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College of Science

Fourth stage

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جامعة المستقبـل
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Medical Image Analysis

Region-Based Segmentation, Segmentation Using the Watershed Transform

1 (preprocessing) 2 (transformation) 3 (**Model Construction**) 4 Model
Evaluation (training / testing)

By

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1. Segmentation by Region Growing and WaterShed Transform

As its name implies, region growing *is a procedure that groups pixels or subregions into larger regions based on predefined criteria for growth*. The basic approach is to start with a set of “seed” points, and from these grow regions by appending to each seed those neighboring pixels that have predefined properties similar to the seed (such as ranges of intensity or color).

The selection of similarity criteria depends not only on the problem under consideration, but also on the type of image data available. For example, the analysis of *land-use satellite imagery depends heavily on the use of color*. This problem would be significantly more difficult, or even impossible, to solve without the inherent information available in color images. When the images are monochrome, region analysis must be carried out with a set of descriptors based on intensity levels and spatial properties.

Region growing based techniques are better than the edge-based techniques in noisy images where edges are difficult to detect.

Region growing is the formulation of a stopping rule. Region growth should stop when no more pixels satisfy the criteria for inclusion in that region. Criteria such as intensity values, texture, and color are local in nature and do not take into account the “history” of region growth. Additional criteria that can increase the power of a region-growing algorithm utilize the concept of size, likeness between a candidate pixel and the pixels grown so far (such as a comparison of the intensity of a candidate and the average intensity of the grown region), and the shape of the region being grown. The use of these types of descriptors is based on the assumption that a model of expected results is at least partially available.

Region growing is known as a simple and fast method to segment an image. Many papers on medical image segmentation have reported the use of this method in a variety of applications, for example, to detect cardiac disease and breast cancer and to delineate tumor volumes. One approach compares *the initial seed pixels with the unassigned pixels*. Another approach compares *the outermost pixels with their unassigned neighbor pixels at each iteration*. The first leads to

consistent segmented areas but is very *sensitive to noise*. The second may result in inaccurate segmentations especially in cases where the pixel attributes change gradually, *but it is robust to noise*.

Region growing refers to the procedure that groups pixels or subregions into larger regions. Starting with a set of seed points, the regions are grown from these points by including to each seed point those neighboring pixels that have similar attributes like intensity, gray level texture, color, etc. It is an iterative process where each seed pixel grows iteratively until every pixel is processed and thereby forms different regions whose boundaries are defined by closed polygons. The important issues in the region growing are:

- *Selection of initial seeds that represent regions and the selection of suitable properties for including the points in various regions during the growing process.*
- **Growing the pixels** based on certain properties of the image may not ascertain good segmentation. Connectivity or adjacency information should also be used in the region-growing process.
- **Similarity:** The similarity denotes the minimum difference in the gray level observed between two spatially adjacent pixels or average gray level of a set of pixels, which will yield different regions. If this difference is less than the similarity threshold value, the pixels belong to the same region.

10 11 100 150 220

Seed1 = 11

Seed2 = 150

Euclidean distance : $(10-11)^2 = 1 = \text{SQRT}(1) = 1$, then distance between seed 11 and point pixel 10 = 1

- **Area of region:** The minimum area threshold is associated with the smallest region size in pixels. In the segmented image, no region will be smaller than this threshold, defined by the user.

Algorithm

Let: $f(x,y)$ denote an input image; $S(x,y)$ denote a seed array containing 1's at the locations of seed points and 0's elsewhere; and Q denote a predicate to be applied at each location (x,y) . Arrays f and S are assumed to be of the same size. A basic region-growing algorithm based on 8-connectivity may be stated as follows.

