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6. Image segmentation

Histogram thresholding techniques (multi-threshold, average, p-tile, hysteresis, fashion, maximum distance, Otsu and adapted). Clustering Region-based techniques (growth, separation and split-and-merge). Transition-based techniques (Canny Edge Detector). Matching Template. Algorithms for segmentation.

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Concept

Image segmentation (IS) refers to the decomposition of a digital image into a series of distinct regions (sets of pixels).

The purpose of IS is to simplify, or change, the initial representation of an image to another representation that has greater meaning and therefore is simpler to analyze.

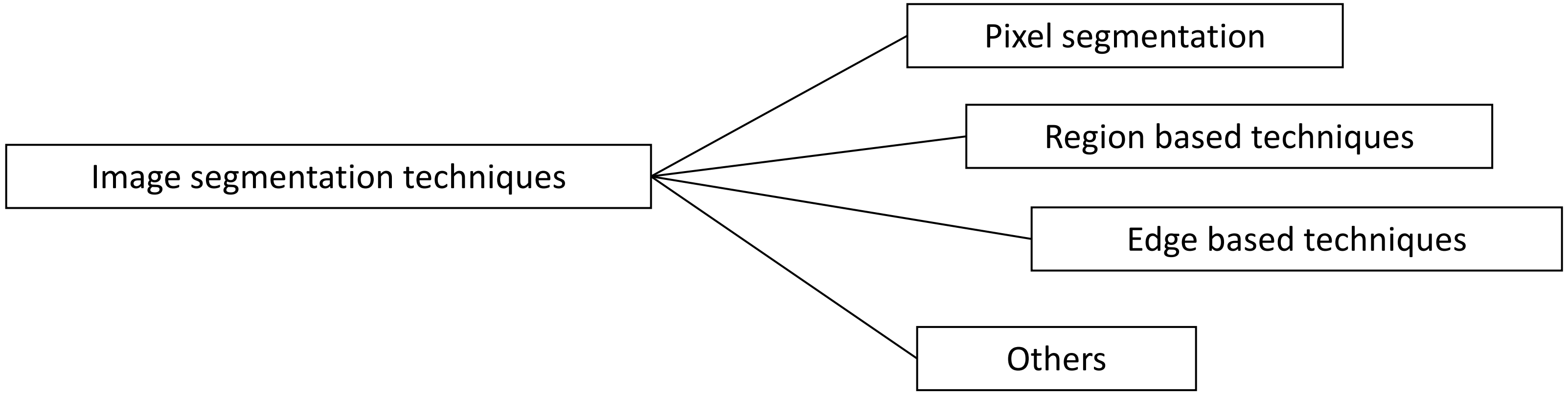
IS is typically used to locate objects and object boundaries in images.

All pixels in a segmented region are similar for certain characteristics, or computational properties, such as color, intensity, or texture.

Techniques

Adjacent regions are significantly distinct in terms of the same characteristics.

IS reduces pixel information to contextual information for regions.



Pixel segmentation

Let f(x,y) be a digital image: Pixel segmentation techniques rely on assigning a certain class to each pixel (x,y), in a set of possible classes $\Omega = \{\omega_k : k = 1 ,...\}$.

Pixels of the same class ω_k all together form a segment of the function f.

The assignment of a class to a pixel is guided by the definition of a certain vector v(x,y) that can be extended to several domains (spatial, spectral, temporal), thus improving segmentation.

The calculation volume is proportional to the number of pixels containing the image (high resolution methods aimed at extracting whole objects).

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Pixel segmentation

Simple histogram threshold: This is one of the most common forms of segmentation associated with the pixel classification technique.

It is useful in discriminating between foreground objects and context regions.

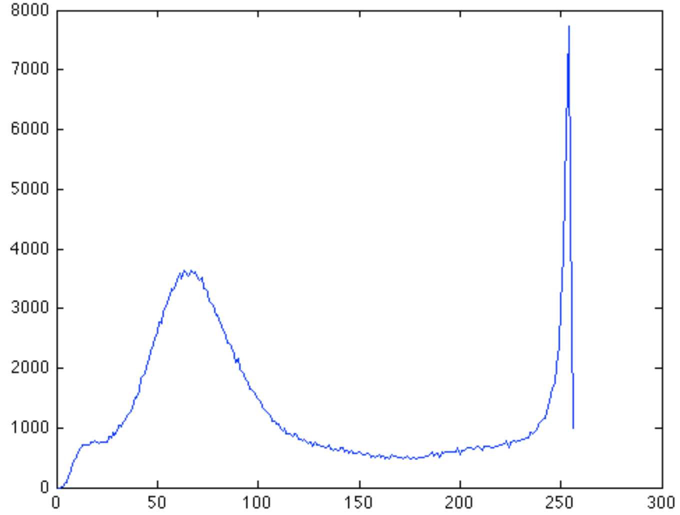
By selecting a certain threshold t value, the intensity image is converted to binary image.

Values for t are estimated by direct observation of the histogram.

Pixel segmentation

Examples of simple histogram threshold.

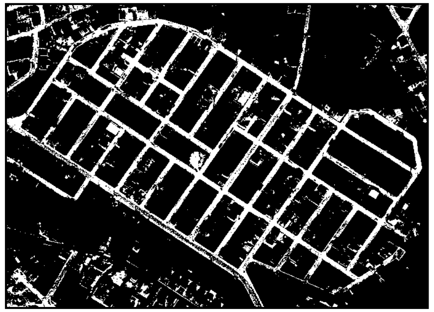
Histogram of F



F

F ≤ 150

150 < F ≤ 220

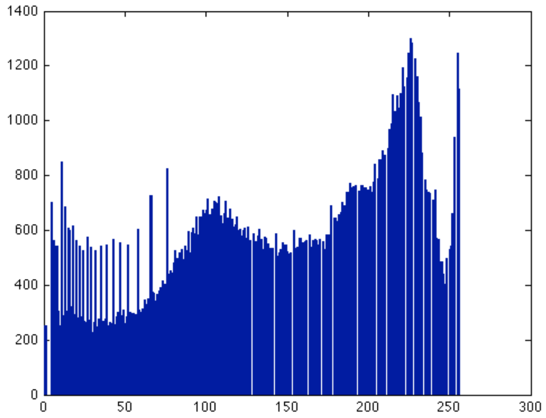


220 < F ≤ 255

Pixel segmentation

Average Threshold: The average value of the image is calculated and used as the value for t. This method is adopted when the image has approximately the same amount of pixels in the foreground and background motifs.

F



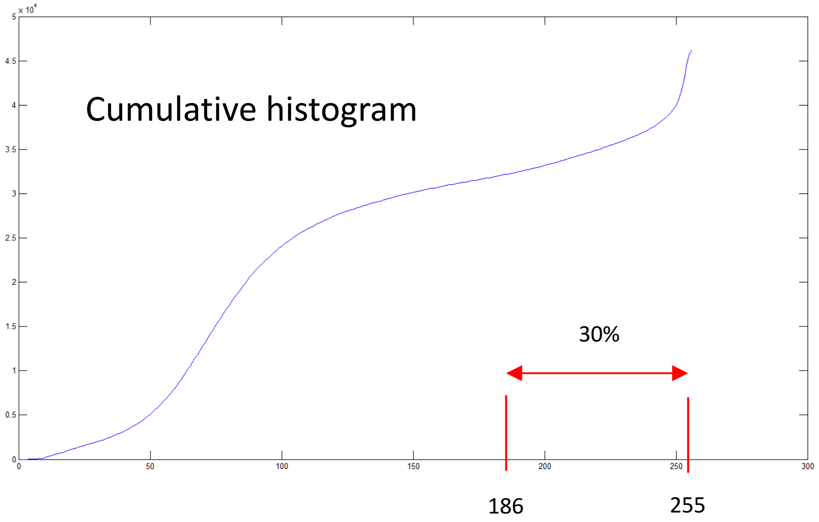
Histogram of F

F < 143 (average)

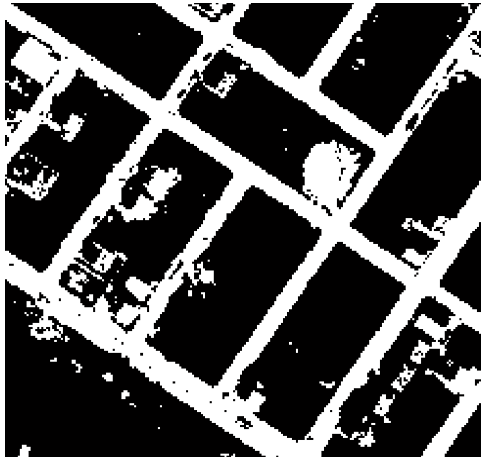
Pixel segmentation

Threshold by **“p-tile” method**: Applies when knowing the approximate fraction that a certain object occupies in the whole image.

- The value of t is determined by finding the intensity value corresponding to the desired number of pixels. The value of t is easily extracted from the accumulated histogram A, estimating A(t) = 1/p.



