Mini Project in Bioinformatics - Bilateral filtering

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Introduction

Bilateral filtering is a crucial technique in the realm of image processing and computer vision. It is widely used for noise reduction while preserving edges, making it an essential tool for enhancing the quality of images in various applications.

Introduced by Tomasi and Manduchi in 1998, bilateral filtering is an edge-preserving and noise-reducing smoothing filter for images. Unlike traditional filters that blur edges while reducing noise, bilateral filtering considers both the spatial closeness and the intensity difference between pixels, thereby preserving edges. This dual consideration allows the filter to effectively reduce noise without sacrificing important structural information in the image. The mathematical formulation of the bilateral filter combines domain and range filtering, resulting in a non-linear process that is computationally intensive but highly effective in preserving details.

This project explores the implementation and application of bilateral filtering, providing insights into its parameters and effects on different types of images.

Here is a link to our Bilateral filtering implementation on Google Colab: Bilateral filtering mini project.ipynb. On the Colab, you can see our fun experiments with various images as input, using varied parameters to observe the filter's behavior and performance.

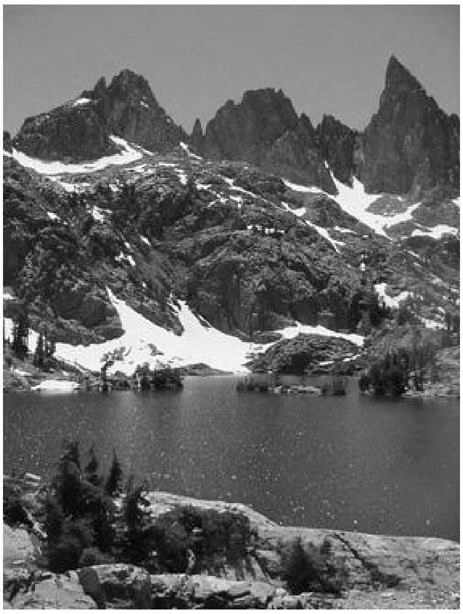
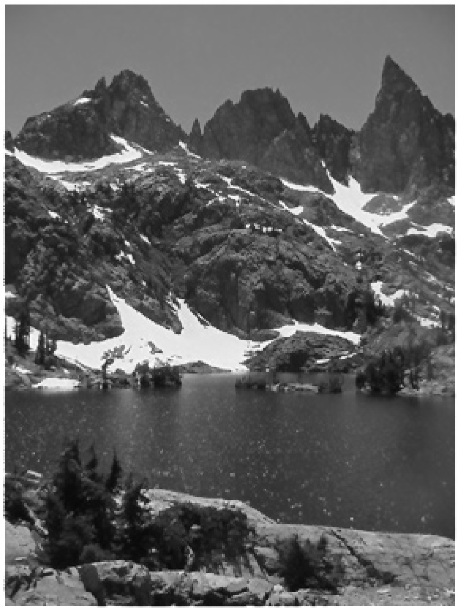
The performance of the bilateral filter is highly dependent on its parameters. There are typically two main parameters to consider:

1. **Diameter:** This parameter specifies the diameter of the pixel neighborhood used during filtering. It determines the size of the area around each pixel that influences the filtering process. A larger diameter means a larger neighborhood of pixels will be taken into account when filtering a particular pixel.
2. **Sigma_i (Intensity Sigma):** Also known as the range parameter, this controls the influence of the intensity difference between pixels. A larger Sigma_i value allows pixels with greater intensity differences to contribute to the filtering. This helps in preserving edges while still reducing noise, as pixels with similar intensities will have more influence on each other.
3. **Sigma_s (Spatial Sigma):** A parameter of the Gaussian function that weighs pixels based on their distance from the center pixel. A larger Sigma_s value

means that a wider area around the pixel will influence the filtering, leading to more spatial smoothing. This helps in reducing noise while considering the spatial closeness of pixels.

In our Google Colab notebook, we explore these parameters by applying the bilateral filter to various images with different settings. By adjusting Diameter, Sigma_i, and Sigma_s, we demonstrate how the filter behaves under different conditions and highlight the trade-offs between noise reduction and edge preservation.

