Understanding Regions and Region Segmentation

By

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Overview

- Introduction to Regions
- Region Segmentation – Approaches
- Thresholding - Automatic
- Region Representation
- Data Structures
- Split and Merge
- Color Image Segmentation
- Morphological Watersheds

What is a Region?

- Basic definition :- A group of connected pixels with similar properties.

- Important in interpreting an image because they may correspond to objects in a scene.

- For correct interpretation, image must be partitioned into regions that correspond to objects or parts of an object.

Partitioning – How?

- Partitioning into regions done often by using gray values of the image pixels.

- Two general approaches :-

    Region-based segmentation

    Boundary estimation using edge detection

Region-based Approach

- Pixels corresponding to an object grouped together and marked.

- Important principles:-
    1. Value similarity
       Gray value differences
       Gray value variance

Region-based Approach (continued)

2. Spatial Proximity

Euclidean distance
Compactness of a region

Assumption: Points on same object will project to spatially close pixels on the image with similar gray values.

Limitation

- The assumption does not hold true in all cases.
- To overcome this, group pixels using given principles and use domain-dependent knowledge.
- Match regions to object models.

Edge Detection Approach

- Segmentation by finding pixels on a region boundary.
- Edges found by looking at neighboring pixels.
- Region boundary formed by measuring gray value differences between neighboring pixels

Segmentation versus Edge Detection

- Closed boundaries
- Multi-spectral images improve segmentation
- Computation based on similarity

- Boundaries formed not necessarily closed
- No significant improvement for multi-spectral images
- Computation based on difference

Region Segmentation

- Problem Statement:-

Given a set of image pixels □ and a homogeneity predicate P(.), find a partition □ of the image □ into a set of *n* regions R_i such that

$$\overset{n}{\underset{i=1}{\square}} Ri = True$$

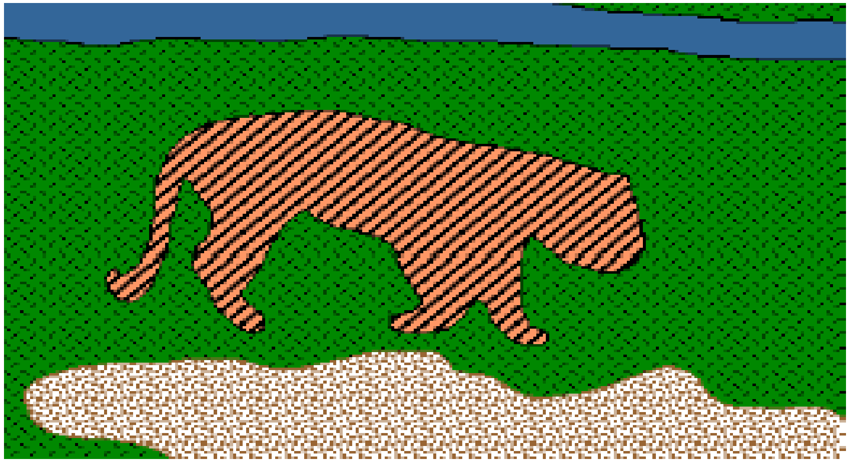
Region Segmentation – Problem Statement (Continued)

- P(Ri) = True , for all i

  i.e any region satisfies the homogeneity predicate
- Any two adjacent regions cannot be merged into a single region

$$P\left(Ri \cup Rj\right) = False$$

Original Image



Region Segmented Image

Thresholding – A Key Aspect

- Most algorithms involve establishing a threshold level of certain parameter.
- Correct thresholding leads to better segmentation.
- Using samples of image intensity available, appropriate threshold should be set automatically in a robust algorithm i.e. no hard-wiring of gray values

Automatic Thresholding

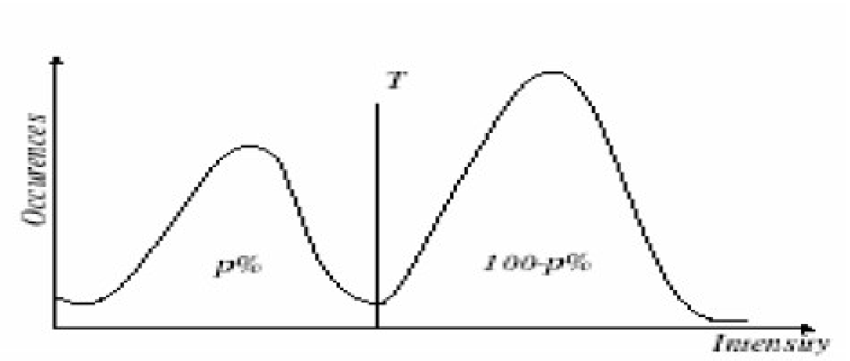
- Use of one or more of the following:-
  1. Intensity characteristics of objects
  2. Sizes of objects
  3. Fractions of image occupied by objects
  4. Number of different types of objects
- Size and probability of occurrence – most popular
- Intensity distributions estimate by histogram computation.

Automatic Thresholding Methods

- Some automatic thresholding schemes:
  1. P-tile method
  2. Mode method
  3. Iterative threshold selection
  4. Adaptive thresholding
  5. Variable thresholding
  6. Double thresholding

Thresholding Methods

- P-tile Method:- If object occupies P% of image pixels the set a threshold T such that P% of pixels have intensity below T.



