AREA-BASED SEGMENTATION

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Abstract

Some basic facts of different segmentation methods are first presented. The problems encountered in area-based segmentation are then discussed. Some special features of split-and-merge segmentation are mentioned and the implementation is described. Finally experimental segmentation results achieved with the split-and-merge method are presented. (This paper is an abridgement of /Hautak90/.)

1. Introduction

The segmentation of image can be defined in many different ways and on many different levels. According to one simple definition, the goal of segmentation is to divide the area of the image into (in some sense) homogenous regions. It is also desired that these regions have their counterparts in the real world.

The approach to segmentation can be very general, like in /Kanade80/. A model with three different levels is proposed: signal, physical, and semantic level. In this paper, however, segmentation is treated as a signal level process. The interpretation of objects is not considered. There are several different segmentation methods. According to the basic principle they can be divided into three different categories: segmentation in measurement space, edge-based and area-based (or region-based) methods.

In segmentation in measurement space - also called spectral clustering - the action takes place in the measurement space, not in the image space like in other methods. In this method the purpose is to define n-1-dimensional border surfaces in the n-dimensional measurement space. After the surfaces are defined, each pixel is classified into that class the measurements suggest. These surfaces can also be dynamic: it is possible that they move in measurement space according to some local neighbourhood in the image space. This is also the way in which some spatial information can be included in spectral clustering.

In the edge-based segmentation the goal is to find discontinuities in the image. This is done in two phases. First the image is scanned through and for each pixel a probability of belonging into a boundary is computed. This is done with some local operator, which approximates a gradient (see /RosKak82/ for different operators). Then these edge pixels are linked together so that they form continuous edges. Some relaxation based method can be used in linking the short edges together (see /ZuHuRo77/). If there is noise or texture in the image, the simplest edge-based methods meet serious problems.

In the area-based segmentation we are interested in the inner pixels of homogenous regions, not the boundaries. A homogenous region is defined by a homogeneity predicate: every homogenous region must fulfil the conditions required by a homogeneity predicate. With rich imagination one can create vast amounts of different homogeneity predicates. There are also many ways to use homogeneity predicates and different area-based segmentation techniques. The most common methods are region growing, region merging, region splitting and mixed methods (like split-and-merge). Noisy and textured images are not so serious problems for area-based segmentation methods.

2. Area-based segmentation

2.1 The problem of data management

Segmentation can be done with many different methods. Several different area-based segmentation methods have been developed, although none of them is as good as the human vision system. That is the reason why segmentation can be considered as a data management problem: which segmentation method to choose?

Region growing is one of the most popular area-based segmentation methods. The first region growing algorithm is presented in /MueAll68/, in which the image is divided into small cells (size of 2*2 or 4*4 pixels). Two adjacent cells are merged if their grey values are statistically close enough to each other. In /BriFen70/ the seed regions are generated from adjacent pixels whose grey values are uniform. Then this result is refined with phagosyte and weakness heuristics: two adjacent regions are merged, if the boundary between them is weak enough.

The first region merging algorithm was presented in /Pavlid72/. In that method the horisontal pixel rows are divided into pieces that can be approximated by a linear function. Then pieces in adjacent rows are merged, if the difference in the approximating functions is small enough.

The reverse operation is region splitting. This kind of algorithm is presented for example in /RoSwFu73/. The whole image is splitted iteratively into smaller pieces (horisontally or vertically), until every region is homogenous.

Region splitting and region merging can be combined into a single segmentation method known as split-and-merge. It was first presented in /PavHor74/, where the image function is approximated with other functions in two dimensions. Adjacent regions with same type of approximating function are merged, and regions with too big approximation error are splitted into smaller regions. In this method a image pyramid is used.

These different area-based methods approach the problem in different ways. Each method has its own weak points and benefits.

2.2 The problem of data processing

In practice, there is always some amount of uncertainty in segmentation. If there was no uncertainty, there would either be no problems. The actual problem in segmentation is how to process the data, and simultaneously handle the uncertainty.

One way to handle uncertainty is simply to ignore it and to segment the image with some heuristic method. In fact, all the methods referenced previously in this paper are heuristic in some sense. They can give reasonably good results although there is no mathematical reason why to segment with a certain heuristic method.

