Chapter 10 Image Segmentation

10.1 Introduction

image segmentation: partition of image into set of nonoverlapping regions
image segmentation: union of segmented regions is the entire image
segmentation purpose: to decompose image into meaningful parts to application
segmentation based on valleys in gray level histogram into 4 regions
=====V. S. Nalwa, *A Guided Tour of Computer Vision*, Fig. 3.20=====

rules for general segmentation procedures

1. region uniform, homogeneous w.r.t. characteristic e.g. gray level, texture
2. region interiors simple and without many small holes
3. adjacent regions with significantly different values on characteristic
4. boundaries simple, not ragged, spatially accurate

clustering: process of partitioning set of pattern vectors into clusters
set of points in Euclidean measurement space separated into 3 clusters
=====Fig. 10.2=====
no full theory of clustering

no full theory of image segmentation
image segmentation techniques: ad hoc, different in emphasis and compromise

10.2 Measurement-Space-Guided Spatial Clustering

The technique of measurement-space-guided spatial clustering for image segmentation uses the measurement-space-clustering process to define a partition in measurement space.

histogram mode seeking: a measurement-space-clustering process
histogram mode seeking: homogeneous objects as clusters in histogram
histogram mode seeking: one pass, the least computation time
pyrite: classic “Fool’s Gold”
pyrite: by far the most common and often mistaken for gold
enlarged image of a polished mineral ore section
=====Fig. 10.3=====
3 nonoverlapping modes: black holes, pyrrhotite, pyrite
=====Fig. 10.4=====
2 valleys in histogram is a virtually perfect (meaningful) segmentation
=====Fig. 10.5=====
example image not ideal for measurement-space-clustering image segmentation

=====Fig. 10.6=====
histogram with three modes and two valleys
=====Fig. 10.7=====
undesirable: many border regions show up as dark segments
=====Fig. 10.8=====
segmentation into homogeneous regions: not necessarily good solution

diagram of an F-15 bulkhead
=====Fig. 10.9=====
image of a section of the F-15 bulkhead
=====Fig. 10.10=====
histogram of the image
=====Fig. 10.11=====
five clusters: bad spatial continuation, boundaries noisy and busy
=====Fig. 10.12=====
three clusters: less boundary noise, but much less detail
=====Fig. 10.13=====

recursive histogram-directed spatial clustering
=====Fig. 10.14=====

applied to the bulkhead image
=====Fig. 10.15=====
performing morphological opening with 3×3 square structuring element
=====Fig. 10.16=====
tiny regions removed, but several long, thin regions lost

a color image
=====Fig. 10.17=====
recursive histogram-directed spatial clustering using R, G, B bands and other
=====Fig. 10.18=====
=====Garfield 17:10=====

10.2.1 Thresholding

Kohler defines the set $E(T)$ of edges detected by a threshold T to be the set of all pairs of neighboring pixels one of whose gray level intensities is less than or equal to T and one of whose gray level intensities is greater than T

$$E(T) = \{[(i,j),(k,l)] |$$

1. pixels (i,j) and (k,l) are neighbors
2. $\min\{I(i,j), I(k,l)\} \leq T < \max\{I(i,j), I(k,l)\}\}$

The total contrast $C(T)$ of edges detected by threshold T is given by

$$C(T) = \sum_{[(i,j),(k,l)] \in E(T)} \min\{|I(i,j) - T|, |I(k,l) - T|\}$$

The average contrast of all edges detected by threshold T: $\frac{C(T)}{\#E(T)}$
The best threshold T_b is determined by the value that maximizes

$$\frac{C(T_b)}{\#E(T_b)}$$

approach for segmenting white blob against dark background
pixel with small gradient: not likely to be an edge
if not an edge, then either dark background pixel or bright blob pixel
histogram of small gradient pixels: bimodal
pixels with small gradients: valley between two modes: threshold point
=====Fig. 10.19=====
FLIR (Forward Looking Infra-Red) image from NATO database
=====Fig. 10.20=====
thresholded at gray level intensity 159 and 190
=====Fig. 10.21=====
pixels having large gradient magnitude
=====Fig. 10.22=====

2D gray level intensity—gradient space
=====Fig. 10.23=====
resulting segmentation: bright object with slightly darker appendage on top
=====Fig. 10.24=====

10.2.2 Multidimensional Measurement-Space Clustering
LANDSAT image: consists of seven separate images called bands
constraints of reality

1. high correlation between band-to-band pixel values
2. large amount of spatial redundancy in image data

=====Gonzalez, *Digital Image Processing*, Fig. 3.31=====

10.3 Region Growing
10.3.1 Single-Linkage Region Growing
single-linkage region-growing schemes: regard each pixel as node in graph
neighboring pixels with similar enough properties: joined by an arc
image segments: maximal sets of pixels belonging to same connected component
simple image and the corresponding graph
=====Fig. 10.25=====
two pixels connected by edge: if 4-neighbor and values differ ≤ 5