- Iterative Thresholding:-

  Successively refines an approx. threshold to get a new value which partitions the image better.

$$T = \frac{1}{2}(\mu 1 + \mu 2)$$

Thresholding Methods (Continued)

- Adaptive Thresholding:- Used in scenes with uneven illumination where same threshold value not usable throughout complete image.
- In such case, look at small regions in the image and obtain thresholds for individual sub-images. Final segmentation is the union of the regions of sub-images.

- Variable Thresholding:- Approximates the intensity values by a simple function such as a plane or biquadratic. It is called background normalization.

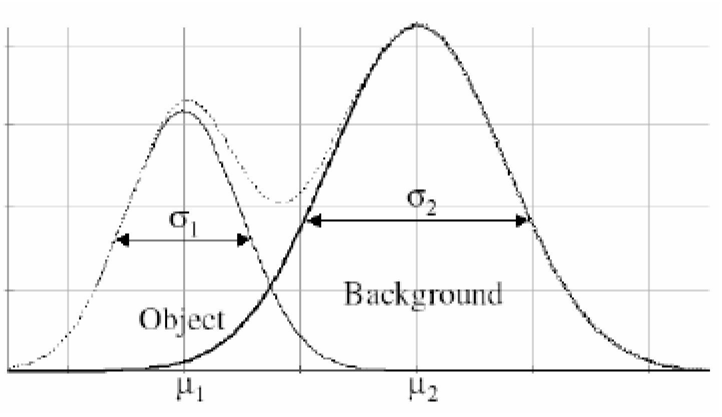
Even more thresholding methods

- Mode method:-

Assume that gray values are drawn from two normal distributions with parameters $(\mu 1, \sigma 1), (\mu 2, \sigma 2)$

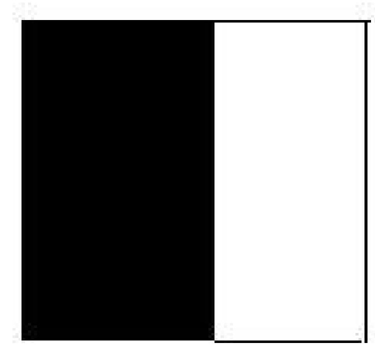
If the standard deviations are zero, there will be two spikes in the histogram and the threshold can be placed anywhere between them.

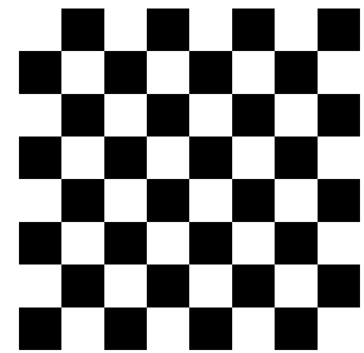
For non-ideal cases, there will be peaks and valleys and the threshold can be placed corresponding to the valley.

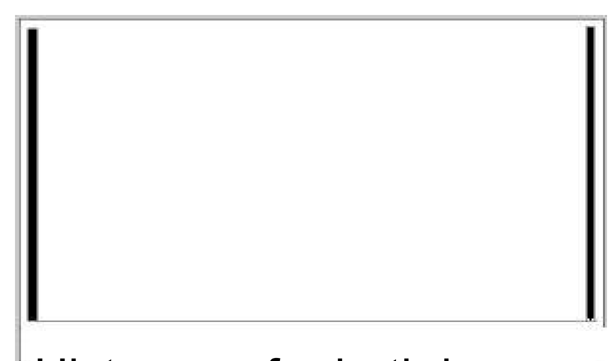


Histograms

- They are applied globally to the entire image. This can be drawback in complex scenes
- Very useful in initial segmentation on the basis of gray levels.
- Spatial information about intensity values is thrown away.
- Very different scenes may give a strikingly similar histogram representation.







Histogram for both images

Region Representation

- Different representations suitable to different applications.
- Three general classes:-

1. Array representation

   - same size arrays, membership arrays

2. Hierarchical representation

   - pyramid, quad tree

3. Symbolic representation

Array representation

- Uses array of same size as original image with entries indicating the region to which a pixel belongs.
- Simplest example – binary image

7	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0
5	0	0	0	0	0	0	1	0
4	0	0	7	8	8	0	0	0
y 3	0	0	7	8	7	0	0	0
2	0	0	0	7	8	0	0	0
1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	2	0
	0	1	2	3 x	4	5	6	7

Image Data

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

Array Region Representation

Membership Arrays

- Membership arrays (images) commonly called masks. Each region has a mask that indicates which pixels belong to which region.
- Advantage – a pixel can be allowed to be a member of more than one region.

Characteristics of array representation method

- Preserves all details of regions required in most applications
- Very popular method with lots of hardware support available
- Symbolic information is not explicitly represented.