1. Find all connected components in $S(x,y)$ and reduce each connected component

- to one pixel; label all such pixels found as 1. All other pixels in S are labeled 0.
2. Form an image f_Q such that, at each point (x, y) , $f_Q(x, y) = 1$ if the input image satisfies a given predicate, Q , at those coordinates, and $f_Q(x, y) = 0$ otherwise.
3. Let g be an image formed by appending to each seed point in S all the 1-valued points in f_Q that are 8-connected to that seed point.
4. Label each connected component in g with a different region label (e.g., integers or letters). This is the segmented image obtained by region growing. The following example illustrates the mechanics of this algorithm

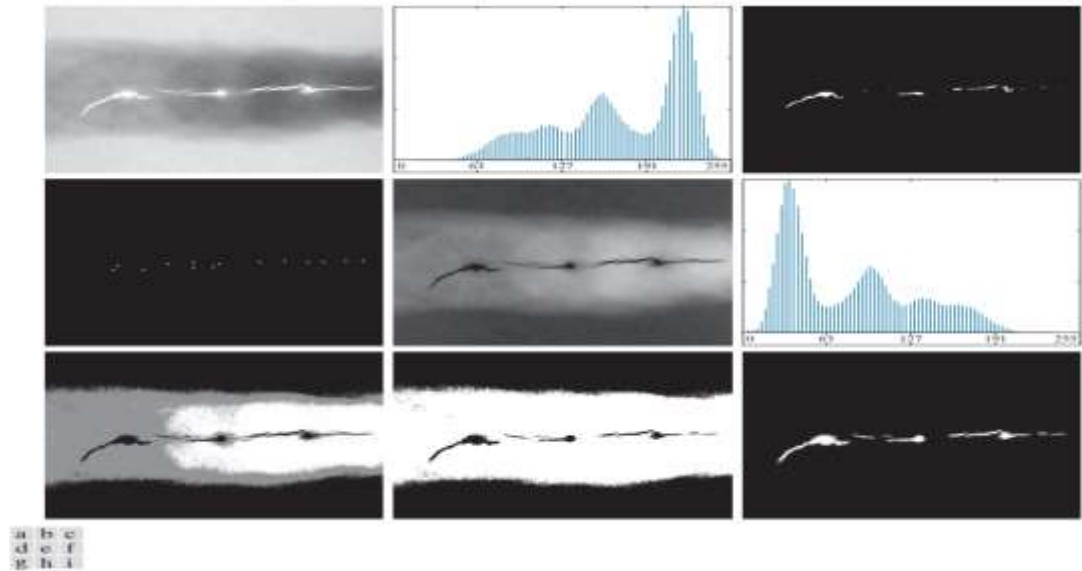


Figure (a) X-ray image of a defective weld. (b) Histogram. (c) Initial seed image. (d) Final seed image (the points were enlarged for clarity). (e) Absolute value of the difference between the seed value (255) and (a). (f) Histogram of (e). (g) Difference image thresholded using dual thresholds. (h) Difference image thresholded with the smallest of the dual thresholds. (i) Segmentation result obtained by region growing.

2. Region Splitting

- Region growing starts from a set of seeds points
- An alternative is to start with the whole image as a single region and subdivide the regions that do not satisfy a condition of homogeneity.

3. Region Merging

- Region merging is the opposite of region splitting.
- Start with small regions (e.g. 2×2 or 4×4 regions) and merge the regions that have similar characteristics (such as gray level, variance).
- Typically, splitting and merging approaches are used iteratively.

A simple way to measure the similarity is a comparison with the original pixel seed intensity. The user can select a single arbitrary pixel and all the neighboring pixels are compared to this. The similarity can be defined as the difference of the intensity. This is a straight forward way to determine

a region and leads to consistent segmented regions. However, this method is very sensitive to noise and results in an unsatisfactory segmentation when the original seed is a noise pixel.

- An alternative way to remove this effect is to compare all assigned pixel to the neighboring pixel that is already in the region of interest. Another approach is to initialize the region with not only a single pixel but with a small set of pixels to better describe the region statistics.
- **Region Growing** An image can be divided simply into two regions, namely background and foreground, using a region growing algorithm. A simple way to do so is to pick a seed and then expand it.

