COMP 6771 Image Processing, FALL 2024

Project Report on

Content-Aware Image Resizing

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1. Motivation and Contribution of the Papers

The aim is to come up with a technique that resizes images without losing any meaningful semantic information, like in case of scaling or cropping. [1]

Seam carving is a process where a seam is understood as an 8-connected path of low energy pixels traversing the image used in Image reduction and enlargement. It discusses the idea & explains mean energy levels w.r.t. the importance of a pixel such as its gradient texture, entropy, and visibility. [1]

Wavelet based technique is a newly amended energy function. It makes use of the multi-segmented nature of wavelet decomposition to illuminate semantically profound content. It embodies an emphasis scheme using several wavelet subbands to enhance the outlines of the principal objects. [2]

2. Main Approach followed

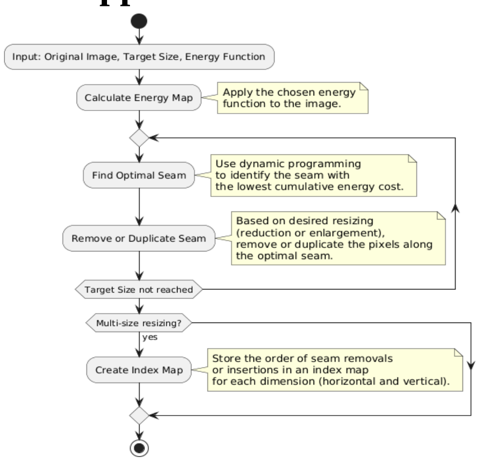


Figure1. Original Seam Carving Process Flowchart

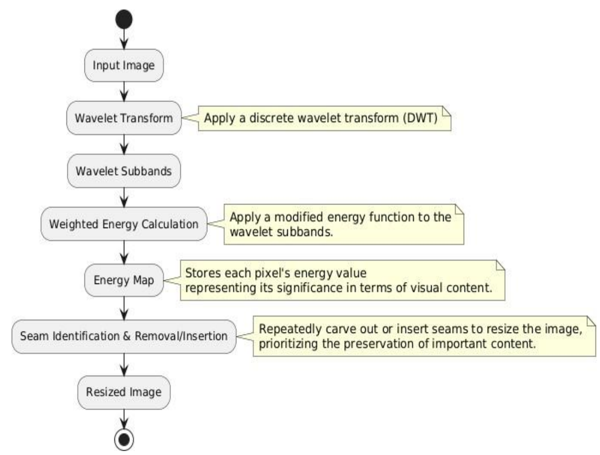


Figure 2. Wavelet Seam Carving Process Flowchart

3. Critiques

In the first paper, Discussing the different forms of energy functions would be more robust with more examination of their pros and cons as well. [1]

In the second paper, the authors could make the analysis of the scheme more illustrative by giving specific examples of the reasoning of weighting factors. [2]

4. Comparison of Approaches and Results

The first paper uses a first order approximation or a histogram of oriented gradients as its primary energy function. Paper 2 on the other hand uses a complex multiscale energy function based on the wavelet decomposition of its constituent parts. This wavelet-based approach is more effective in emphasizing the more crucial aspects by focusing on appropriate frequency bands [1] [2].

It is likely that the wavelet-based method is more effective for targeting salient regions in “Ice Age”, particularly the shapes of objects during resizing (in Paper 2). In the “Ice Age” image example, the proposed method retains the shape and contours of the squirrel’s face much better than the conventional seam carving indicates. This advancement is, in our opinion, the result of a more robust structural image description afforded by the wavelet-based energy function described above. [1] [2]

5. Re-implementation of the Algorithm

** The code files implementing the algorithm are attached with the report.*

For image resizing purposes, we sought to apply the seam carving technique in our project. The idea was to either shrink or enlarge images but do so in a way to retain the salient features of the image effectively. This is accomplished by evaluating the energy of various areas within the picture and either omitting or replicating the pixels to make sure the main icons are intact within the image throughout the modification stages.