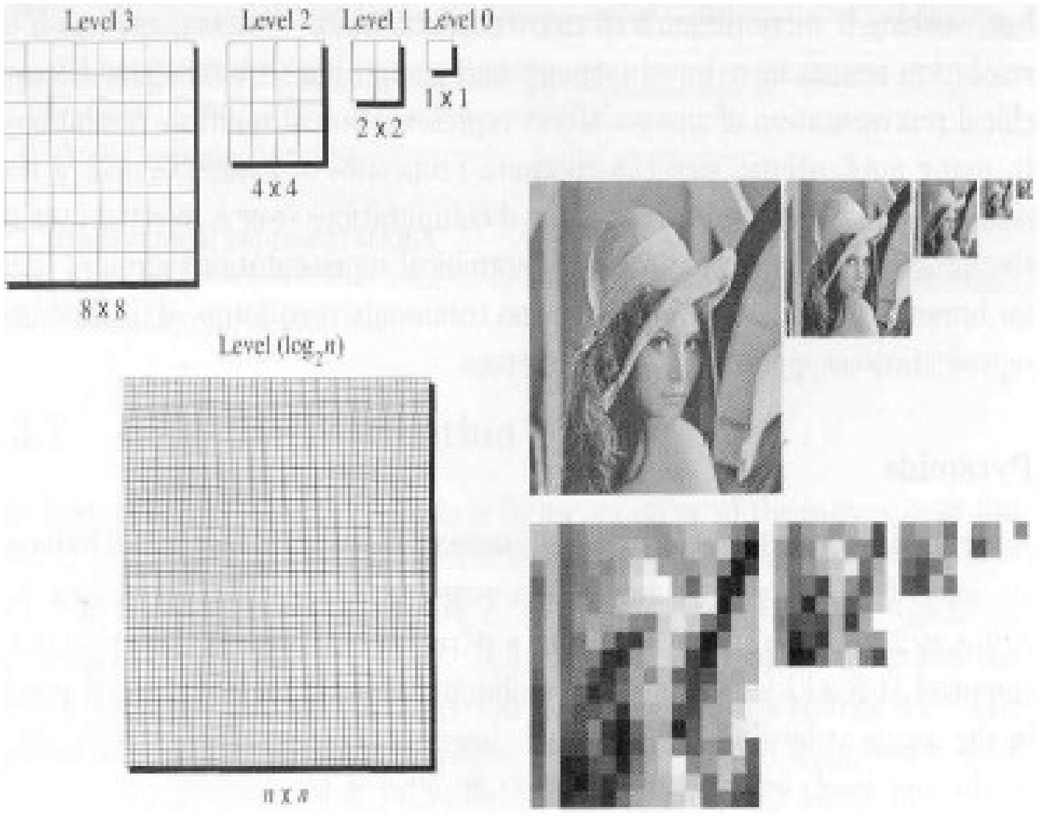
Hierarchical Representation

- Images represented at many resolutions
- As resolution ↓, array size ↓ and some data is lost. More difficult to recover information.
- But, memory and computation requirements are also decreased.
- Used to accommodate various segmentation algorithms which operate at different resolutions.

Pyramids

- An '$n \times n$' image represented by the image and 'k' reduced versions of the image.
- Pixel at level 'l' has combined information from several pixels at level '$l+1$'
- Top level – level 0 – single pixel
- Bottom level – original image
- Simplest method for resolution reduction is averaging .