Let $X \in I$ be a randomly selected pixel in a 2D image I . Let R_F is a region of interest of the image I , namely foreground and δ_1 is tolerance of the difference in intensity. A simple way to expand R_F is to compare all neighborhood pixels with the initial seed and assign each pixel to R_F if it satisfies

$$|x - N(P)| \leq \delta_1 \dots (1)$$

Where $N(P) \in I$ is a neighborhood pixel of R_F and $|\cdot|$ is the absolute of the difference of intensity. Once a pixel is assigned to R_F . The new neighborhood pixel can be evaluated in the same way. Unfortunately, when a noise pixel is chosen accidentally (See figure below for (a) and (c), the results will lead to an undesirable results.

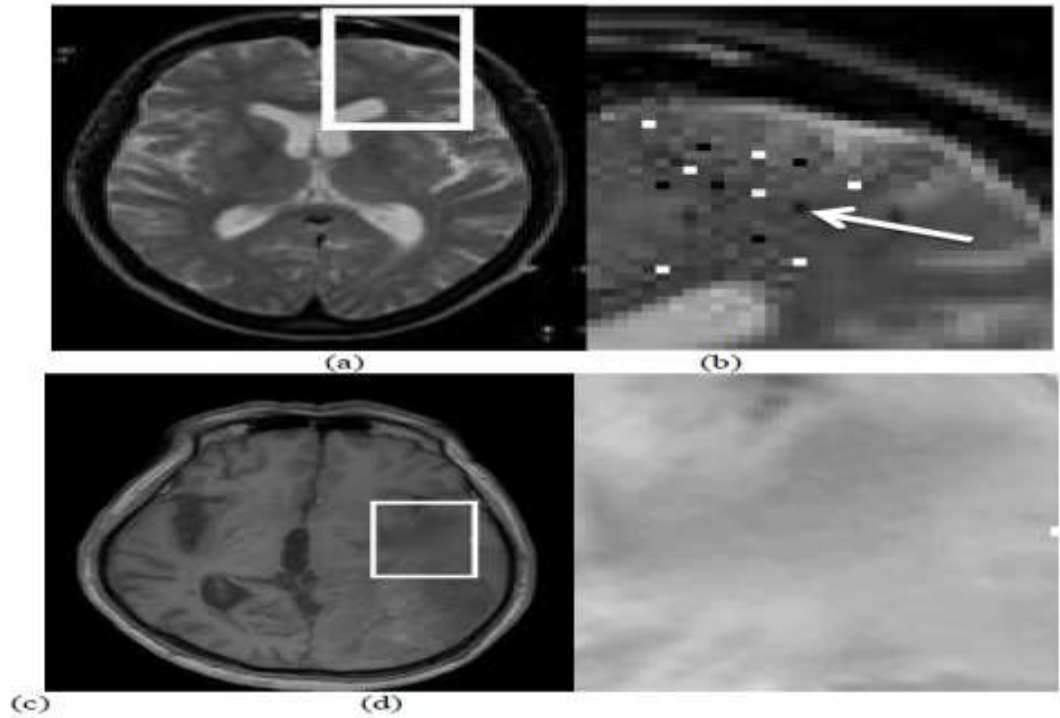


Fig . Zoom view: (a) and (c) are original images, (b) is a noise pixel chosen in (a), (d) is a gradual area in (c)

Another approach is to compare the pixel at the outer most region with the closest neighborhood pixel (see figure below). This is similar to eq. (1) but the comparison is between $N(P)$ and outermost pixel R_F , namely $S(x)$:-

$$|S(x) - N(p)| \leq \delta_2 \quad (2)$$

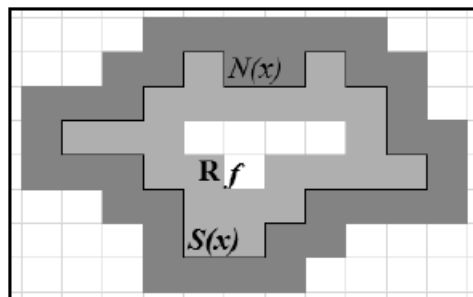


Fig. . Outermost pixels R_f in (brighter gray) and neighborhood pixels (darker gray)

The first approach leads to consistent segmented areas but is *very sensitive to noise* while the second approach may result in inaccurate segmentations especially in cases where the pixel attributes change gradually (see Figs 1(c) and (d)), *but is robust to noise*.