10.3.2 Hybrid-Linkage Region Growing

hybrid single-linkage techniques: more powerful than simple single-linkage
hybrid techniques: assign property vector to each pixel
property vector: depends on $K \times K$ neighborhood of the pixel
pixels similar: because neighborhoods similar in some special sense
R_1, R_2: mutually exclusive neighborhoods having N_1, N_2 pixels
intensity mean:

$$\bar{X}_i = \frac{1}{N_i} \sum_{x \in R_i} X$$

intensity scatter:

$$S_i = \sum_{x \in R_i} (X - \bar{X}_i)^2$$

region cannot be declared segment unless completely surrounded by edge pixels
edge image with gaps in the edges can cause problems in segmentation
=====Fig. 10.26=====
edges from second directional derivative zero-crossing
=====Fig. 10.27=====
after region-filling
=====Fig. 10.28=====

Pong et al. suggest an approach to segmentation based on the facet model
one iteration of Pong algorithm
=====Fig. 10.29=====
second iteration of the Pong algorithm
=====Fig. 10.30=====
third iteration of the Pong algorithm
=====Fig. 10.31=====
after removing regions smaller than size 25
=====Fig. 10.32=====
=====Oldie 33:21=====

10.3.3 Centroid-Linkage Region Growing

In centroid-linkage region growing, the image is scanned in some predetermined manner, such as left-right, top-bottom. A pixel's value is compared with the mean of an already existing but not necessarily completed neighboring segment. If its value and the segment's mean value are close enough, then the pixel is added to the segment and the segment's mean is updated. If more than one region is close enough, then it is added to the closest region. However, if the means of the two competing regions are close enough, the two regions are merged and the pixel is added to the merged region. If no neighboring region has a close-enough mean, then a new segment is established having the given pixel's value as its first member.

caption of Fig. 10.33 explains and the figure illustrates the geometry
=====Fig. 10.33=====
second image of the F-15 bulkhead
=====Fig. 10.34=====
one-pass centroid-linkage segmentation
=====Fig. 10.35=====
two-pass centroid segmentation of the bulkhead image
=====Fig. 10.36=====

10.4 Hybrid-Linkage Combinations

centroid linkage, hybrid linkage: can be combined to use relative strengths
single linkage strength: boundaries are spatially accurate
single linkage weakness: edge gaps result in excessive merging
centroid linkage strength: to place boundaries in weak gradient area
one-pass combined centroid- and hybrid-linkage segmentation of bulkhead
=====Fig. 10.37=====
two-pass combined centroid- and hybrid-linkage segmentation
=====Fig. 10.38=====

10.5 Spatial Clustering

spatial-clustering: combining clustering with spatial region growing
spatial-clustering: combine histogram-mode-seeking with region growing or spatial-linkage technique

10.6 Split and Merge

A splitting method for segmentation begins with the entire image as the initial segment. Then the method successively splits each of its current segments into quarters if the segment is not homogeneous enough; that is, if the difference between the largest and smallest gray level intensities is large. A merging method starts with an initial segmentation and successively merges regions that are similar enough.
segmentation tree: quadtree data structure (nonleaf node each has 4 children)
split-and-merge segmentation of the bulkhead image
=====Fig. 10.40=====

image, segmentation, reconstruction based on least-squares-error polynomial
=====V. S. Nalwa, *A Guided Tour of Computer Vision*, Fig. 3.23=====

10.7 Rule-Based Segmentation

rule-based seg.: easier to try different concepts without reprogramming
knowledge in the system: not application domain specific

general-purpose, scene-independent knowledge about images, grouping criteria
allowable data entry types in the Nazif and Levine rule-based segmentation
=====Table 10.1=====
numerical descriptive features that can be associated with condition
=====Table 10.2=====
numerical spatial features that can be associated with condition
=====Table 10.3=====
logical features that can be associated with condition
=====Table 10.4=====
area, region, and line analyzer actions
=====Table 10.5=====
focus-of-attention and supervisor actions
=====Table 10.6=====
examples of rules from the Nazif and Levine system
=====Table 10.7=====

10.8 Motion-Based Segmentation

In time-varying image analysis the data are a sequence of images instead of a single image. One paradigm under which such a sequence can arise is with a stationary camera viewing a scene containing moving objects. In each frame of the sequence after the first frame, the moving objects appear in different positions of the image

from those in the previous frame. Thus the motion of the objects creates a change in the images that can be used to help locate the moving objects.
(a) image t_i (b) image t_j (c) difference image
=====Gonzalez, *Digital Image Processing,* Fig. 7.40=====

10.9 Summary
single-linkage region-growing schemes: simplest and most prone to errors
split-and-merge: large memory usage, excessively blocky region boundaries
=====joke=====

Project due Jan. 11, 1994
Write a program to segment images with single-linkage region growing schemes as in Section 10.3.1 and Figure 10.25.
Try values different by less than 5, 10, 20.
Scan from left to right, top to bottom, mark each pixel with region number.
Superimpose region boundaries on the original image.