5.1. Success of Reimplementation

We managed to reimplement the algorithm again and proved its efficiency using the program created by us. The program implements image input and subsequent transformations such as content carving, or content extension, which shows good dynamic real-time image resizing and its resizing on multiple dimensions at once. The quality of the images is subject to human evaluation to determine if the algorithm can resize the images without cutting out semantically important content.

A remarkable benefit that could be achieved because of our implementation is that image resizing and retargeting is possible with a content weight definition based on an energy function. We tested various energy functions like e_1, $e_{Entropy}$ and gradient, and gradient proved to be the best overall among all, while e_1 proved to be the simplest and computationally fastest. Moreover, we tested various techniques like resizing using seam carving, modifying columns of image matrix based on energy, modifying pixels based on energy in each row, global modification of pixels based on energy, and simply cropping or upscaling the image for comparison.

Our seam insertion approach eliminates visible seams and artifacts in the enlarged images. Both horizontal and vertical enlargements produce smooth results, demonstrating the robustness of the implementation. Moreover, the implementation supports both reduction and enlargement in both dimensions, providing flexibility for various use cases. The custom function implemented by us allows resizing images to arbitrary dimensions while preserving content.

The seam carving method, from a technological perspective, is a breakthrough in the processing of images. It features the capability of inhomogeneous image changes in sizes with certain important parts intact making sure that the key visual elements are not distorted.

5.2. Validation of the Algorithm

The algorithm was reassessed using controlled image experiments in which the images had varying aspect ratios, and the algorithm had to find the most typical to generalize over different cases. The target image sizes, and their proportions were analyzed after resizing the images using up sampling and cropping and during the evaluation stage the amount of ratio distortion and the amount of image detail loss were assessed. The algorithm's success in such tasks was demonstrated by comparative tests of interpolation methods, for example, during bicubic scaling, it was able to resize the image while retaining the image structure and reducing the distortion present in the image.

The assessment was also undertaken by visually inspecting the images and then performing a statistical analysis of the pixel value distributions before and after the resizing operations. In every case this allowed checking the resized images for the same disadvantages. The image display integrity algorithms most importantly adjusted the cropping or upscaling needed to fit the image instead of making the content look strange also proving their efficiency in such cases.

5.3. Experimenting with different methods

Original Image: It presents a serene scene with a person standing on a rocky hill, arms outstretched, facing a vibrant sky. The person is placed near the center, making them the focal point of the image with natural elements, like the tree on the left and the rocky hill, adding depth to the scene. This image is used to perform computations and save results for comparison.

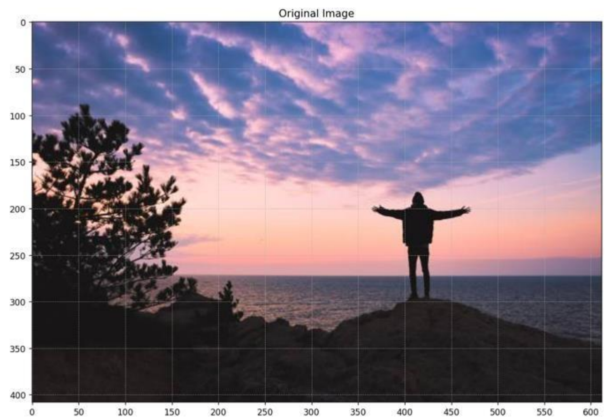


Figure 3: Original Image

5.3.1 Image Energy Functions

The energy functions used by us to perform seam carving for content aware resizing of image are as follows:

i **e_1 Energy Function:** It is defined as the sum of the absolute differences between a pixel and its neighboring pixels in the x and y directions. Specifically, for a pixel at position (x,y), the energy E(x,y) is calculated as:

$E(x,y) = | I(x + 1, y) - I(x - 1, y) | + | I(x ,y + 1) - I(x , y-1)|$ where:

- $I(x,y)$ is the intensity of the pixel at position (x,y).
- $| I(x + 1, y) - I(x - 1, y)|$ measures the horizontal energy (difference between left and right neighbors).
- $| I(x ,y + 1) - I(x , y-1)|$ measures the vertical energy (difference between top and bottom neighbors).