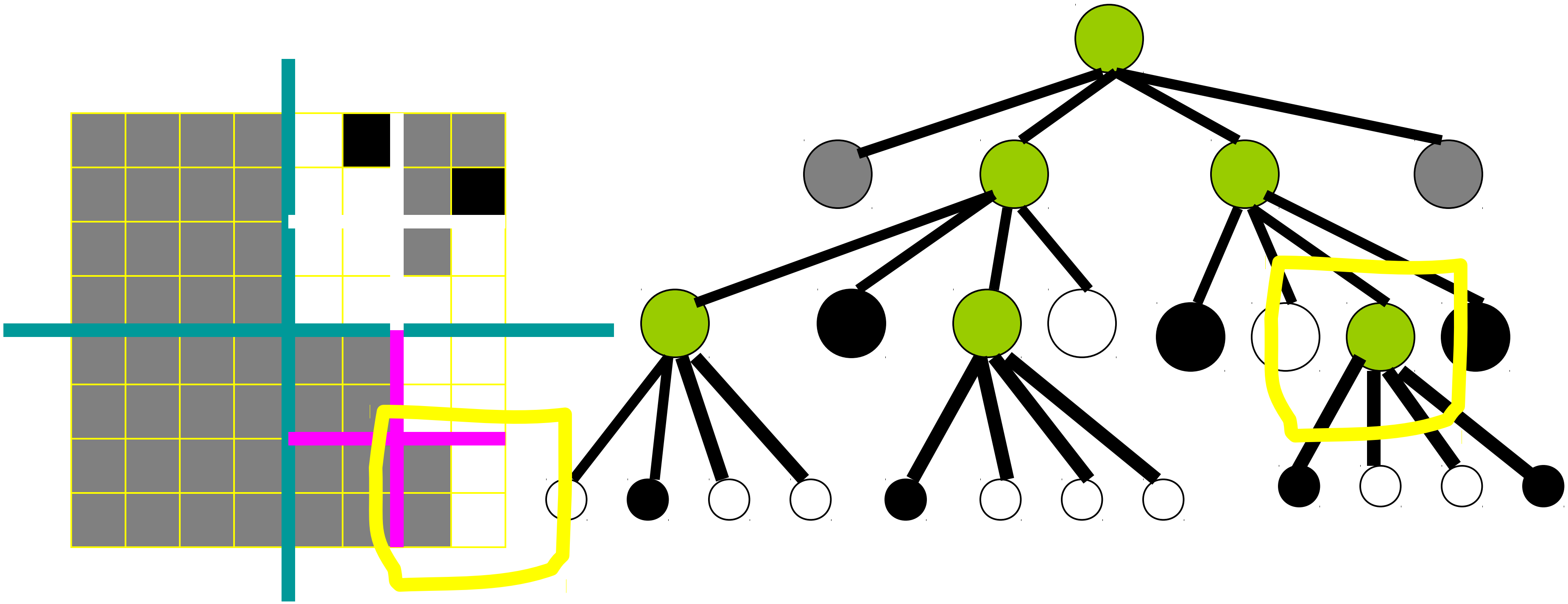
Pyramid Structure



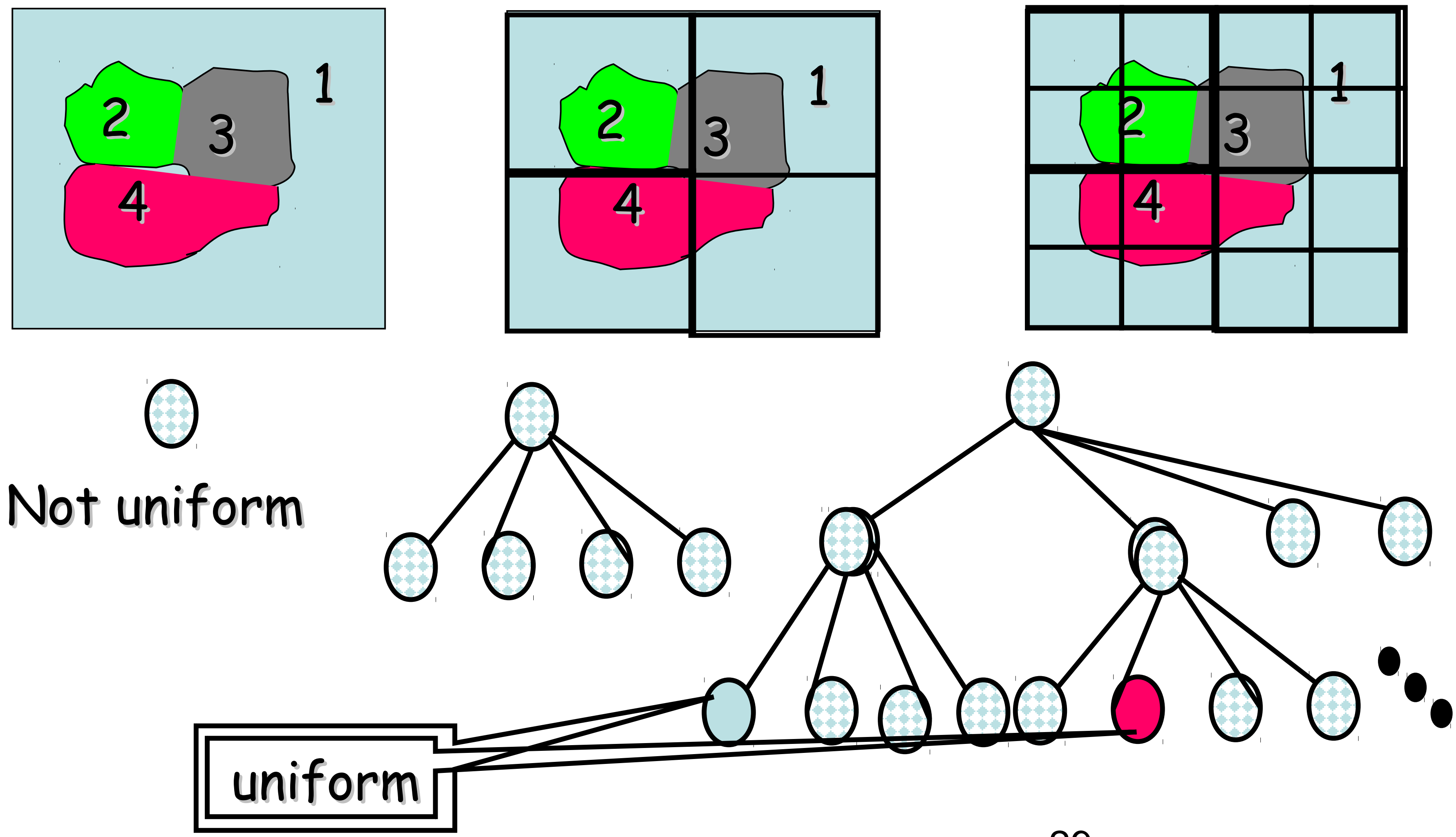
Quad Trees

- Extension of pyramids for binary images.
- Three types of nodes – white, black, gray.
- White or black node – no splitting.
- Gray node – split into 4 sub-regions.
- Each node is either a leaf or has 4 children.

Quad Tree Example
Binary Image



Quad Tree Example
Non-binary image



Symbolic Representations

- Commonly used symbolic characteristics:

  1. Enclosing rectangle

  2. Centroid

  3. Moments

  4. Euler number

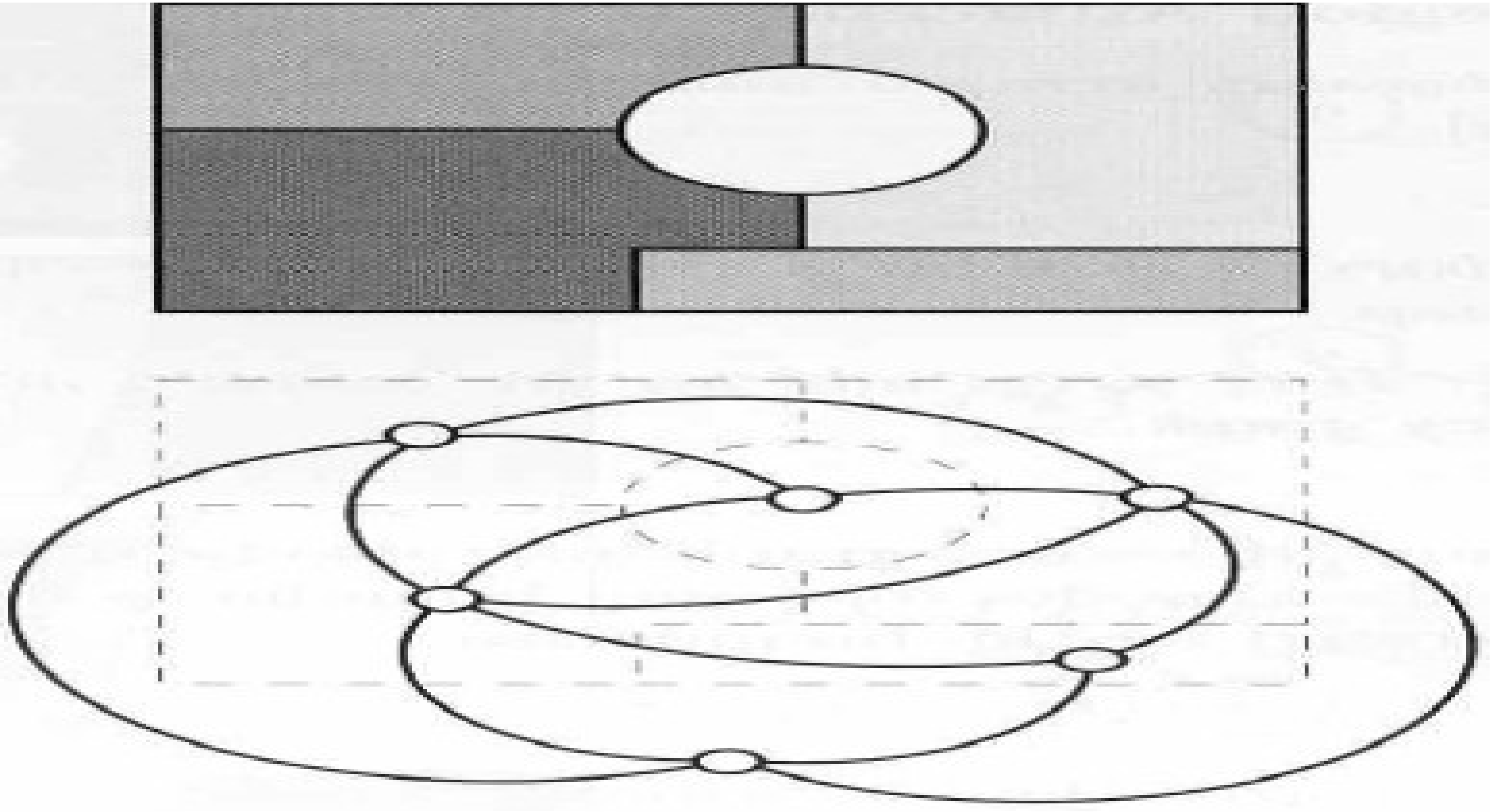
Data Structures for Segmentation

- Data structures used for storing region information during operations like splitting and merging.
- Commonly used data structures:-
  1. RAG – Region Adjacency Graph
  2. Picture trees
  3. Super grid

RAG

- Nodes represent regions; arcs between nodes represent a common boundary between regions.
- Different properties of regions stored in node data structure.
- After initial segmentation, results stored in RAG and regions combined to obtain a better segmentation.

RAG Example



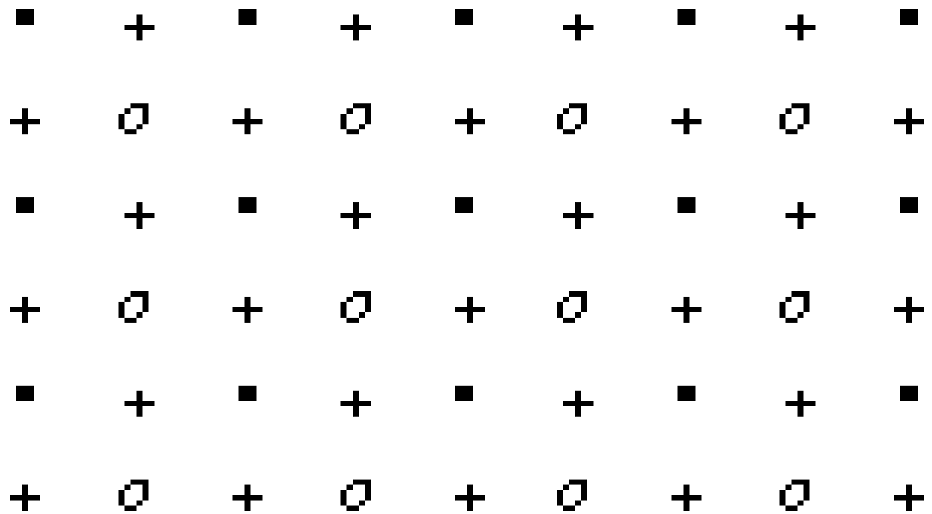
Picture Trees

- Emphasize inclusion of a region within another region.
- Recursive splitting of an image into component parts. Splitting stops with constant characteristic conditions.
- Quad tree is a special case.