Results

Original Photo	Photoshop output	Our Bilateral filter output
		
		

Comparison

1. The Cameraman:
   Original Photo: The image is highly noisy, obscuring details of the photographer and the camera. The noise is prominent throughout the entire image, affecting the overall clarity.
   Photoshop Output: The Photoshop output shows a noticeable smoothing effect, which reduces much of the noise present in the original photo. However, this comes at the cost of slightly blurring the image, leading to a loss of fine details, especially around the edges of the photographer and the camera.
   Bilateral Filter Output: The sky is brighter and smoother, while edge preservation is fairly similar between the bilateral filter and Photoshop.

1. Landscape:
   Original Photo: The image is detailed with visible noise in the water region. The sharp edges of the mountains are clearly defined.

Photoshop Output: The Photoshop output again shows smoothing, which reduces noise but at the cost of some loss in sharpness and details especially in the mountains.
Bilateral Filter Output: The Bilateral filter output maintains the sharpness of the edges but reduces noise less effectively than the Photoshop output, resulting in a more detailed image but with more noise than the photoshop output.

2. Taj Mahal:
   Original Photo: The image has noticeable noise throughout, affecting the clarity of the details, especially in the sky and the building's surface.
   Photoshop Output: The Photoshop output effectively reduces the noise while maintaining more of the fine details and edges of the Taj Mahal compared to the Bilateral filter output. The structure appears clearer and more defined
   Bilateral Filter Output: The Bilateral filter output shows a reduction in noise, but it also introduces some extra brightness to the structure and adds some blur to the trees.

3. The Lady:
   Original Photo: The image is noisy, especially in the background and on the hat, affecting the overall sharpness and detail.
   Photoshop Output: The Photoshop output reduces the noise but also smooths out some details, making the image appear softer, particularly in the textures of the hat and hair.
   Bilateral Filter Output: The Bilateral filter output reduces noise while better preserving the textures and details in the hat and hair, providing a clearer and more detailed image compared to the Photoshop output.

Conclusion

In comparing the performance of Photoshop and the Bilateral filter across various types of photos: portraits, landscapes, architectural shots, and detailed subjects, it becomes evident that each tool has its strengths and trade-offs. Photoshop generally excels in noise reduction, effectively smoothing out images but sometimes at the cost of fine details and sharpness, particularly noticeable around edges and textures. On the other hand, the Bilateral filter tends to preserve more details and textures while reducing noise, although it may introduce minor artifacts like brightness variations or slight blurring. The choice between these tools should be based on specific needs: Photoshop is ideal for scenarios where maintaining clarity and structural details is paramount, such as architectural photography, while the Bilateral filter is advantageous for preserving textures and finer details, particularly in portraits and subjects where maintaining authenticity and intricate details is critical.

Algorithm Improvment

We chose the paper "Fast Adaptive Bilateral Filtering" by Ruturaj G. Gavaskar and Kunal N. Chaudhury. The basic idea of the paper is:

The proposed method leverages the idea of performing filtering in the range space using a local histogram. Imagine you have a large number of objects to count, and instead of counting each object individually, you group them and then use a mathematical shortcut to quickly estimate the total. Similarly, fast adaptive bilateral filtering groups pixel values using histograms, approximates these groups with simple math functions (polynomials), and then uses efficient shortcuts (integral computation) to quickly apply the filter. This approach drastically cuts down the number of calculations, making the process much faster without losing the filtering quality.

Here are the key points of their approach:

Local Histogram Approximation:

- Instead of directly using the local histogram, the method approximates it using a polynomial.
- The polynomial is fitted to match the moments of the actual histogram, and this fitting is achieved using fast convolutions.

Integral Calculation Using Polynomials:

- The filter approximation is computed using integrals of the polynomial, allowing for analytic functions to be derived.
- Recursive computation of these integrals is performed using integration-by-parts, which significantly accelerates the process.

Efficiency:

- By using polynomial approximations and integral computation, the number of operations required per pixel is drastically reduced.
- This translates to a significant speedup, often 20× to 60× faster than traditional methods.

In summary, this paper presents a novel and efficient approach to adaptive bilateral filtering, making it feasible for real-time image processing applications by leveraging local histogram approximation and polynomial fitting techniques.

Bibliography

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