Uncertainty can be handled in a relaxation process, which takes into account the context of an object. In relaxation, the probabilities an object belongs to different classes are first computed. Then these probabilities are updated according to probabilities of neighbouring objects. In this way, the classification of the objects is found.

One can cope with uncertainty by computing it precisely. For every possible segmentation the conditional probability is computed, and the segmentation with the largest probability is chosen as the true segmentation. This is often called estimation theoretic (or decision theoretic) pattern recognition. This can be done on signal level, as in /Besag85/, where the purpose is to restore noisy images. The method described in /Therri83/ is based on the observation that natural textures can be modelled with 2-dimensional random processes when there are textured regions larger than one pixel in the image. Mathematical decision theory is utilized in /FelYak74/ in a different way: semantics is included in this approach, and the regions are interpreted simultaneously. The computing of a numerical utility function is used in making decisions.

Rule-based method is one possibility to handle uncertainty in segmentation. The idea is to predict all possible situations in the image during the segmentation, and to set precise rules for each situation. This kind of approach is developed in /LevNaz85/, where the rules are combined with kind of split-and-merge segmentation method. There will be vast amount of different rules, and the organization of the rules is a very important task.

3. Split-and-merge segmentation method

In principle, split-and-merge (described e.g. in /Pavlid-77/) starts with initial segmentation, which contains errors. This erroneous segmentation is improved by splitting non-homogenous regions into smaller homogenous regions, and merging similar homogenous neighbouring regions. Often used data structure is quadtree, in which the root can be divided into four leaves, and each leaf can be divided into four new leaves again, and so on. In segmentation, this means that the whole image is divided into quadrants which can be divided into smaller quadrants, and so on. As in other area-based segmentation methods, the decision of homogeneity is based on a homogeneity predicate. Another often used data structure is a graph. It is used to keep the segmentation system aware of neighbourhood relationships between the regions.

Split-and-merge is a very flexible and universal segmentation method, but it has some drawbacks, too. One problem is that it is not shift variant. This means that if the origin of the image coordinate system is shifted by some pixels, the segments can change considerably. Another problem is that split-and-merge is not 'order invariant': the order in which the regions are tested for merging can affect the result remarkably. Also, when using the quadtree as data structure, the usage of shape of regions is difficult in split-and-merge. In splitting all the regions are squares, and in the beginning of merging they are squares or 'almost squares', and it is not worth trying to use shape.

Some experimental work was done with the split-and-merge segmentation method. The implemented system is described in more detail in /Hautak89/; here are presented only the basic principles.

Several different homogenous predicates were implemented: mean value, minmax test, fitness of a plane to the grey tone space, standard deviation, closeness of cooccurrence matrices, shape of regions, size of regions, and phase of segmentation. Also many predicates can be used in the same time. This is done by giving each predicate a symbol (character string) and combining these symbols into one logical clause.

Some pre- and postprocessing operations can be done. Preprocessing operations include the computation of 'busyness channels' (see /DonRos82/), channel of local standard deviation, edge preserving smoothing (see /NagMat80/) and standard deviation in directed neighbourhood. Postprocessing operations include the elimination of small regions and merging of elongated regions.

4. Results of experimental segmentations

When we segmented different kind of digitized aerial images and satellite images, we were able to reach some conclusions.

The basic predicates in almost every satisfying combination were mean value and standard deviation homogeneity predicates. Their function is very easy to understand, and they are easy to compute, so no wonder that they were the most often used predicates.

Minmax test does not work well with natural images. With split-and-merge method minmax test often yields to a result where there are almost identical neighbouring regions, but the minmax test predicate cannot merge them.

Plane fitting in the grey tone space is in principal a generalization of a mean value predicate. It is a very useful predicate if there are slowly, smoothly changing regions in the image. This is often the effect of light, when the object is strongly 3-dimensional.

Segmenting according to texture was done with special texture channel. The cooccurrence matrices are better in finding regular textures, but in natural images the texture is almost always irregular. Also, in order to be reliable, there should be at least as many observations in the cooccurrence matrix as there are elements in the matrix; so, it can not be used with small regions.

It was noticed that the best result was often reached by using different predicate combinations in split and merge phases. A predicate set working well in split phase was not satisfactory in merge phase.

5. Conclusions

Viewed from different aspects, area-based segmentation has some problems. Especially the handling of uncertainty is an interesting question. Therefore it would be a very challenging project to model the uncertainty in the segmentation in the future projects.

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