Multiple-seeds can be an alternative to solve the problem above. The initialization is not a single pixel but a small set of pixels to better describe the region using statistical tools such as mean or variance. Then the expansion also involves a statistic operation. This is an expensive operation because every neighborhood pixel is evaluated not as a single pixel but as an area. We combine the approaches above by modifying the multiple-seeds as a way to obtain the ground truth value of the area of interest (Fig 3). First, we use 5x5 multiple-seeds to get a better initialization.

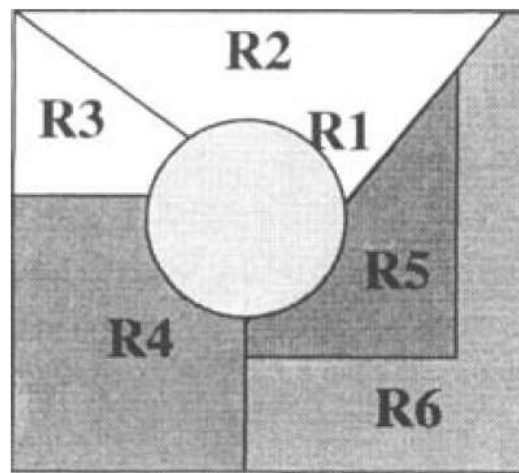
34	34	34	34	35	34	34	34	34	0
33	34	34	34	34	33	34	34	34	34
32	33	32	34	34	32	33	0	34	34
32	32	34	34	34	32	32	34	34	34
33	33	33	34	33	33	33	33	0	33

Fig .Left: 32 is chosen. Right: 0, a noise pixel, is chosen

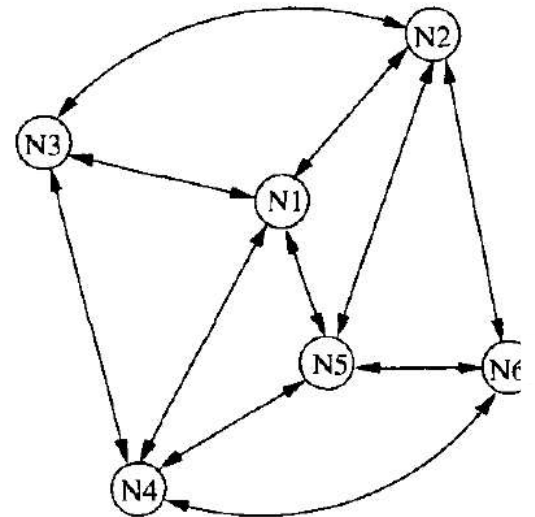
To handle the case when the chosen pixel is not representative of the area, we compute the median of the initial multiple-seeds. For example, both initializations in Fig. 3 result in 34. In our experiment, applying blurring image using Gaussian results in a better segmentation. Image using Gaussian results in a better segmentation.

4. Region Adjacency Graph

The adjacency relation among the regions in a scene can be represented by a region adjacency graph (RAG). The regions in the scene are represented by a set of nodes $N = \{ N_1, N_2, \dots, N_m, \}$ in the RAG, where node N_i , represent the region R , in the scene and properties of the region R , is stored in the node N_i . The edge $e_{i,j}$, between N_i , and N_j represent the adjacency between the regions R_i , and R_j . Two regions R_i , and R_j are adjacent if there exist a pixel in region R_i , and a pixel in region R_j which are adjacent to each other. The adjacency can be either 4-connected or 8connected. The adjacency relation is reflexes and symmetric, but not necessarily transitive. In Figure 4, we show the adjacency graph of a scene with five distinct regions.