F



P-tile (30%): F > 186

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Pixel segmentation

Hysteresis Threshold: If there is no well-defined “valley” in the histogram, it means that there are background pixels that have gray values similar to the foreground pixels and vice versa. As such, two thresholds t1 and t2 (t2> t1) are made according to the following principles:

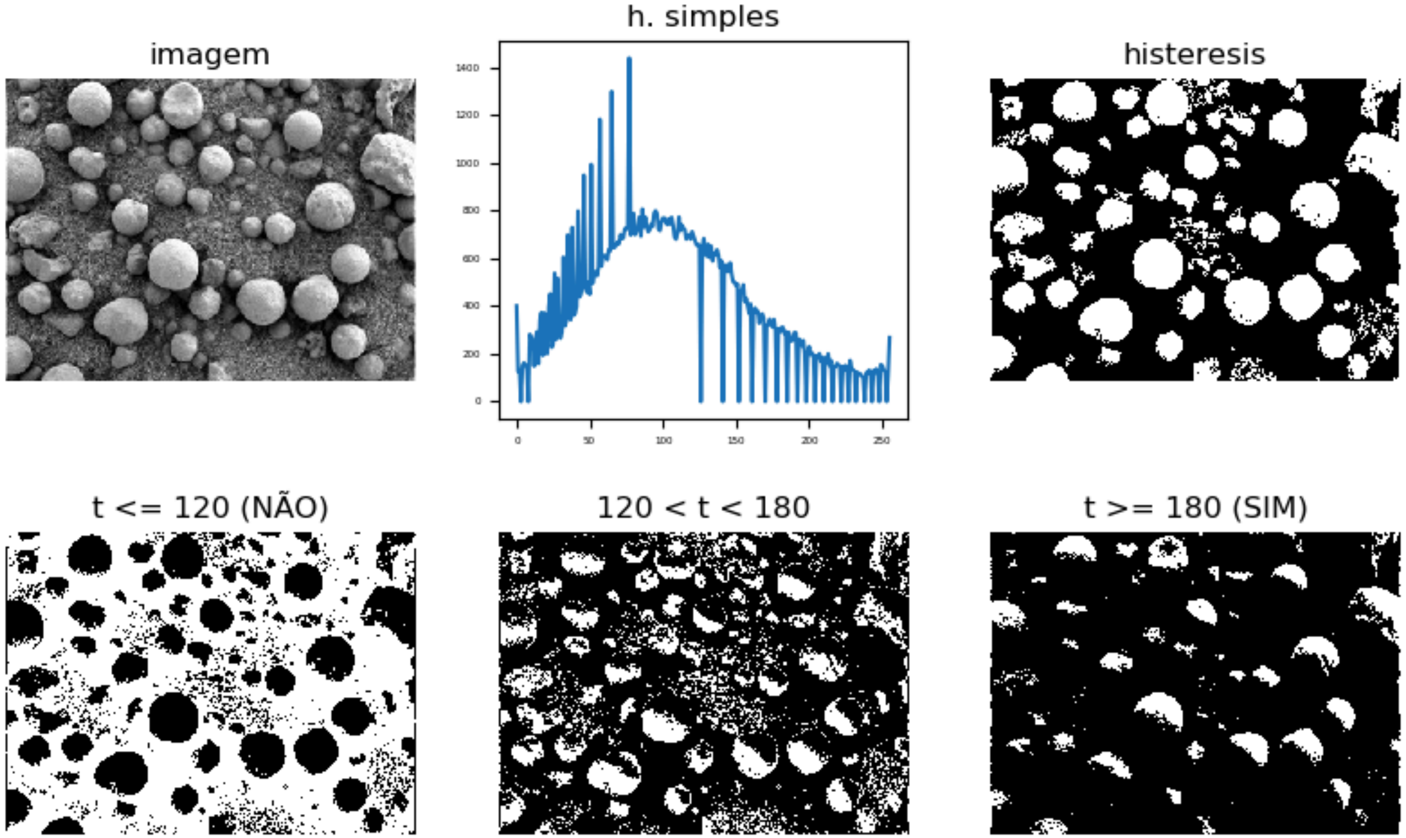
i. Pixels with values <t1 belong to the background;

ii. Pixels with values >t2 belong to the object;

iii. Pixels with values within the range [t1, t2] belong to the object if they are spatial adjacent to the object pixels.

Pixel segmentation

- Example of the hysteresis threshold method.



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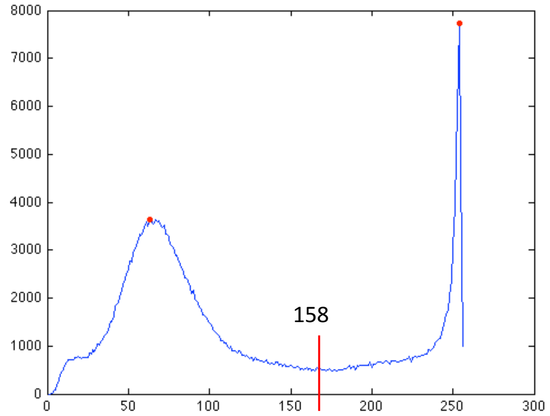
Pixel segmentation

Threshold by mode survey: determination of frequency peaks and local minimums between peaks (multimodal histograms).

F



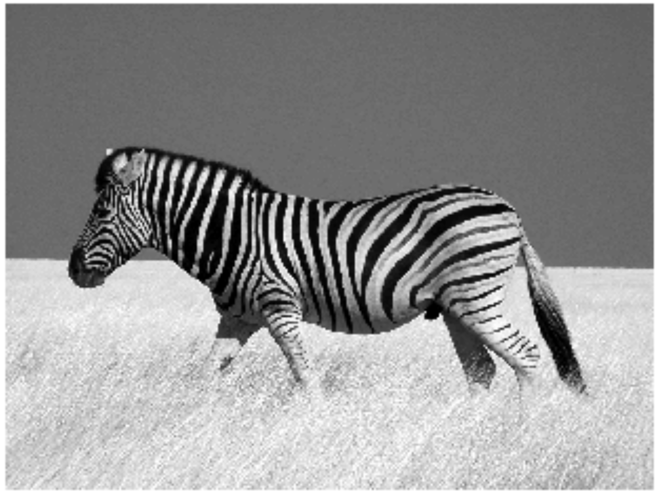
Histogram / modes

F < 158

Pixel segmentation

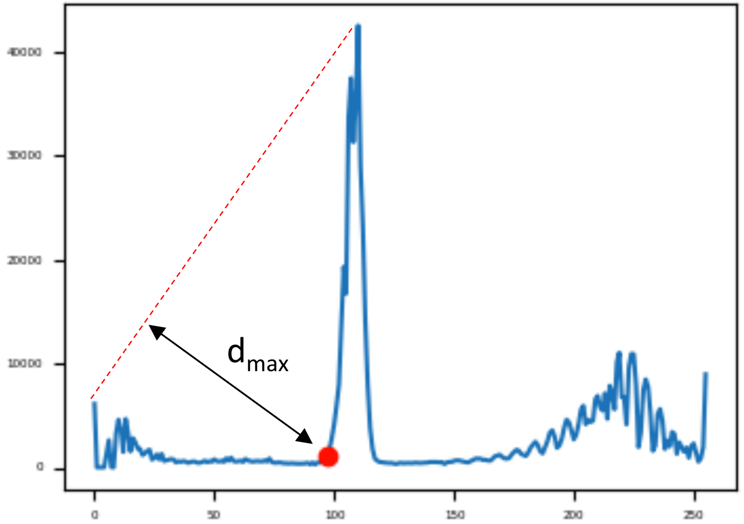
Maximum Distance Threshold (d): Determination of the gray level at the longest distance from the line joining the first non-zero frequency index and the significant peak of the histogram.

imagem

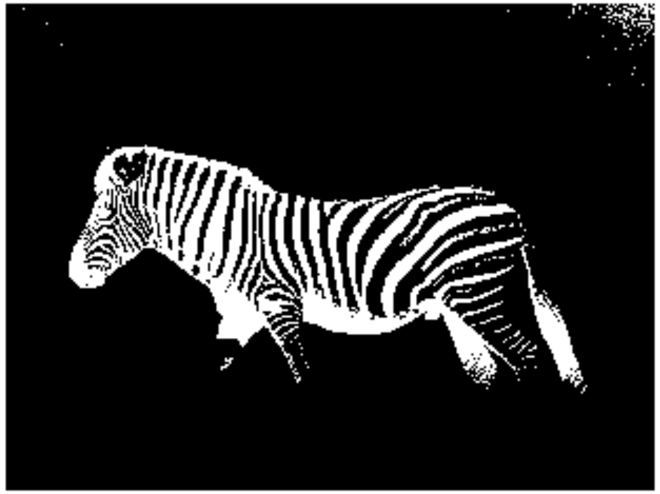


F

histograma



Máx. Dist. (t = 97)



F < 97

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Pixel segmentation

Threshold by Otsu method: This method is used to perform automatic thresholding of a gray image in two classes by means of an optimized statistical analysis.

