ; \text{ If } m=0, \text{ then } m = \text{Next available}$$

If m= Next available, then $LUT(m) := m$ else $LUT(m) := \text{minimum} \{LUT(v) : v \vee M(*)\}$

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

for non-background pixels is:

```

if E(i,j) <> background
then
  begin
    test := max (E(i,j-1) , E(i-1,j)) ; {4- 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
end

```

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

2.2 One-Pass Segmentation Algorithm for Gray scale Images

Extending the above one-pass segmentation algorithm to gray-scale images requires a definition of background, which is assumed to have pixel value (gray-scale or colour index) zero. The segmented labels are placed in an image array F, that is the pixel label image of the image E.

As usual we use * to refer to the pixel location of the "centre" of the mask. The gray scale of the image E at * is p. If p= 0, then a 0 is loaded into F 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
        {4- 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
end

```

3- Parallelisable Segmentation Algorithm

The parallelisable algorithm for the segmentation of gray-scale images involves performing the one-pass algorithm on rectangular sub-images, with a single row or column overlap. What is thus produced is a label for each image pixel, together with a connectivity LUT for each region. Then, from the overlap rows and columns produce overlap tables, showing how labels in each region are related. We show the general scheme of the method with regard to the segmentation of the 64x64 gray-scale collage of Fig 1. The image is split at row 32, which is duplicated, and the one-pass