(a)



(b)

Fig (a) A scene with 6 distinct regions, (b) the adjacency graph of the scene

A binary matrix A is called an adjacency matrix when it represents a region adjacency graph (RAG). When the nodes N_i and N_j in RAG are adjacent, $a_{i,j}$ in A is 1. Since adjacency relation is reflexive, the diagonal elements of the matrix are all 1. The adjacency matrix (relation) of a multiregion scene in Figure 5(a) is shown below.

$$A = \begin{bmatrix} & N1 & N2 & N3 & N4 & N5 & N6 \\ N1 & 1 & 1 & 1 & 1 & 1 & 0 \\ N2 & 1 & 1 & 1 & 0 & 1 & 1 \\ N3 & 1 & 1 & 1 & 1 & 0 & 0 \\ N4 & 1 & 0 & 1 & 1 & 1 & 1 \\ N5 & 1 & 1 & 0 & 1 & 1 & 1 \\ N6 & 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix}$$

Region Merging and Splitting

A segmentation algorithm can produce too many small regions because of fragmentation of a single large region in the scene. In such a situation, the smaller regions need to be merged based on similarity and compactness of the smaller regions. A simple region merging algorithm is presented below.

Step 1: Segment the image into R_1, R_2, \dots, R_r , using a set of

thresholds.

Step 2: Create a region adjacency graph (RAG) from the segmented description of the image.

Step 3: For every R_i , $i = 1, 2, \dots, m$, identify all R_j , $j \neq i$ from the RAG such that R_i is adjacent to R_j .

Step 4: Compute an appropriate similarity measure $S_{i,j}$ between R_i , and R_j , for all i and j .

Step 5: If $S_{ij} > T$, then merge R_i , and R_j .

Step 6: Repeat steps 3 to 5 until there is no region to be merged according to the similarity criteria.

There are situations, when too little regions are generated because of inaccurate preliminary segmentation. This is due to wrong merger of different regions into a single one. In such situation, the variances of the gray values in a segmented region may be above a threshold (T) and hence the region needs to be split in smaller regions such that each of the smaller regions has uniform small variances. Splitting and merging can be combined together for segmenting complex scenes where a rule-based may guide the applications of split and merge operations.

5. Segmentation using Watershed Transform

Thus far, we have discussed segmentation based on three principal concepts: edge detection, thresholding, and region extraction. Each of these approaches was found to have advantages (for example, speed in the case of global thresholding) and disadvantages (for example, the need for post-processing, such as edge linking, in edge based segmentation). In this section, we discuss an approach based on the concept of so-called morphological watersheds. Segmentation by watersheds embodies many of the concepts of the other three approaches and, as such, often produces more stable segmentation results, including connected segmentation boundaries.

Watershed segmentation is another region-based method that has its origins in mathematical morphology. Since then, it has been widely applied to a variety of medical image segmentation tasks. *In watershed segmentation* an image is regarded as a topographic landscape with *ridges and valleys*. The elevation values of the landscape are typically defined by the gray values of the respective pixels or their gradient magnitude. Based on such a 3D representation the watershed transform decomposes an image into catchment basins. For each local minimum, a catchment basin comprises all points whose path of steepest descent terminates at this minimum (see Fig.).

Watersheds separate basins from each other. The watershed transform decomposes an image completely and thus assigns each pixel either to a region or a watershed. With noisy medical image data, a large number of small regions arises. This is known as the “over-segmentation” problem (see Fig.).