The optimal threshold value that separates the two classes results from minimizing both weighted variances from all possible histogram thresholds.

$$\sigma_i^2 = w_e(t_i) \times \sigma_e^2(t_i) + w_d(t_i) \times \sigma_d^2(t_i)$$

$$\sigma^2 = \min(\sigma_i^2)$$

$$w_e(t) = \sum_{i=0}^{t-1} p_i \qquad w_d(t) = \sum_{i=t}^{255} p_i$$

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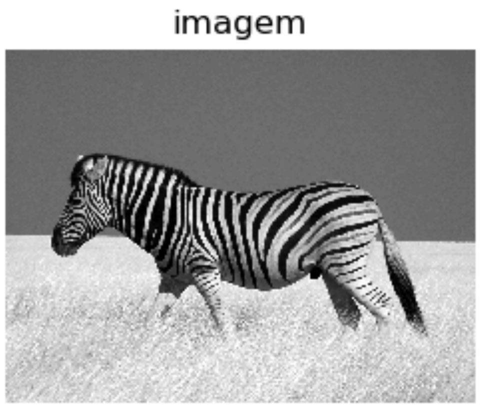
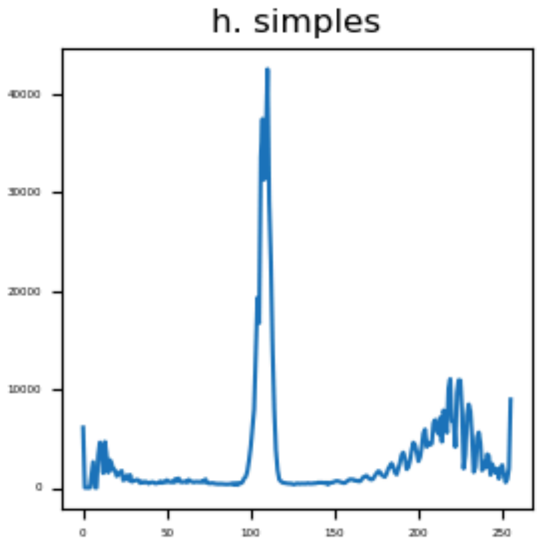
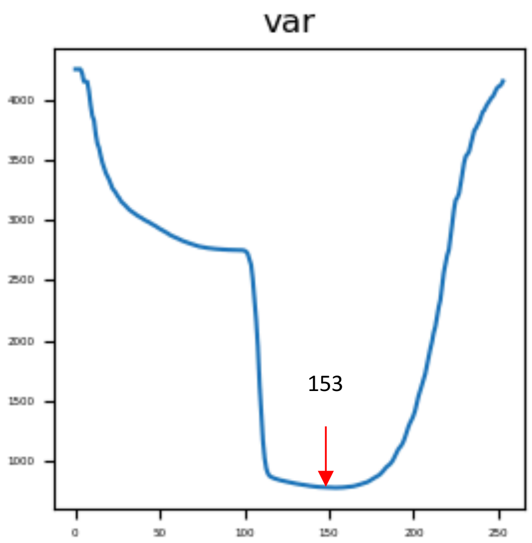
Pixel segmentation

Otsu threshold method example.

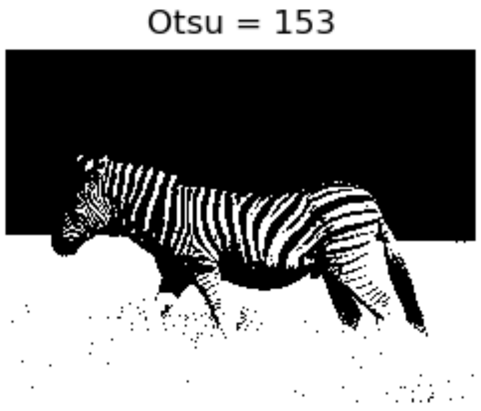


F





Variance for t_i



F > 153

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Pixel segmentation

Adaptive Threshold: This is a slightly refined pixel segmentation technique, applied in circumstances of varying brightness throughout the image. Thus, proceed as follows:

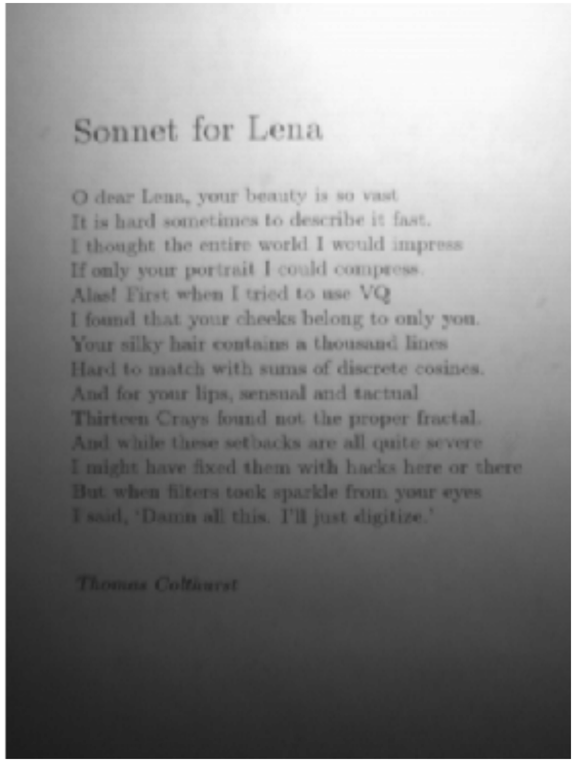
i. Apply low pass filter (average) with a filter of sufficiently large size (eg 11x11) to "blur" the aimed information;

ii. Determine the absolute value of the subtraction between the filtered image and the original image, followed by the subtraction of a constant K (i.e. 10) from the result;

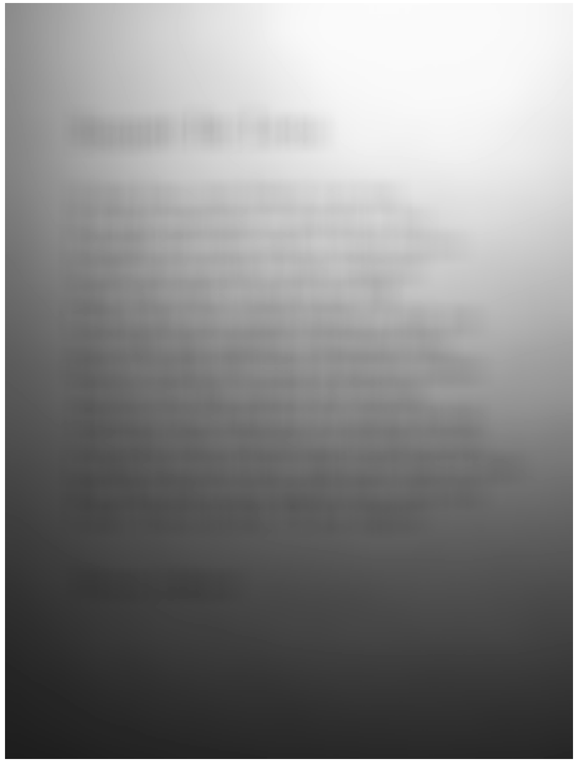
iii. Simple thresholding of the previous result.

Pixel segmentation

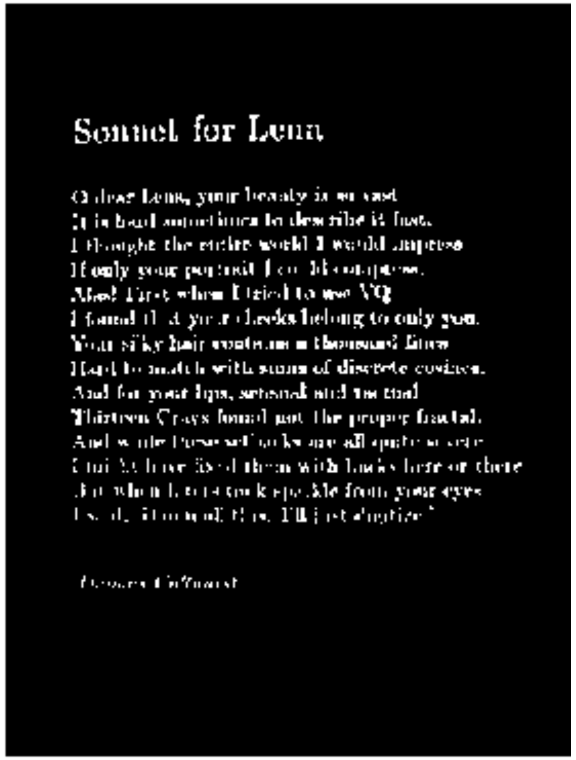
Example of adapted threshold method.



F



Low-Pass filtering



Adaptive threshold

Pixel segmentation

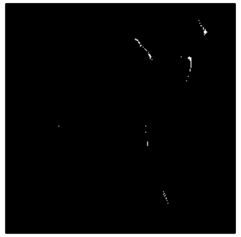
Multi-level Threshold (Quantization): Some images may contain objects of different intensities. For this purpose thresholds at various intensity levels can be used to separate these objects.


F


F ≤ 75


75 < F ≤ 125


125 < F ≤ 225


F > 225


Multi-level threshold

Pixel segmentation

In summary, threshold operations generally have the following:

Benefits:

- Ease of implementation.
- Speed (especially if repeated on similar images).
- Suitable for certain types of images (eg text documents).

Disadvantages:

- Segmentation is sometimes ineffective as it does not guarantee object coherence (eg voids, “strange” pixels, etc.).

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Clustering

Clustering: This is a segmentation technique that aims to organize/group pixels into clusters based on their attributes.

- Set initial centroids for clusters.
- Determine which pixels are closest to each centroid of the clusters.
- Each centroid is re-determined from a given measure of its cluster.
- The process is iterative and ends when the centroids do not change position.