This is simpler in computation and faster compared to other energy functions and it captures local intensity variations effectively. When a neighbor is out of bounds (e.g., at the edges), we use the current pixel's value which effectively sets the difference to zero, assuming no change at the boundary [1] . The generated energy map highlighting different areas of importance is as follows:

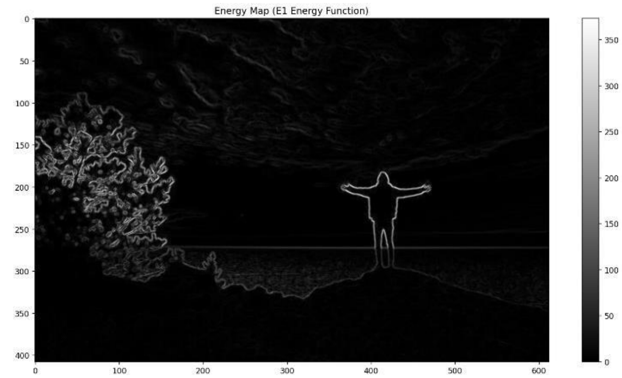


Figure 4: Energy map of e_1 energy function

ii **$e_{Entropy}$ Energy Function:** In this, we computed the entropy in a local neighborhood (e.g., 9x9 window) for each pixel, which is calculated using the normalized histogram of pixel intensities within the neighborhood. For each pixel (i, j), we extracted a square window centered at that pixel, whose size is defined. Following this, the histogram of grayscale intensities is computed within the neighborhood and normalized [1]. Entropy is calculated as follows:

$$Entropy = -\sum_k p(k)[log_2\ p(k)],\text{ where}$$

p(k) is the normalized histogram value at intensity level k.

Computing entropy for each pixel was computationally intensive and it was also dependent on kernel size. Algorithm using this energy function took a long time computing the results. In case of image enlargement, it led to addition of minute artifacts along with image resizing [1]. The generated energy map representing areas of high entropy (complex regions) with higher values is as follows:

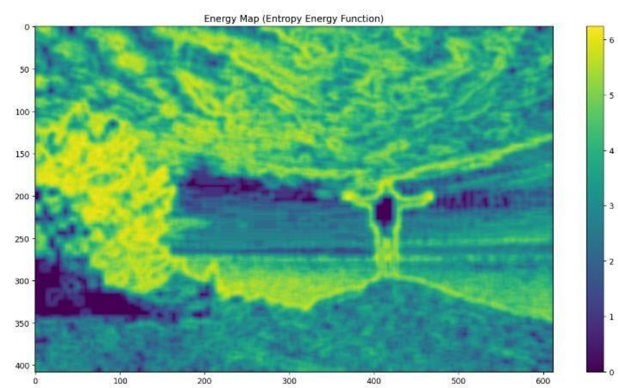


Figure 5: Energy map of $e_{Entropy}$ energy function

iii **$e_{Gradient}$ Energy Function:** It calculates the energy map of the image by computing the gradient magnitude, i.e. the first derivative of the image intensity function. X-direction gradient is calculated by setting the dx parameter to 1 and dy to 0, and vice-versa for Y-direction gradient, using Sobel Operator. This energy map is crucial for content-aware seam carving, as it helps determine which pixels are least important and can be removed or duplicated when resizing the image [1]. It is computed by adding the absolute values of the gradients in both directions:

$$E(x,y) = |G_x(x,y)| + |G_y(x,y)|, \text{ where}$$

$E(x,y)$ is the energy at pixel (x,y)(x, y)(x,y).
$G_x(x,y)$ is the gradient in the x-direction.
$G_y(x,y)$ is the gradient in the y-direction.