Super Grid

- Problem of boundaries becoming actual pixels of a region instead of being between pixels of two regions.
- For *NxN* image, super grid will be *(2N+1) x (2N+1).*
- Each pixel surrounded by 8 non-pixel points which are used to indicate boundary.
- Simplifies merge and split operations.

Super grid Example



Split and Merge

- Refining and reforming regions.
- Need : O/p of thresholding algorithm may contain many extra regions. Also, used after RAG representation.
- Eliminate false boundaries and spurious regions.
- Add missing boundaries

Region Merging

- Combine regions considered similar based on a few region characteristics.
- Determining similarity between two regions is most important step.
- Approaches for judging similarity based on:

  Gray values

  Color

  Texture

  Size

  Shape

  Spatial proximity and connectedness

Region Merging
A Statistical Approach

- Assumption:- Regions have constant gray values corrupted by statistically independent, zero-mean Gaussian noise

  Gray values are now taken from normal distributions.
- Suppose two adjacent regions R1 and R2 contain points m1 and m2 respectively. Possible hypotheses are:

  H_0: Both regions belong to same object. Intensities are all drawn from a single Gaussian distribution with parameters $(\mu 0, \sigma 0)$

  H1: Regions belong to different objects. Intensities are drawn from separate Gaussian distributions with parameters $(\mu 1, \sigma 1), (\mu 2, \sigma 2)$

- These parameters are generally not know, but estimated using the available samples.

Statistical Approach (Continued)

- Assume a region contains *n* pixels having gray levels, g_i, i =1,2,….*n given by*

$$p(gi) = \frac{1}{\sqrt{2\pi\sigma}} \; e^{\frac{-(gi-\mu)^2}{2\sigma^2}}$$

- The Maximum Likelihood Estimation can be used to determine parameters like mean and variance.

- Under H0, the joint probability density can be found. Similarly, under H1, assuming normal distributions for regions R1 and R2, the joint probability density can be obtained.

Statistical Approach (Another slide!!)

- The likelihood ratio, L, is the defined as the ratio of the probability densities under the two hypotheses:

$$L = \frac{p(g1, g2, \ldots. \mid H1)}{p(g1, g2, \ldots. \mid H0)} = \frac{\sigma 0^{m1+m2}}{\sigma 1^{m1} \sigma 2^{m2}}$$

- If L < threshold T, strong likelihood that there is only one region and the two regions may be merged.
- NOTE: Can also be applied for edge detection.
- Modifications: Possible to assume planar or quadratic intensity distributions instead of constant gray values.

Removing Questionable Edges for Region Merging

- Merge regions if boundary is weak.
- Length of common boundary is considered.
- Weak boundary – intensities of either side differ by less than amount T
- Imp:- Consider relative lengths of the weak and complete boundaries between regions.
- Two main approaches:-

1. Merge adjacent regions R1 and R2 if

$$\frac{W}{S} > \tau$$

W = length of weak part of boundary

S = min(S1,S2) is minimum of two perimeters

 = a threshold

- If is too small → too many region merges

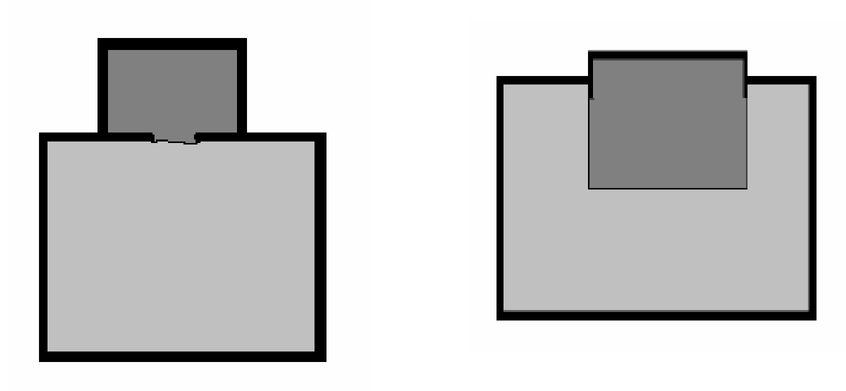
   is big → very conservative algorithm; valid candidates for merging might be ignored.

Removing edges (Continued)

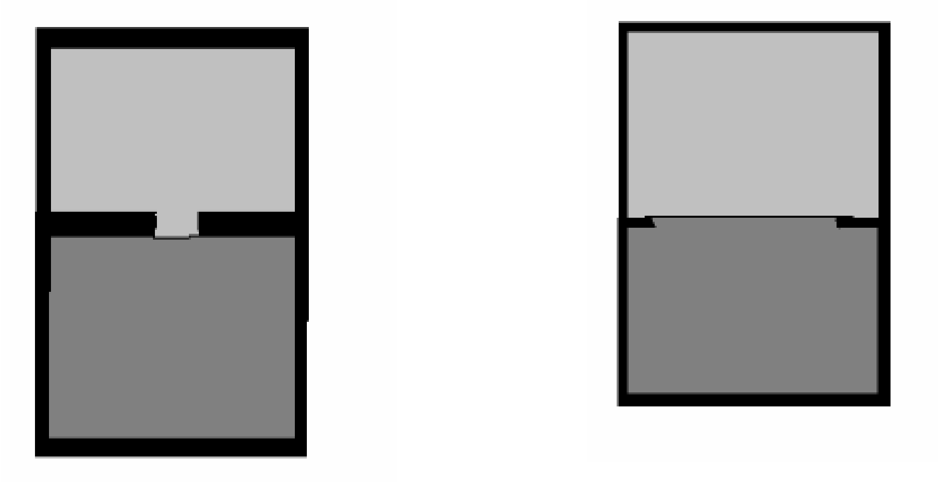
2. Merge adjacent regions R1 and R2 if

$$\frac{W}{S} > \tau$$

where S = common boundary
W = length of weak part of boundary
τ = threshold



Approach 1



Approach 2

Region Splitting

- Property of a region is not constant - SPLIT
- Segmentation starts with large regions. Whole image can be used to start with.
- Important decisions before splitting:-