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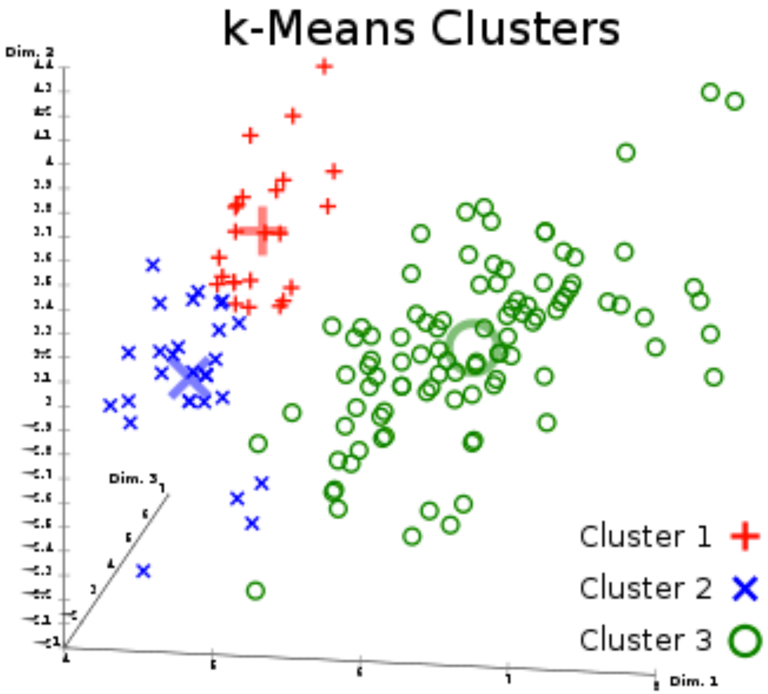
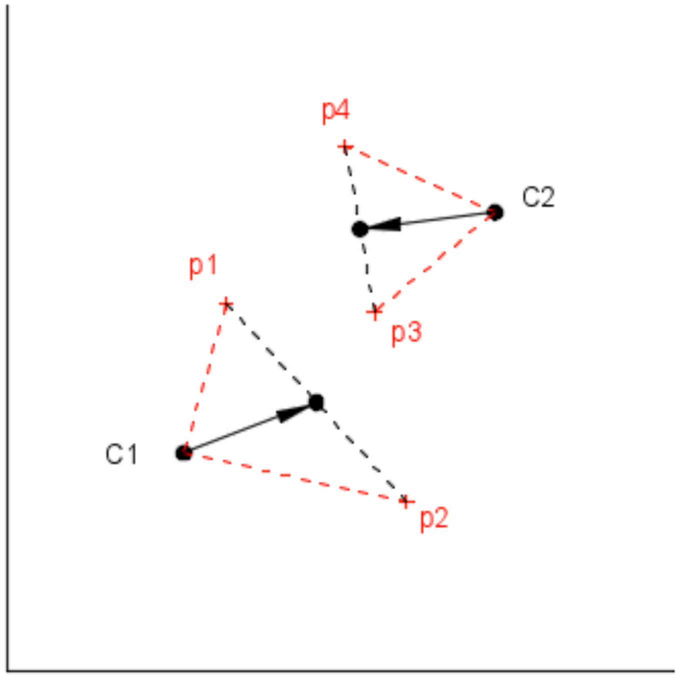
K-Means Clustering

Technique that aims to group pixels into clusters by their average.





$$W(C) = \sum_{k=1}^{K} N_k \sum_{C(i)=k} \| x_i - m_k \|^2$$

x_i : samples

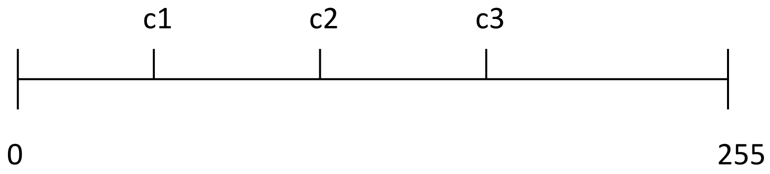
m_k : mean value of cluster k

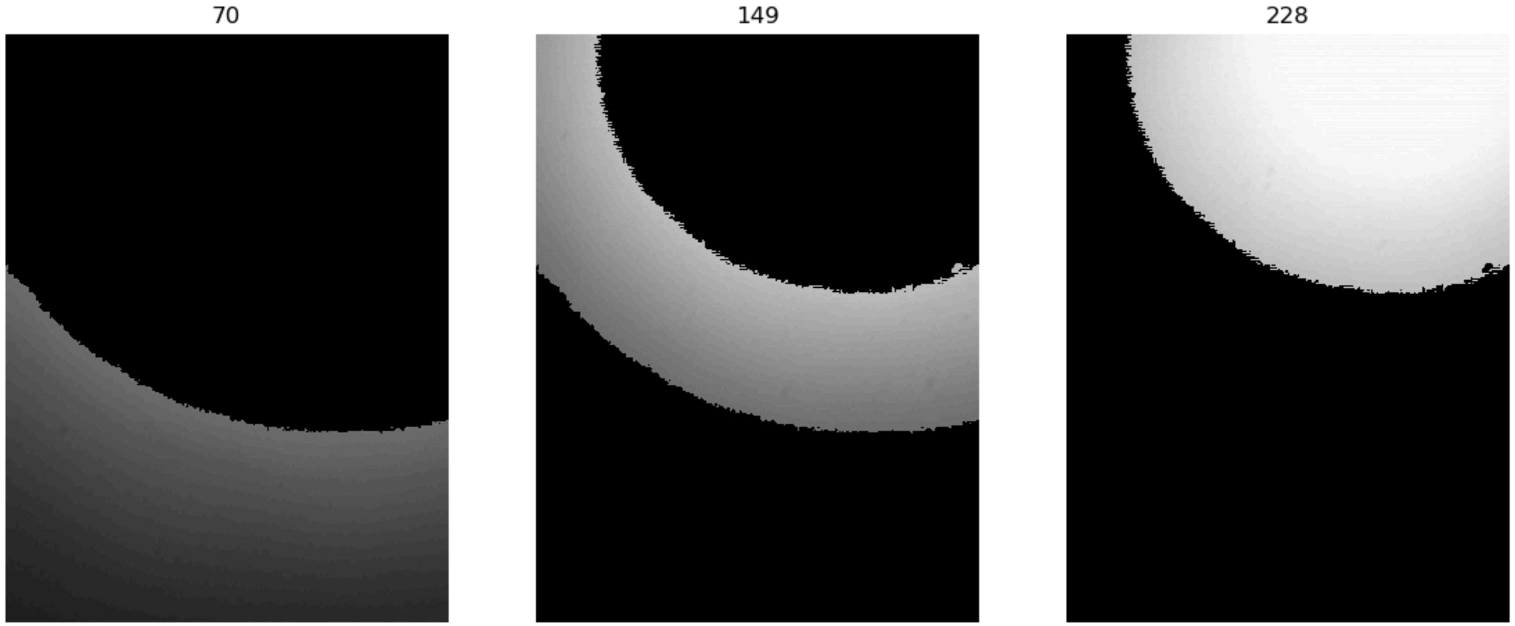
N_k : number of samples of cluster k

Gray K-Means Clustering

Aggregation of pixels of a gray image in clusters.

Image





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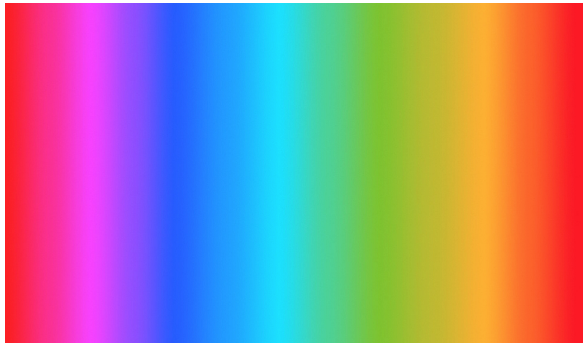
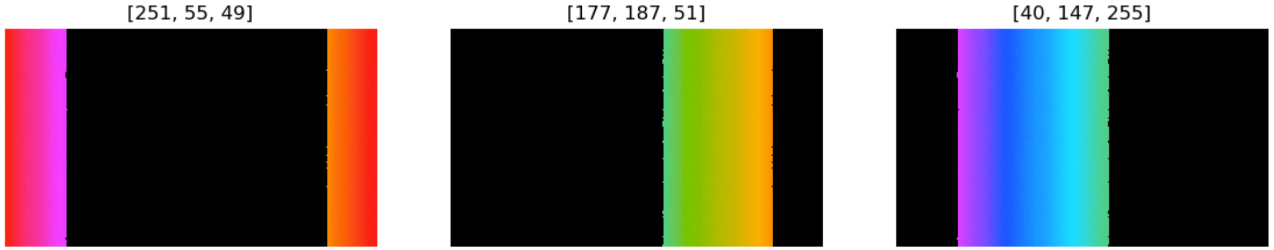
Color K-Means Clustering

Color example:

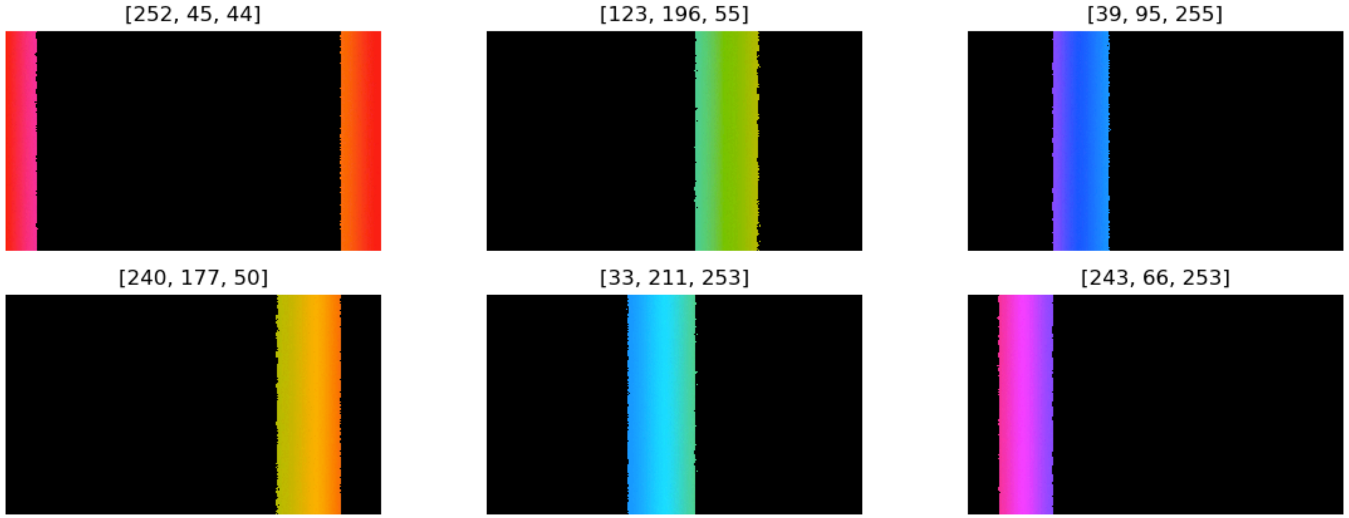


Imagem

3 clusters



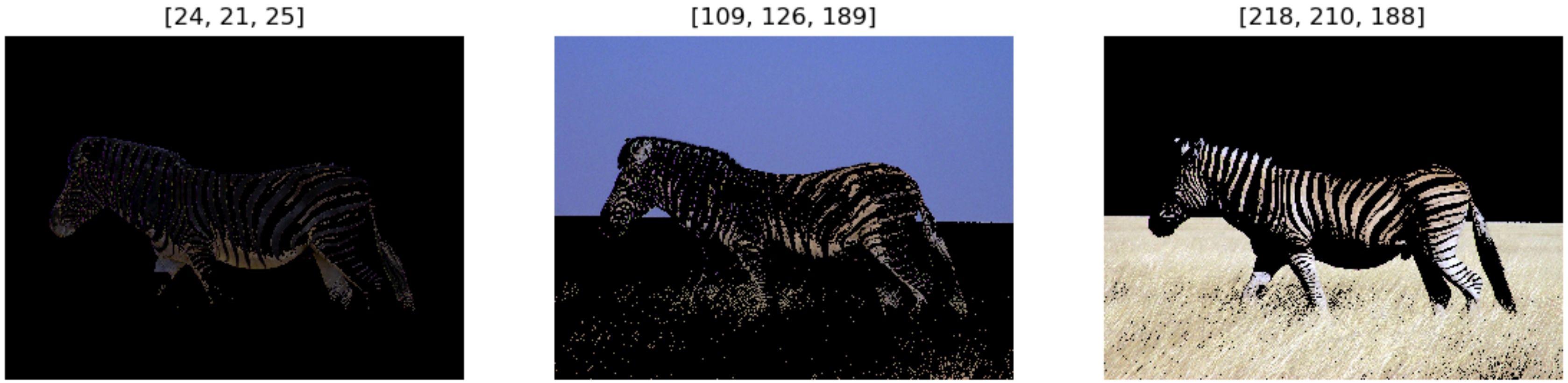
6 clusters



Color K-Means Clustering

24-bit image color example.

Image



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Multivariate histogram(HMV)

The goal of multivariate analysis is to establish and use spatial correlations of pixel intensities to reduce data information to a finer level for easier interpretation.

Since multivariate analysis investigates the spatial correlation of intensities between images, if there is little or no complementary information between them, the technique is unlikely to produce more relevant information.

In this context, multivariate histogram analysis should be seen as a complementary tool to conventional means of image analysis.

Bivariate or trivialized histograms are therefore the tools that can be produced for further analysis.

Multivariate histogram(HMV)

The HMV calculation of an RGB image is as follows:

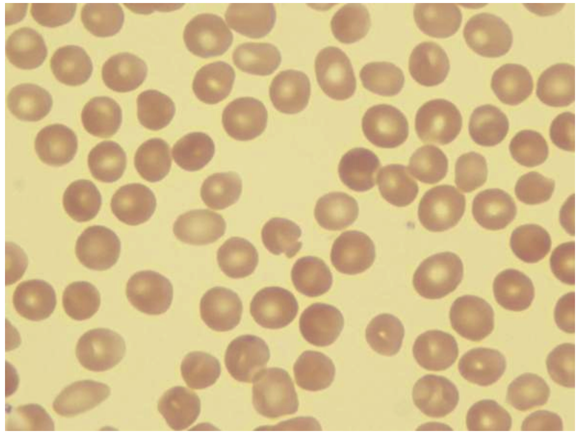
$$HMV[p,q,0] = HMV[p,q,0] + 1 \qquad \begin{cases} p = F[i,j,0] \\ q = F[i,j,1] \end{cases}$$

$$HMV[p,q,1] = HMV[p,q,1] + 1 \qquad \begin{cases} p = F[i,j,0] \\ q = F[i,j,2] \end{cases}$$

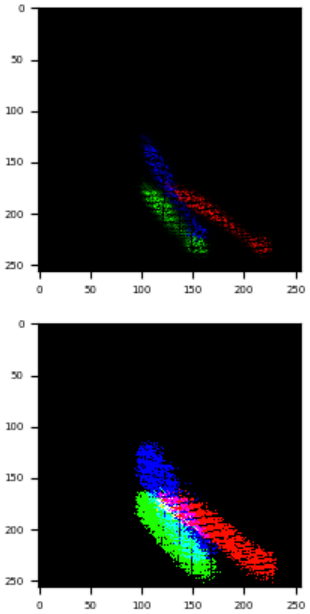
$$HMV[p,q,2] = HMV[p,q,2] + 1 \qquad \begin{cases} p = F[i,j,1] \\ q = F[i,j,2] \end{cases}$$

Multivariate histogram(HMV)

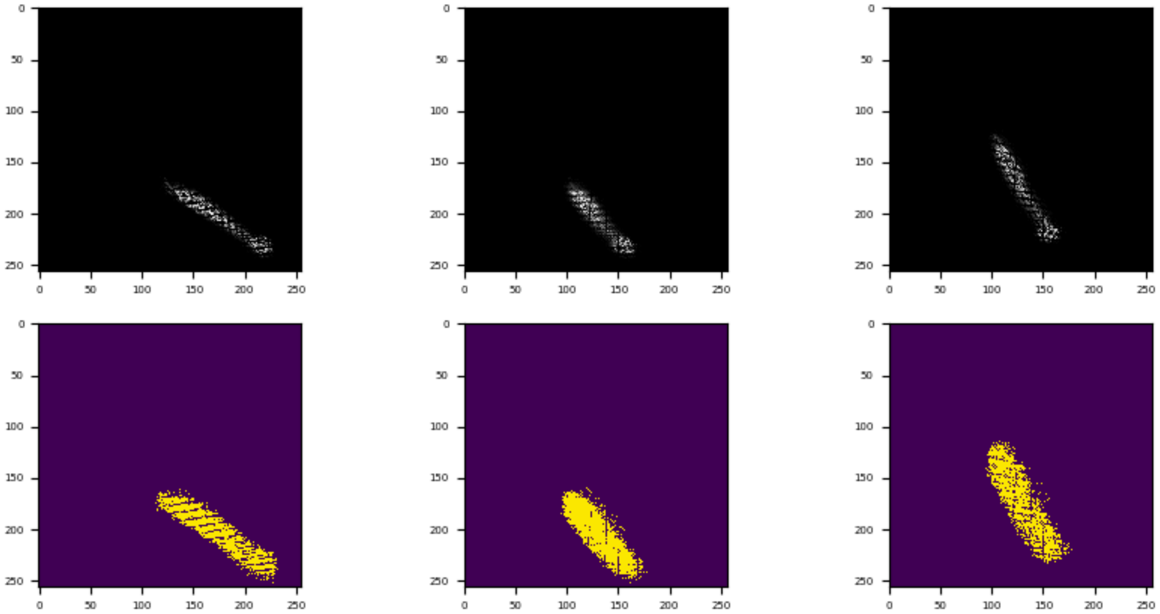
Example.



Inicial image



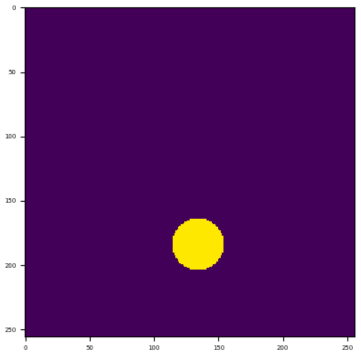
HMV



Components

HMV segmentation

Segmentation of HMV by choosing a region of interest.



Region of interest in the histogram

Pixel selection

Final image

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Region based techniques

These techniques aim to partition or aggregate regions according to characteristics associated with image pixels (pixel intensity value of the original image or calculated using a certain operator; texture, or pattern of objects; spectral profiles that provide multidimensional data).