This energy function is significantly better in edge detection and content awareness with minimum to no artifacts. It is computationally expensive, but less than $e_{Entropy}$ function. It is simple, effective and works well across various types of images without the need for parameter tuning [1]. The generated energy map is as follows:

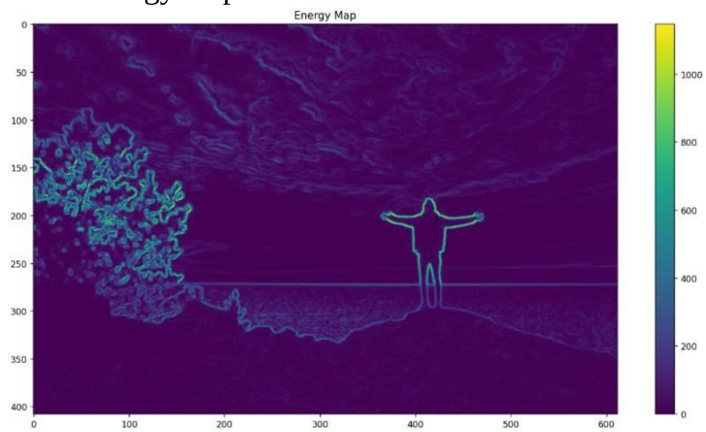


Figure 6: Energy map of $e_{Gradient}$ energy function

Results: The resultant images obtained after using different energy functions and different horizontal and vertical resizing methods are saved for comparison. Considering the required length of this document, only one of the methods (Image reduction horizontally by 50 pixels) is shown below, while the files attached to this report contain results for all the methods:

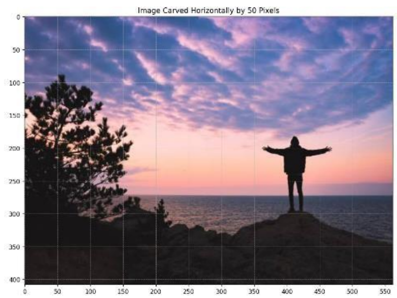


Figure 7: Image Carved Horizontally by 50 pixels using e_1 Energy

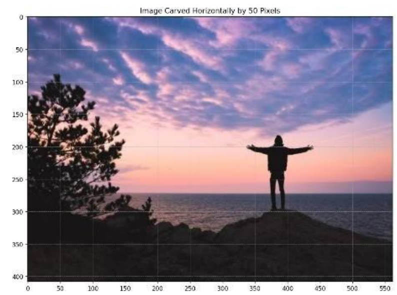


Figure 8: Image Carved Horizontally by 50 pixels using $e_{Entropy}$ Energy

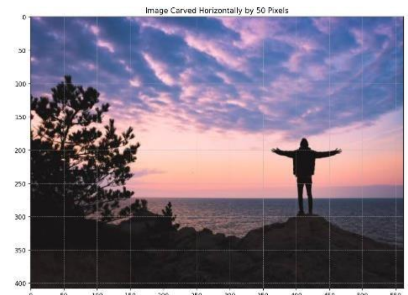


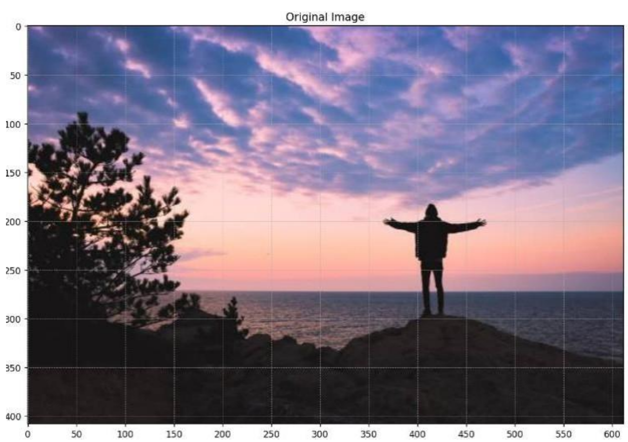
Figure 9: Image Carved Horizontally by 50 pixels using $e_{Gradient}$ Energy

It can be observed that the size of the image is reduced from around 600 pixels to 550 pixels. There is not significant difference in resultant images in this method, but in other implemented methods such as vertical image enlargement, $e_{Entropy}$ didn't work as expected every time and introduced artifacts for some images.