algorithm run (independently) over both sub-images. Region labels 0,1,2... used in top, 0 (BACKGROUND), A,B,C, in lower sub-image. The output is as Fig 1,2 together with the look-up-tables for top and bottom (independent) segments, plus overlap correspondence table:

The Connectivity Look-up-tables for the two sub-images determined during forward scan are:

1	2	3	4	5	6	7	8	A	B	C	D	E	F	G	H	I
1	2	3	4	5	6	7	2	A	B	C	A	E	F	F	G	E

The Overlap tables are

0	1	2	2	3	7
0	E	C	A	B	D

Combining these three tables completes the segmentation, via the production of a single look-up-table, for region labels of the whole image versus pixel labels. In sum, over a single pass each pixel is given a pixel label, while a LUT for region labels in terms of these labels is completed. Although demonstrated only for a single split, the scheme is clearly extensible.

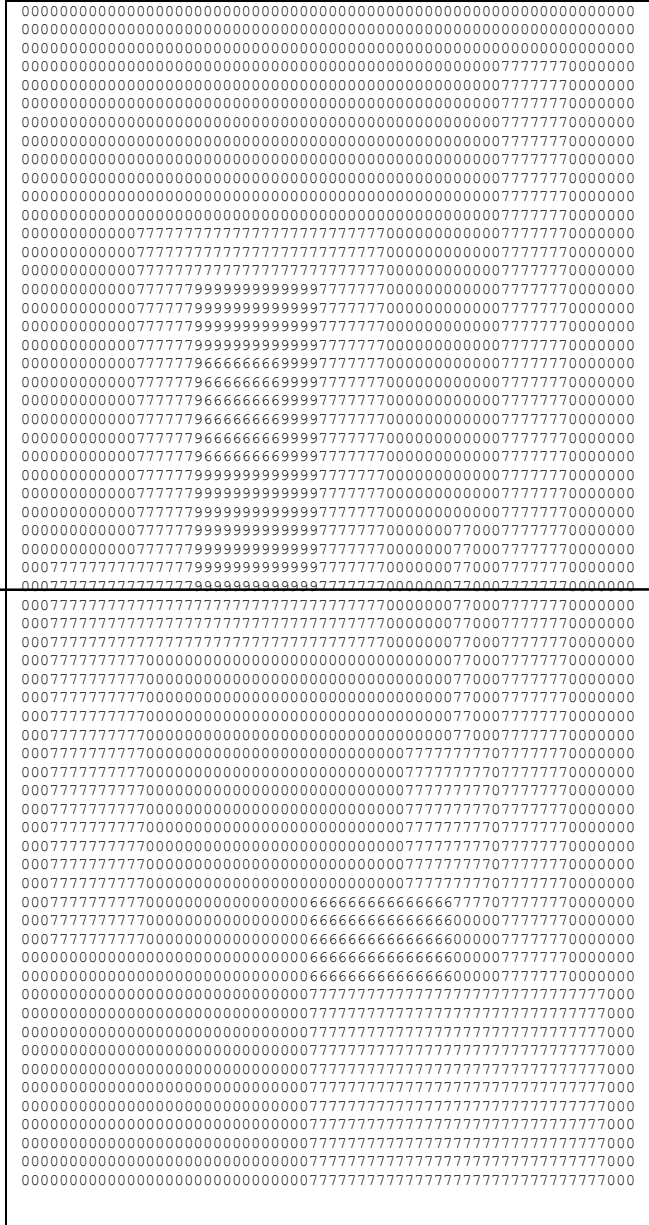
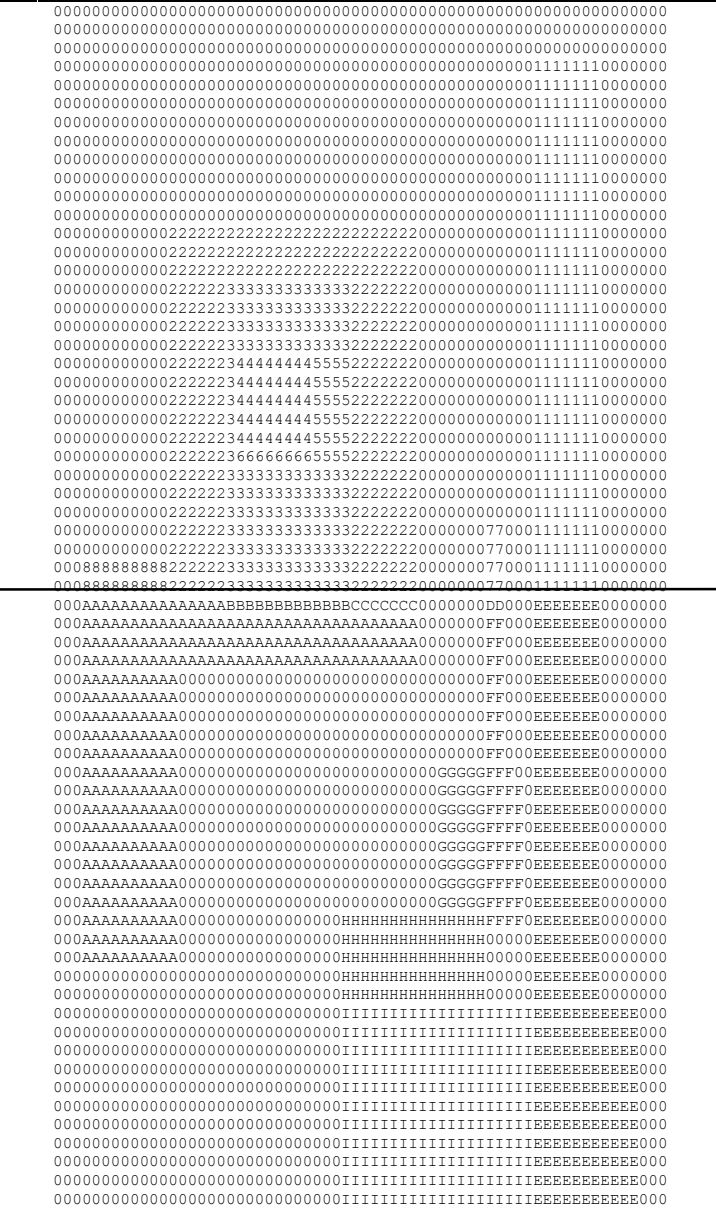
	
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Fig 1: Gray-scale image to be segmented

Fig 2: After passes through two sections:
Note the repetition of row 32 in both top and bottom sub-images

4 Conclusions

The original one-pass scheme, whereby the computational cost of performing an entire backwards pass was reduced by producing a connectivity look-up-table during the forward pass, has proven very amenable to reformulation as a parallelisable algorithm, suitable for coarse-grain parallel implementation. Our approach to parallelisation of distance transform-related operations should be contrasted with a recent approach to the parallelization of thinning algorithms. [7]

5 References

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