Based on these characteristics and according to criteria of similarity between the pixels of the image, the homogeneous regions are progressively constructed with iterative algorithms and the iterative process is terminated as soon as all the pixels of the image are classified according to the designated characteristics. .

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Region based techniques

The boundary between each two different regions is defined where both meet.

In the final characterization of the R_i regions of an image I, the condition of spatial independence for all of them must be respected.

$$I = \bigcup_{i}^{s} R_i \quad \wedge \quad R_i \cap R_j = \phi \quad , \quad i \neq j$$

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Region based techniques

Region growing: starts from a set of small regions previously segmented and with properties considered homogeneous, in the set of pixels that constitute them.

In the simplest methods, regions from small regions of 2×2, 3×3, or 4×4 pixels (seed regions) are appended.

Each region is generally described according to statistical properties of its gray levels. When adjacent regions resemble each other, they attach, thus giving rise to a new, larger region. Otherwise they will be classified as non-similar and remain separate.

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Region based techniques

The attachment process thus continues between other neighboring regions, including newly attached ones.

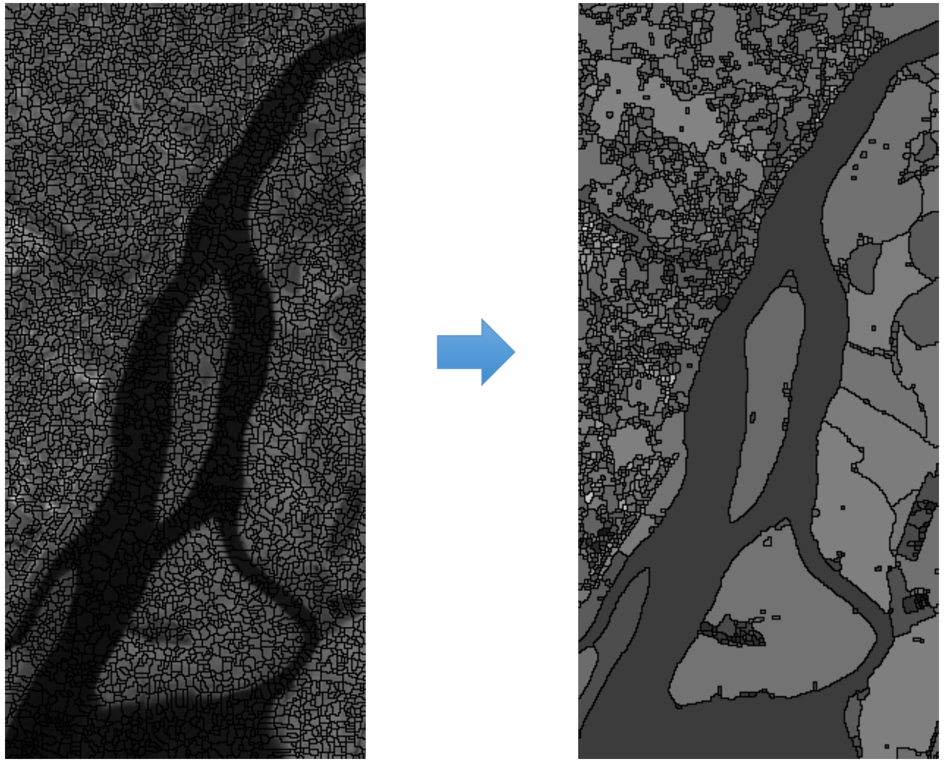
When a certain region cannot be attached to any other region, the attachment process ends, or the attachment criteria is redrafted.

The method ends when each region is uniquely ranked relative to the others without any other attachments. The homogeneity criteria that determine the various region attachments are diverse: levels of gray, color, texture, shape, according to a certain model, etc.

Watershed morphological transformation is often referred to as the technique used in the preliminary definition of regions.

Region based techniques

Example of image resulting from the process of region growth from the attachment of smaller regions, based on radiometric criteria.



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Region based techniques

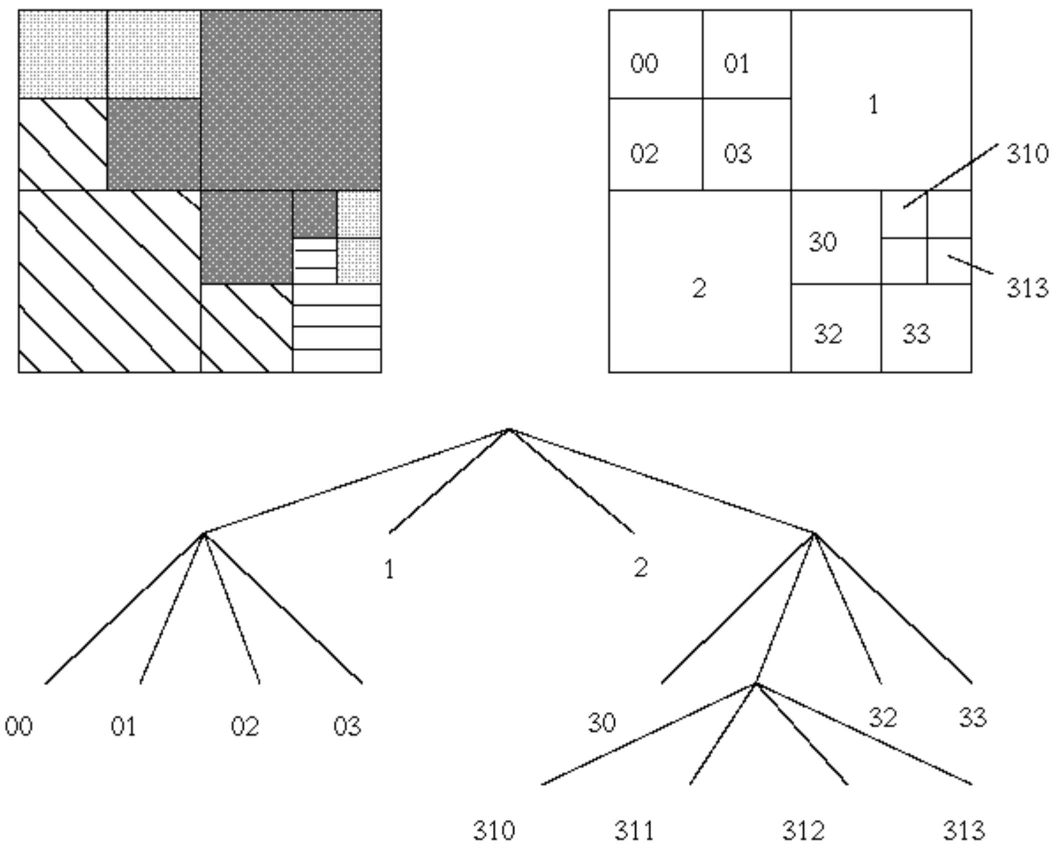
Region splitting: separation of the image, or one or more areas of interest of an image into a set of disjoint regions, so that there is coherence between the pixels of each region for certain properties.

Total area divided into disjoint regions if the corresponding pixels do not respect a certain constraint of similarity. As a rule, the initial partition is made in four quadrants.

The process continues in each new area of interest until no further partitions occur.

Region based techniques

Illustration of a region-splitting methodology.



Region based techniques

Successive division into four equal squares; one region remains if it meets the homogeneity criterion (difference> 1); ends when there are no more divisions.

1	1	1	1	1	1	1	2
1	1	1	1	1	1	1	0
3	1	4	9	9	8	1	0
1	1	8	8	8	4	1	0
1	1	6	6	6	3	1	0
1	1	5	6	6	3	1	0
1	1	5	6	6	2	1	0
1	1	1	1	1	1	0	0

F

1	1	1	1	1	1	1	2
1	1	1	1	1	1	1	0
3	1	4	9	9	8	1	0
1	1	8	8	8	4	1	0
1	1	6	6	6	3	1	0
1	1	5	6	6	3	1	0
1	1	5	6	6	2	1	0
1	1	1	1	1	1	0	0

1st step

1	1	1	1	1	1	1	2
1	1	1	1	1	1	1	0
3	1	4	9	9	8	1	0
1	1	8	8	8	4	1	0
1	1	6	6	6	3	1	0
1	1	5	6	6	3	1	0
1	1	5	6	6	2	1	0
1	1	1	1	1	1	0	0

2nd step

1	1	1	1	1	1	1	2
1	1	1	1	1	1	1	0
3	1	4	9	9	8	1	0
1	1	8	8	8	4	1	0
1	1	6	6	6	3	1	0
1	1	5	6	6	3	1	0
1	1	5	6	6	2	1	0
1	1	1	1	1	1	0	0

3rd step

Region based techniques

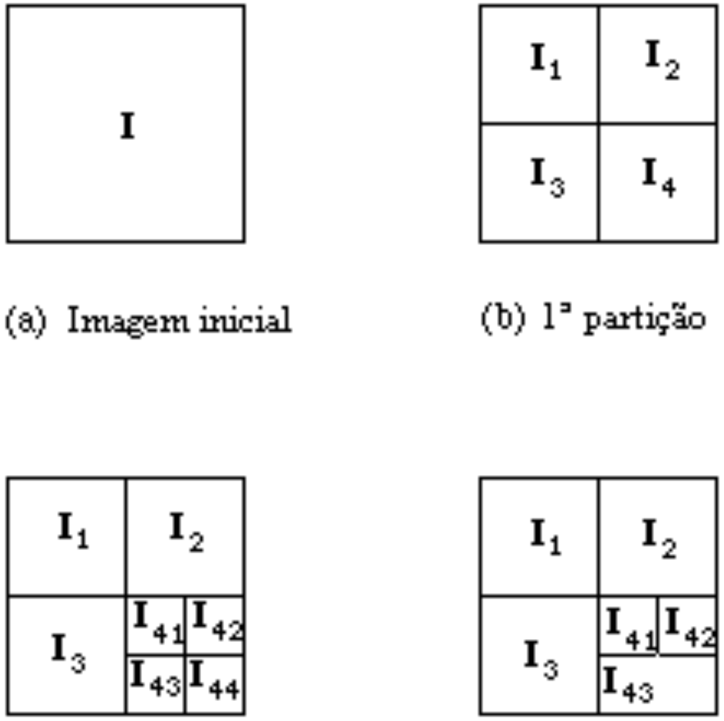
Split and merge: A combination of region splitting and region growing techniques.