5.3.2 Image Resizing Techniques:

We used several resizing techniques for comparison based on combination of pixel selection, energy intensities, and modifications (reduction or enlargement). All the results for all the techniques with different method implementations such as horizontal or vertical image reduction and enlargement and 2-dimensional image enlargement dependent on target values of height and width, are saved in the file attached. Again, taking into consideration the length of this document, only for Seam-based Image Resizing, all the results are shown. For all other techniques, only 1 to 2 resultant images (i.e. maximum 2 method implementations) are shown randomly.

i. **Resizing using Content-Aware Seam-Removal:** It dynamically identifies and removes (or duplicates) the least significant seams of pixels based on an energy map. It was observed that it preserved the most critical content (e.g., the silhouette of the person in our example) while keeping its dimensions consistently same throughout. By removing or duplicating paths of low-energy pixels, it avoided abrupt distortions and handled both complex and uniform regions adaptively. It required dynamic programming to identify seams, which was computationally expensive compared to entire column-removal technique. It offered the smoothest and most content-preserving modifications, as other pixel/row-based methods introduced visible disruptions and artifacts.



Original Image

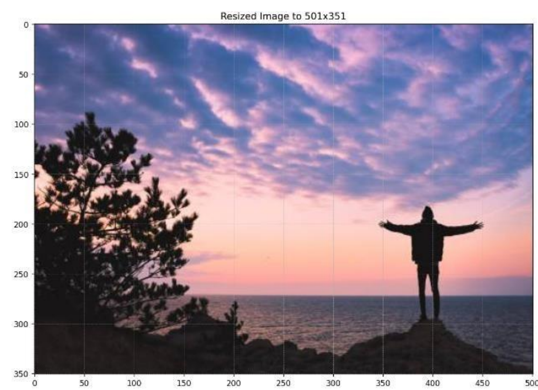