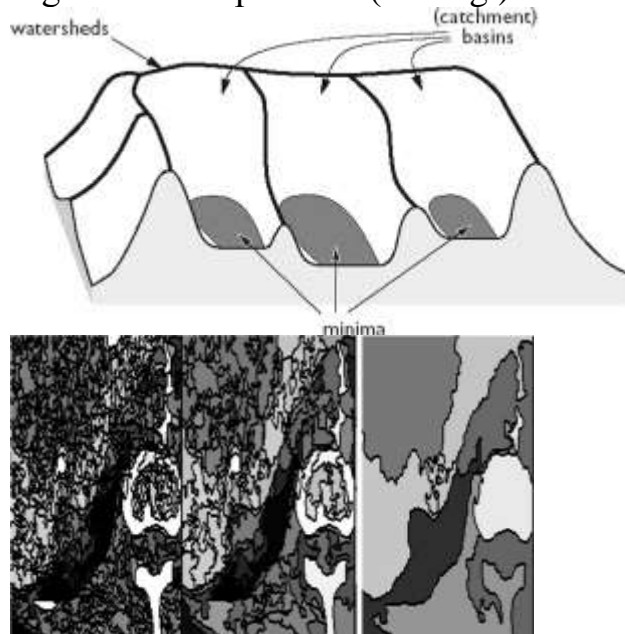


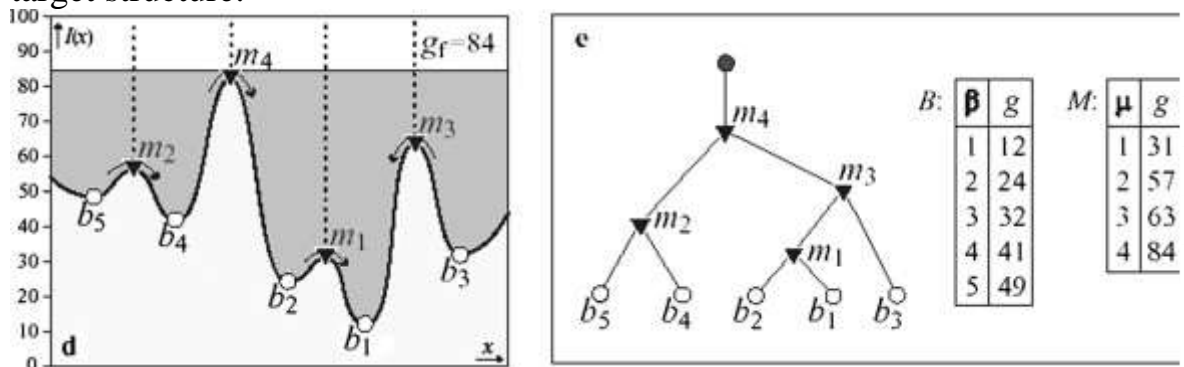
Figure. Principle of the watershed transform where the intensity values define hills and basins applied to an axial

Figure. Illustration of the over-segmentation problem of the watershed transform slice of a CT image

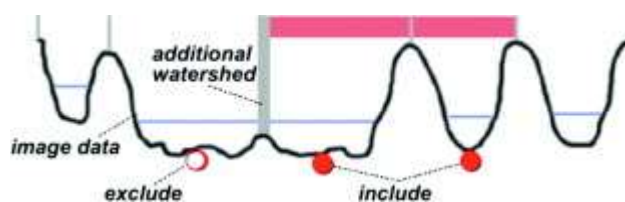
The most widespread variant employs the gradient image as the basis for the watershed transform. Gradient magnitude, however, is strongly sensitive to image noise. Therefore, appropriate filtering is essential. There are many variants how the watershed transform may be used as a basis for a general segmentation approach. The “over-segmentation” problem may be solved by some criteria for merging regions. The user must be provided with some facilities to influence the merging process.

Merging Basins The decomposition of an image into regions is the basis for merging them. In the metaphorical sense of a landscape, catchment basins are merged at their watershed locations by flooding them. While some regions merge early (with low flooding level), other regions are merged later. In order to support interactive merging, they introduced a *merge tree*. This tree consists of the original catchment basins as leaves and of intermediate nodes that represent *merging events*. A merging event is characterized by the nodes that are merged and by the flood level that is necessary for

merging. As a first step, a certain amount of flooding may be applied (“pre-flooding” which may already be sufficient for segmenting the target structure.



