CS419 Digital Image and Video Analysis
Assignment 2

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Question 4

a) The opening operation will be sufficient if it is paired with the right range of structuring elements. This is because the algorithm considers the rate of change in intensity caused by the openings and not the actual values of the pixels. By definition, an opening will enhance bright regions while suppressing the dark ones. For granulometry, it is not important whether the item expanded or its background did, what matters is whether the current SE was able to consume a region causing a big intensity change. Combining this idea with various SE sizes will show the structural changes made by each sized filter by outputting how the intensity changed with which sized filter.

b) The size of the structuring elements should range from the smallest object size to the biggest type of gravel to identify. Each SE will help reveal the details of that size. This is because an opening is erosion by dilation. At first, the objects that are smaller than the SE will erode then the remaining ones are recovered by dilating. So the objects smaller than se will remain eroded while the ones that fit the se will retain. This way, opening the image with each SE, which is similar to a sieve in this context, will help identify objects of that size using the intensity changes caused by the opening.

c) The opening operation should be used as it suffices all the following properties a granulometry needs:

- The operation should be anti-extensive meaning that it should remove things not add new ones. In other words, when the SE is applied, it should reveal the details about what has been removed instead of adding new elements. => Opening is anti-extensive, it removes structures smaller than the SE.
- It should be increasing so that if another image is greater, it should give a bigger result than the smaller one. => Opening is an increasing operation.

- For a larger-sized SE, it should remove more details/structures. Similar to a sieve when the holes are bigger, more items are gone. => Opening will remove more details when the SE is bigger.
- Lastly, the effect of the largest SE should suppress all the smaller ones' effect. This means that prior sievings with smaller SE elements do not matter if followed by a bigger SE. => The dilation phase of the opening with a bigger SE will be more extensive than the smaller SE's dilation by definition. This will make it so that its effects will overshadow the smaller one's restorations.

d) In order to do classification, I need to store the effects of each SE's effect on the images along with the image label. The main information to be stored is the intensity changes caused by each SE. I will remove the intensity of the bigger sieves' result image from the smaller ones' results to isolate the effects of that single SE. This way only the intensity change caused by a specific SE size will stay in the granulometry result.

For each image, the granulometry result will include information about the intensity changes caused by each SE allowing it to represent image structural characteristics. This information will similarly be calculated for images to be classified. Deciding to which labelled granulometry this result is closest will require using a distance metric. I chose Euclidean for this because it considers the direction of the change compared to Manhattan or Chebyshev. This will consider the amount of change and whether it's an increase or a decrease allowing the algorithm to see the similarities of intensity patterns better. As a result, the granulometry result of the unlabeled image will be compared to all the labelled ones regarding the effects of all SE sizes, and the decreases and increases between the points. Finally, the label with minimum distance will be picked.

Question 5

I have applied all four filters to three different conditions. I applied them to RGB images using both 3x3 and 5x5 filters. Additionally, I applied the filters to the HSV version of the same images, using 3x3 filters. I then computed the MSE performance of each version of conditions for each filter by individually calculating it for all 10 images and then averaging them. The following are the overall results for all types I have tried (I ordered them from least MSE to most):

HSV with 3x3 SE:

1- Marginal Median Filter 3x3 for HSV, avg MSE: 0.0026830361311861325

2- Norm Ordered Median Filter with 3x3 for HSV, avg MSE: 0.010354975137226203

3- Bitmix Ordered Median Filter with 3x3 for HSV, avg MSE: 0.025061666538736815

4- Lexicographical Ordered Median Filter 3x3 HSV, avg MSE: 0.031233981684058925

RGB with 3x3 SE:

1- Marginal Median Filter 3x3, avg MSE: 0.0015345738376595242

2- Norm Ordered Median Filter with 3x3, avg MSE: 0.009115701258039248

3- Lexicographical Ordered Median Filter 3x3, avg MSE: 0.02744382353953235

4- Bitmix Ordered Median Filter with 3x3, avg MSE: 0.02762722845166628

RGB with 5x5 SE:

1- Marginal Median Filter 5x5, avg MSE: 0.0023613430425094154

2- Norm Ordered Median Filter with 5x5, avg MSE: 0.009166307624995188

3- Lexicographical Ordered Median Filter 5x5, avg MSE: 0.028407798953336654

4- Bitmix Ordered Median Filter with 5x5, avg MSE: 0.02871789754920358

a) After analyzing and comparing three different versions, Marginal Median filters performed best by giving the least mean square error. I calculated the improvements with the following formula: $\left(\frac{old}{old-new}\right) \times 100$.