After splitting by region splitting, a fusion process of the subregions meeting the established homogeneity criteria is performed.

The Image Segmentation Method, known as quadtree decomposition, is an example of the split-and-merge technique, which consists of partitioning the image into identical squares (square-area images and 2^L dimensions) and then attaching the regions that have similar radiometric properties.

Region based techniques

Illustration of split and merge method.



(a) Imagem inicial
(b) 1ª partição
(c) 2ª partição
(d) Fusão

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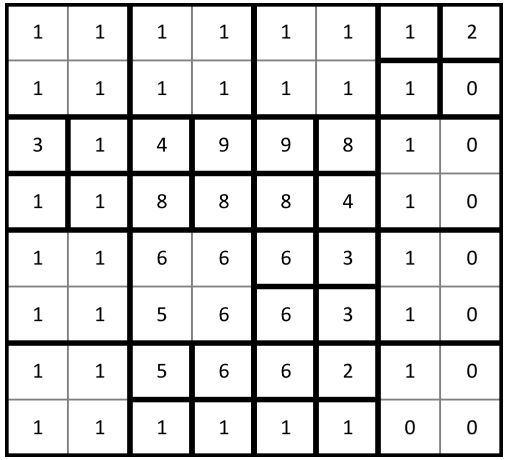
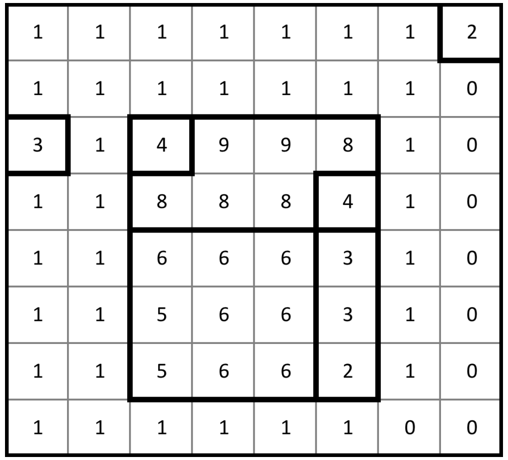
Region based techniques

Illustration of split and merge method.



Splitting



Merging

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Edge based techniques

These techniques rely on determining transition lines in an image by using transition zone detection operators (transitions correspond to radiometric, textural discontinuity zones, etc.).

The radiometric variation in the boundary pixels between two adjacent distinct regions is much more significant than the variation between the pixels internal to each of these regions.

However, the results of segmentation detection by transitions must go through further processing steps in order to match the lines found to the specific objects to be delimited.

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Edge based techniques

Performing one of the techniques of segmentation, region growing, or detection of transitions, it becomes intuitive to define the other, as built regions becomes accessible from knowledge of their transitions, as well as defining transitions, from the knowledge of the regions.

It may be that the regions of an image obtained with region growth methodologies do not coincide with those obtained by transition detection methodologies, or vice versa.

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Edge based techniques

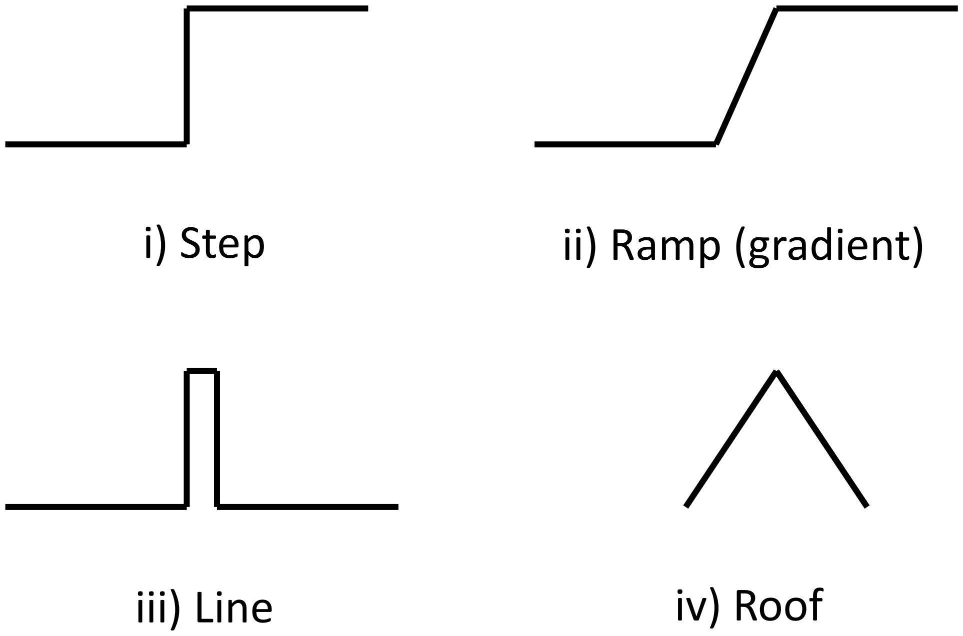
Transitions are discontinuities in the intensity of a given image, and may be of the following types:

- “Step”: where the change is made abruptly between two distinct values.
- “Line”: where the change happens, however returning to the previous value after a short distance.

However, these changes are indeed rare and almost always occur with the ramp and roof models.

Edge based techniques

Illustration of the transition models.



Edge based techniques

Canny-Edge detector: is an algorithm designed to be a border detector.

We start from a gray image and obtain a binary image with the positions of the striking radiometric discontinuities of the initial image.

It runs in several steps that focus on various concepts of image processing, such as filtering, quantization, and gradient.

Edge based techniques

1. The image is smoothed with a gaussian filter.

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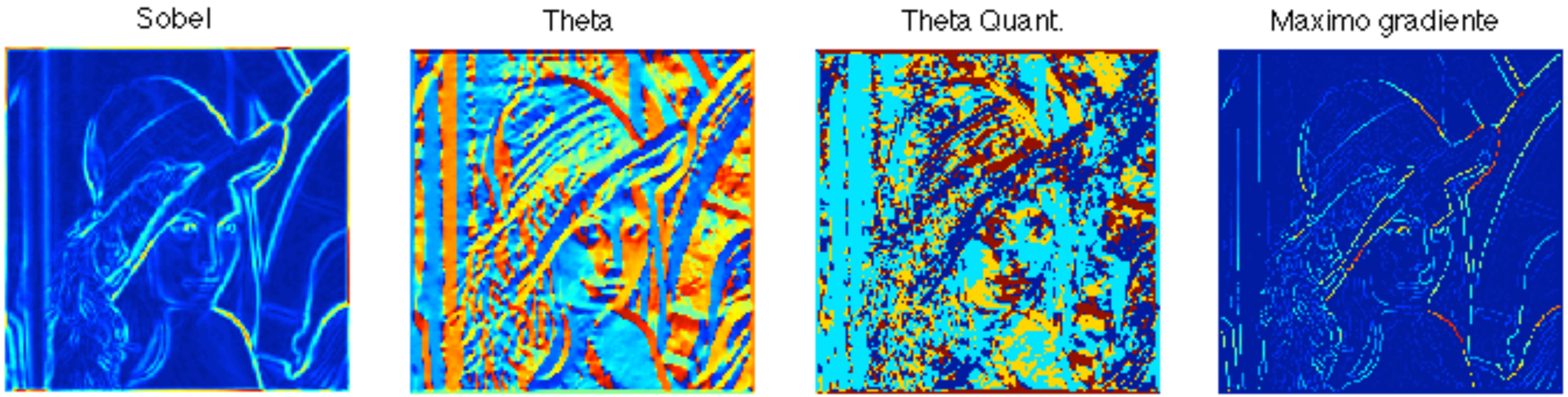
Edge based techniques

2. A simple derivative filter (eg Sobel's) is performed over the smoothed image to highlight the first higher spatial derivatives.

Edge based techniques

3. The algorithm performs a search along the junction lines and zeroes all non-topline pixels, resulting in only one line (a process known as non-maximal suppression).



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Edge based techniques

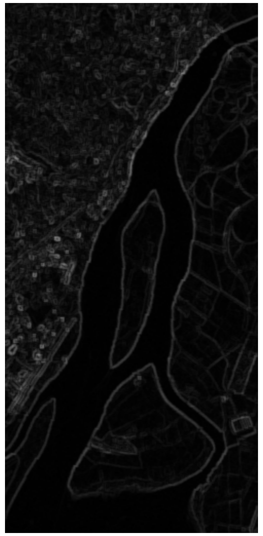
4. The thread segmentation process is controlled by two thresholds t1 and t2 where t1> t2. All pixels above t2 (strong pixels) belong to the boundary lines; all below t1 (weak pixels) do not belong. Between t1 and t2, the choice of pixels is performed by hysteresis (hysteresis).