Marker-based Watershed often however, no examined flooding levels sufficient to segment target structures. Therefore, the user may specify image locations that belong to the target structure (include points), or that do not belong the target structure (exclude points). If the user specifies an include point and an exclude point, an additional watershed is constructed at the maximum level between them. The merge tree is traversed such that each region contains either include points or exclude points but not both. This interaction style is called *marker-based watershed segmentation*. There are many variants of the watershed transform. For example, merging may consider also gradient information or other criteria for homogeneity. A frequently used variant is to merge regions where the difference of the mean gray value is below a threshold. This process can be carried out iteratively and results also in a hierarchical merging tree.



Multiple-Choice Questions (MCQs):

1. In the context of image segmentation, what is the primary goal of region growing?

- A) To enhance image intensity.
- B) To blur the image for better visualization.
- C) To group pixels into larger regions based on predefined criteria for growth.
- D) To amplify background intensity.
- E) To eliminate abrupt changes in intensity.

Correct Answer: C) To group pixels into larger regions based on predefined criteria for growth.

2. What is the role of seed points in the region-growing algorithm?

- A) To enhance image intensity.
- B) To blur the image for better visualization.
- C) To act as initial points from which regions grow by appending neighboring pixels.
- D) To amplify background intensity.
- E) To eliminate abrupt changes in intensity.

Correct Answer: C) To act as initial points from which regions grow by appending neighboring pixels.

3. What criterion is crucial for stopping the region growth in the region-growing algorithm?

- A) Intensity values.
- B) Texture.
- C) Color.
- D) All of the above.
- E) Shape.

Correct Answer: D) All of the above.

4. How is the similarity between pixels determined in region growing?

- A) Based on Euclidean distance.
- B) By calculating the variance.
- C) Through statistical operations.

- D) All of the above.
- E) Only A and B.

Correct Answer: E) Only A and B.

5. What is the minimum area threshold associated with in region growing?

- A) It defines the smallest region size in pixels.
- B) It determines the largest region size in pixels.
- C) It specifies the region's color.
- D) It regulates the region's shape.
- E) It controls the region's texture.

Correct Answer: A) It defines the smallest region size in pixels.

6. What is the primary purpose of a region adjacency graph (RAG) in image segmentation?

- A) To enhance image intensity.
- B) To blur the image for better visualization.
- C) To represent the adjacency relations among regions.
- D) To amplify background intensity.
- E) To eliminate abrupt changes in intensity.

Correct Answer: C) To represent the adjacency relations among regions.

7. When too many small regions are generated, what can be a potential issue that needs to be addressed in image segmentation?

- A) Over-segmentation.
- B) Under-segmentation.
- C) Lack of initial seeds.
- D) Region adjacency.
- E) Noisy image.

Correct Answer: A) Over-segmentation.

8. In the context of segmentation algorithms, what does the "over-segmentation" problem refer to?

- A) The lack of initial seeds for region growing.
- B) The presence of too many small regions due to noise.
- C) The merging of large regions.

- D) The under-segmentation of regions.
- E) The absence of a region adjacency graph.

Correct Answer: B) The presence of too many small regions due to noise.

9. What concept does the watershed segmentation algorithm borrow from mathematical morphology?

- A) Edge detection.
- B) Thresholding.
- C) Region extraction.
- D) Morphological watersheds.
- E) Region adjacency.

Correct Answer: D) Morphological watersheds.

10. What is the metaphorical representation used in watershed segmentation?

- A) A topographic landscape with ridges and valleys.
- B) A binary matrix.
- C) A region adjacency graph.
- D) A segmentation tree.
- E) A flood level.

Correct Answer: A) A topographic landscape with ridges and valleys