1. For 3×3 filtered RGB images, the average MSE of the Marginal Median Filter is 0.0015345738376595242, which offers 83.15% improvement compared to its closest competitor, the Norm Ordered Filter, with an average MSE of 0.009115701258039248.
2. For 5×5 filtered RGB images, the average MSE of the Marginal Median filter is 0.0023613430425094154, offering about 74.23% improvement over its closest competitor, the Norm Ordered Filter, with an average MSE of 0.009166307624995188.
3. For 3×3 filtered HSV images, the average MSE of the Marginal Median filter is 0.0026830361311861325, showing 74.03% improvement compared to its closest contender, the Norm Based Filter, with an average MSE of 0.010354975137226203.

b) Not really. After printing out the individual MSE results for all filters, it is safe to say that, even though there are small exceptions where the relative order is different— for instance, image 4 performed better in Bitmix filter than Lexiographical ordered filter— the overall performances of the filters remain the same relative to each other for most of the individual images.

c) In my code, image groups (1, 4, 7, 10), (2, 5, 8), and (3, 6, 9) exhibit the same amount of noise. To assess the impact of the noise level, I averaged the MSE values within each group. The results for each respected group are as follows:

Group (1, 4, 7, 10) has generated noise with an amount of 0.08:

- Marginal Median Filter with 3x3 SE: 0.00125
- Lexicographical Ordered Median Filter with 3x3 SE: 0.0168
- BitMix Ordered Median Filter with 3x3 SE: 0.0168
- Norm Ordered Median Filter with 3x3 SE: 0.003064

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- Norm Ordered Median Filter with 3x3 SE: 0.003064

Group (2, 5, 8) has generated noise with an amount of 0.14:

- Marginal Median Filter with 3x3 SE: 0.00198
- Lexicographical Ordered Median Filter with 3x3 SE: 0.0256
- Bitmix Ordered Median Filter with 3x3 SE: 0.0266
- Norm Ordered Median Filter with 3x3 SE: 0.00972

Group (3, 6, 9) has generated noise with an amount of 0.20:

- Marginal Median Filter with 3x3 SE: 0.00181
- Lexicographical Ordered Median Filter with 3x3 SE: 0.0434
- Bitmix Ordered Median Filter with 3x3 SE: 0.0166
- Norm Ordered Median Filter with 3x3 SE: 0.0147

The results indicate that lexicographical ordering and norm-based ordering are highly affected by the noise, displaying a gradual increase in error rate as the noise level rises. On the other hand, Marginal Median and Bitmix ordering do not seem to be as affected by the variation in noise, maintaining a more consistent error rate as the noise increases.

d) According to my results, filter size appears to perform better when it is smaller. Comparing the results of each filter on RGB images with 3x3 and 5x5 filter sizes, the results indicate the following.

- For Marginal Median filter, the average MSE of 3×3 SE on RGB images is 0.0015345738376595242, which offers 34.87% improvement compared to 5×5 SE with an average MSE of 0.0023613430425094154.

- For Lexicographical Ordered Median filter, the average MSE of 3×3 SE on RGB images is 0.02744382353953235, which offers 3.39% improvement compared to 5×5 SE with an average MSE of 0.028407798953336654.
- For BitMix Ordered Median filter, the average MSE of 3×3 SE on RGB images is 0.02762722845166628, which offers 3.80% improvement compared to 5×5 SE with an average MSE of 0.02871789754920358.
- For Norm based Median filter, the average MSE of 3×3 SE on RGB images is 0.009115701258039248, which offers 0.55% improvement compared to 5×5 SE with an average MSE of 0.009166307624995188.

As a result, it can be concluded that the marginal median filter is highly sensitive to SE size and performs better when the filter is smaller. For BitMix and Lexicographical filters, a smaller-sized filter also offers improvement, but it is not as sensitive as the marginal median. Norm-based, on the other hand, doesn't seem to be much affected by the SE size according to my results.

e) To compare the effect of color spaces I calculated the percentage difference of their MS results using the following formula: $\left|\frac{A-B}{\frac{A+B}{2}}\right| \times 100$.

- Marginal Median filter performed about 30.34% better in RGB images than HSV ones.
- Norm Ordered Median Filter RGB performs 13.49% better than HSV.
- Bitmix Ordered Median Filter HSV performs 9.31% better than RGB.
- Lexicographical Ordered Median Filter RGB performs 6.85% better than HSV.

As a result, the Marginal Median filter seems to perform better in RGB compared to HSV. Similar results are observed for the Norm-based and Lexicographical filters; however, the differences are not that significant. A different observation is that Bitmix seems to perform better in HSV than in RGB, but again, the percentage difference is not very significant.