Canny Programado

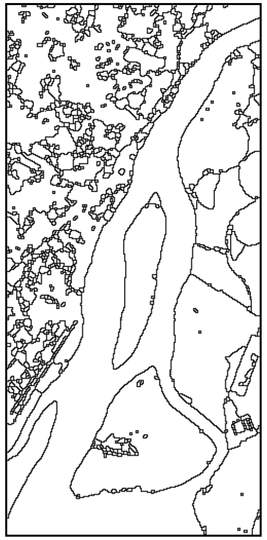
Hybrid techniques

Combining the various results is generally a good option in the final characterization of regions.

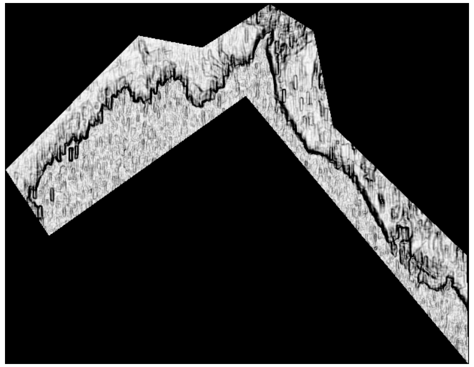
Combinations of transitional detection region growth techniques are referred to as **hybrid segmentation techniques**.



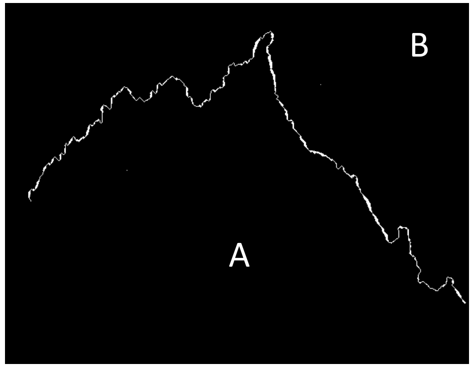
Morphological gradient



Regions



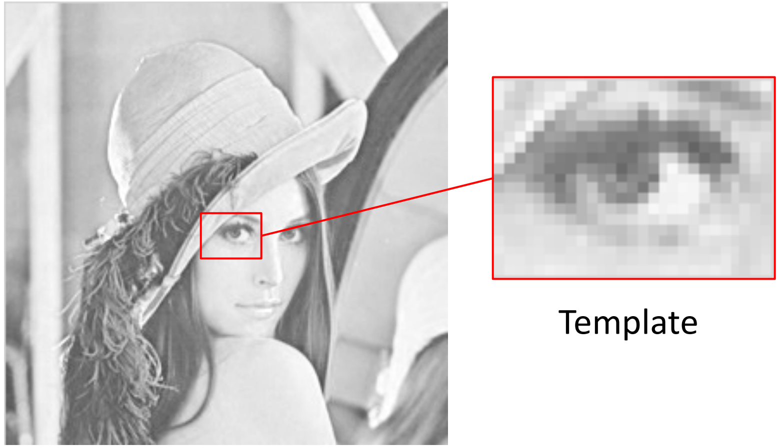
Sobel high-pass filter



Regions

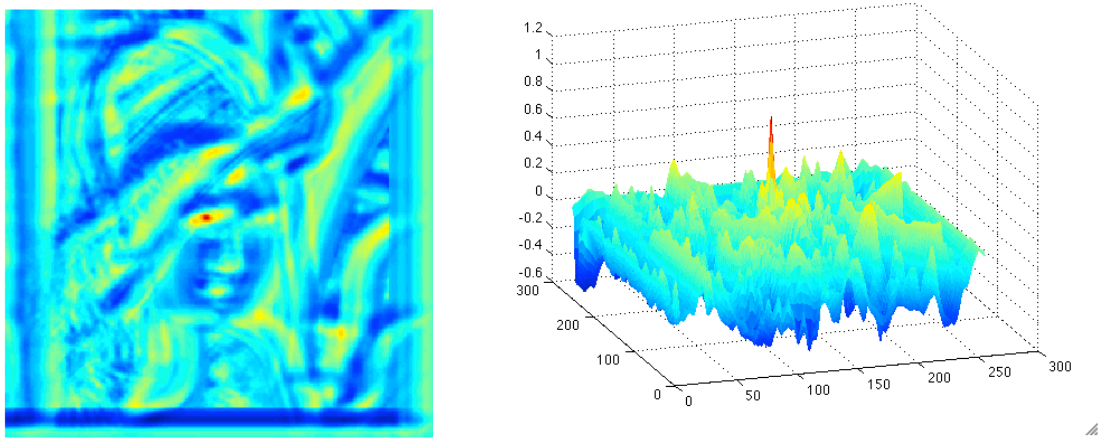
Template Matching

Template matching: A segmentation technique that aims to find objects similar to a given object called a template. It is usually performed based on the normalized cross correlation operator.



Template

Image



Normalized cross correlation

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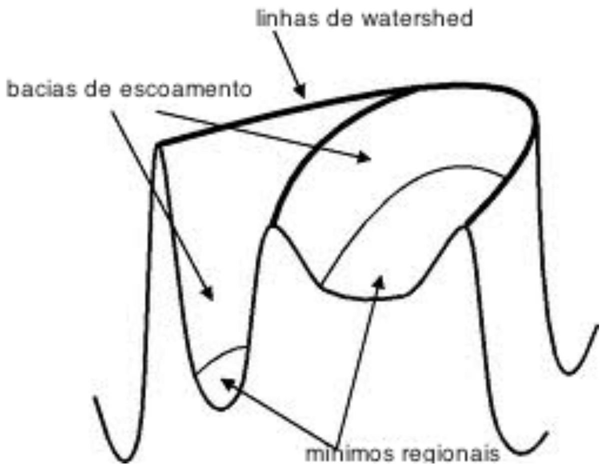
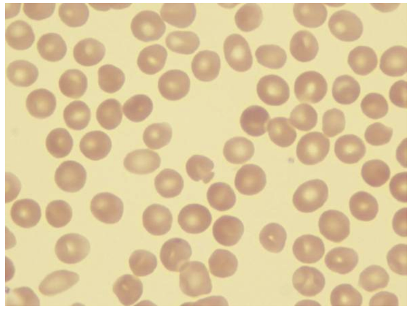
Morphological segmentation

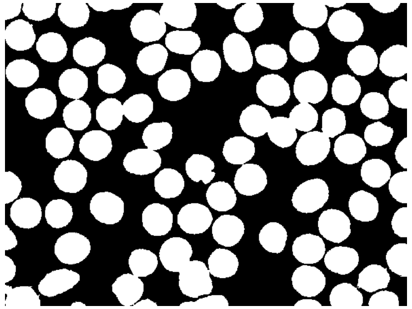
The morphological image segmentation approach combines region growth and transition detection techniques. This approach groups pixels around the regional minima of the image. The boundaries of adjacent pixel groups are precisely positioned on the "crest" lines of the gradient image. This result is achieved with the watershed transformation.

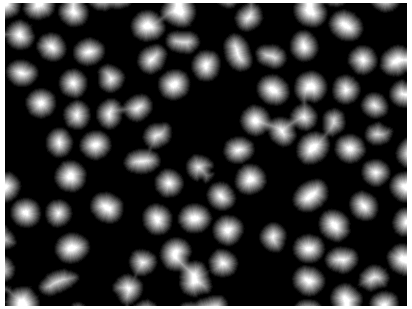


Morphological segmentation

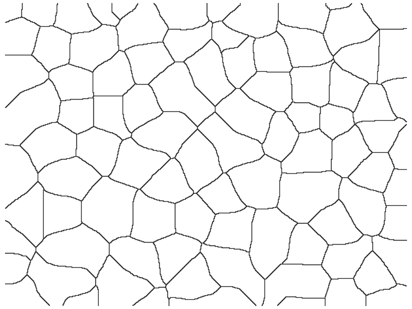
Example: Separation of overlapping cells (combination of various morphological techniques).

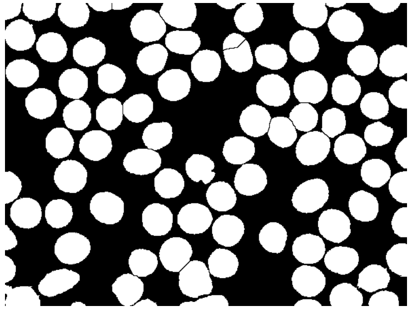

F


TH (threshold) + Filtering


D (distance)


Markers (maxima of D)


W (watershed of NOT[D])


Result

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Hierarchical Segmentation

The hierarchical approach of image segmentation makes it possible to relativize the importance of the regions segmented among themselves, due to the results obtained in different phases of an iterative process.

It is based on the systematic application of the same algorithm to an image resulting from its application.

Allows you to achieve multiple levels of segmentation where, from one iteration to another, sets of pixels or regions are extinguished.

Associated with each output image, its information is associated with a hierarchical level of segmentation.

Hierarchical Segmentation

Example: Mosaic Image (by morphological methods).

Intensity

Watershed of gradient

Mosaic 1

Mosaic 2

Hierarchical Segmentation

Example: Waterfall methodology

TerraSAR (banda X) de uma área costeira de Lisboa
Resolução espacial = 3 m
Dimensões: 1209 × 2770

Método 1

Método 2