1. Is a property not constant over a region?
   - Variance of intensity values
   - Function fitting and error calculation
2. Where to split a region? (tough one!)
   - Measures of edge strength within region
   - Regular decomposition methods

Split and Merge Application on same image

- Yes! Both can be used together
- Segmentation using thresholding → succession of splits and merges to refine segmentation.
- Useful in complex scenes.
- Image partitioned into regions $\{R_k\}$, k=1,2,…..m
- Predicate H applied to the region.

ex: variance of gray values as a predicate gives

H(R) = 1, if variance is small

= 0, otherwise

Region Growing

- Groups pixels or sub-regions into larger regions based on pre-defined criteria.
- “Seed” points – append neighboring pixels.
- No a priori knowledge – compute properties at every pixel; centroids of clusters as seeds.
- Similarity criteria - application and type of image data available.

Similarity Criteria for Region Growing

- Satellite imagery – color

- Monochrome images –
  Descriptors :
  Gray levels, moments, texture
  Connectivity or adjacency information

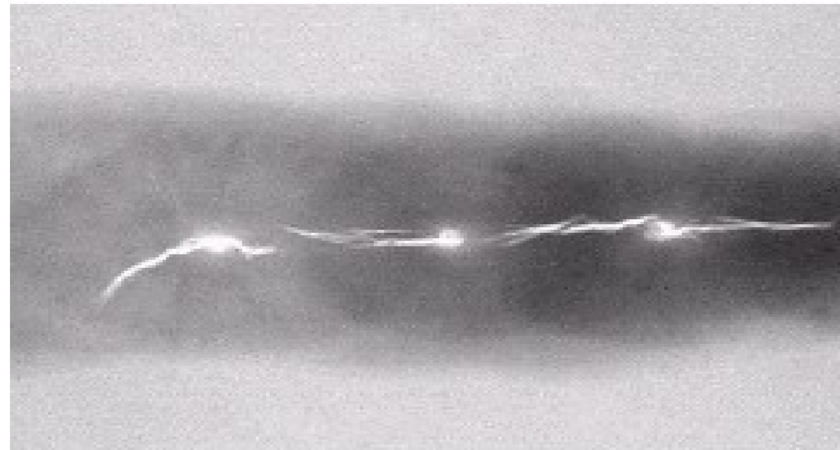
- Size and shape

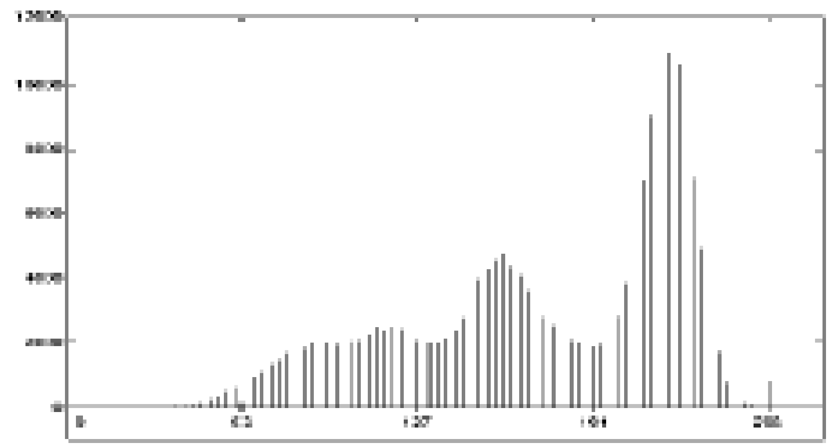
Trouble Spots

- Grouping without connectivity information.
- Stopping rule

Example – Region Growing

- Fig. shows x-ray image of a weld with defects and a histogram of the image.
- Defects have max. value (255). All these point are used as seed regions.
- Clean multimodal histogram





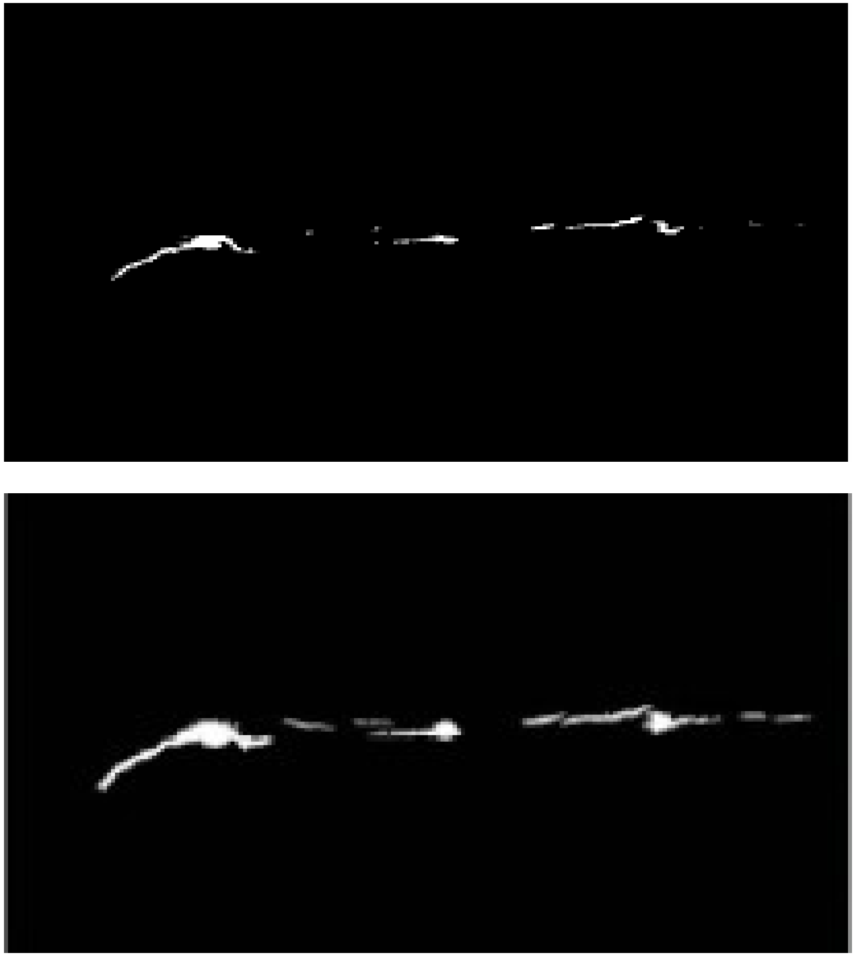
Example (continued)

- Criteria for region growing:

  Absolute gray level difference less than 65.

  Pixel 8-connected to at least one pixel in the region.

- Figs. show seed points and results of region growing



Color Image Segmentation

- Unsupervised or Supervised
- Supervised:-

  - Down-sampling → Blurring by LPF → color quantization
- Unsupervised:-

  - Palettized format → Wavelet transform → hue and chroma operations → recognize main colors → match color palettes

Segmentation by Morphological Watersheds

- Stable segmentation; continuous segmentation boundaries.

- Topographic - Visualizing in 3 dimensions: two spatial coordinates versus gray levels

Watershed 101

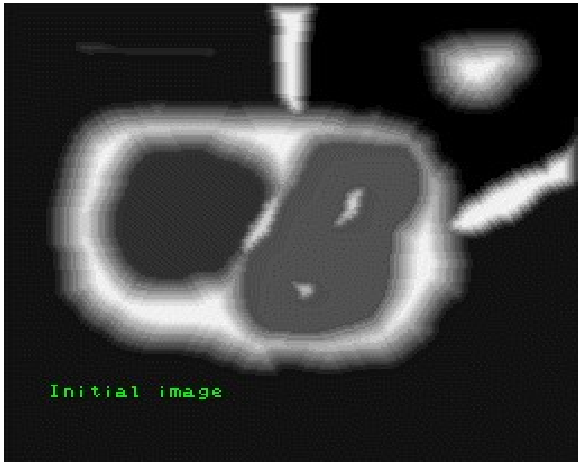
- Three types of points:
  1. regional minimum
  2. drop of water fall to single minimum
  3. drop of water fall to more than one minimum
- Catchment basin or watershed
- Divide lines or watershed lines

Watersheds: Concept and Method

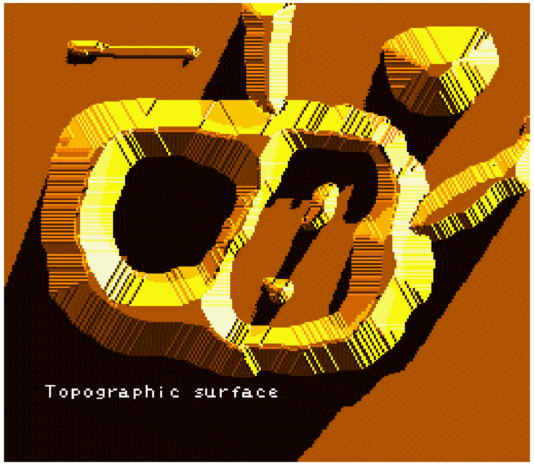
- Watershed lines hold the key.
- Basic idea:

  Hole in regional minimums → topography uniformly flooded from below → build dams to prevent merging → dam boundaries correspond to divide lines.
- Process continued till max. level of flooding (corresponding to highest gray-level value) is reached.
- Watershed lines form connected path – continuous boundaries.
- Often applied to gradient of image rather than image.

Example of Watershed Segmentation



Initial Image



Topographic Surface

Final watersheds

Drawbacks

- Concept difficult to understand!!
- Over-segmentation in gradient method.
- Modification:

  Markers

    Internal – associated with objects of interest

    External – associated with background

Summary

- Segmentation – essential preliminary step in most scene analysis and automatic pictorial pattern recognition problems.
- Choice of technique depends on peculiar characteristics of individual problems.

Further Reading

- Watershed method using markers
- Hierarchical segmentation using watersheds
- Use of motion in segmentation

References

- Jain R., Rangachar K., Schunk B. "*Machine Vision*" McGraw-Hill 1995
- Gonzalez R., Woods R. "*Digital Image Processing*" 2nd Ed. Pearson Education
- http://cmm.ensmp.fr/~beucher/wtshed.html