Figure 10: 2D Image resizing to custom dimensions (500 x 350) using Seam-Removal

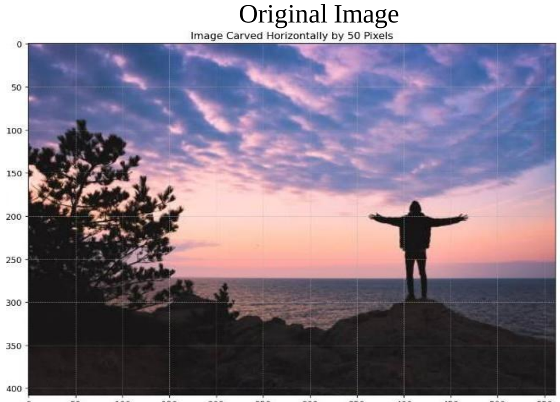


Figure 11: Image Carved Horizontally by 50 pixels using Seam-Removal

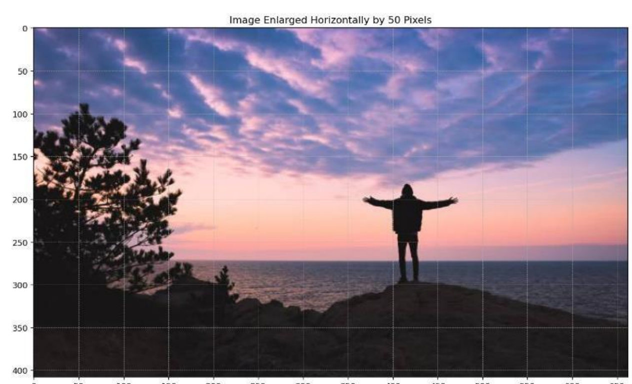


Figure 12: Image Enlarged Horizontally by 50 pixels using Seam-Removal

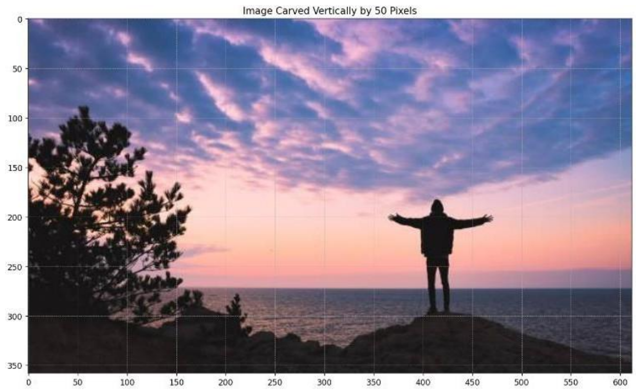


Figure 13: Image Carved Vertically by 50 pixels using Seam-Removal

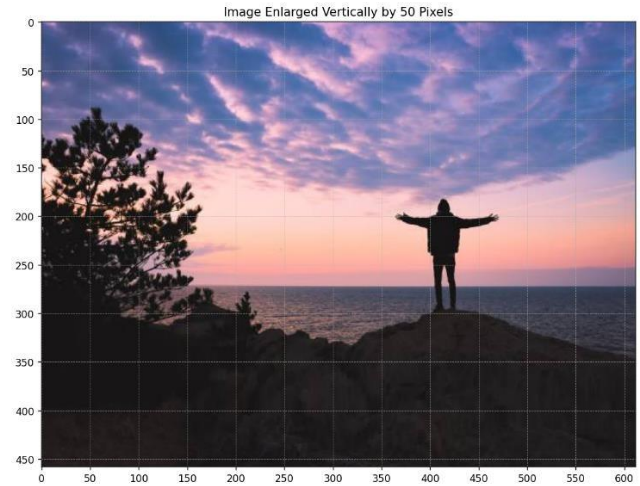


Figure 14: Image Enlarged Vertically by 50 pixels using Seam-Removal

ii. **Resizing using Cropping and Upscaling:** It is the most straightforward implementation that uses basic process of cutting off a portion of the image and linear interpolation for resizing. When computational efficiency is a priority, and the image does not have high content sensitivity (e.g., simple patterns or non-detailed textures), then cropping is an effective technique. While seam carving maintains the visual context by being selective, cropping can remove important parts of an image without considering their relevance. Moreover, for significant enlargements, linear interpolation led to blurry & distorted images.

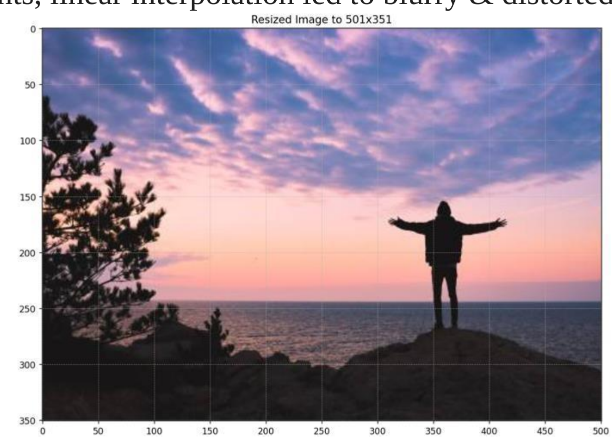


Figure 15: 2D Image resizing to custom dimensions (500 x 350) using simple Cropping and Upscaling

iii. **Resizing by modifying columns:** This strategy is somewhat between removing pixels and Cropping. Columns are either removed (for carving) or duplicated (for enlargement) based on their cumulative energy, with low-energy columns being removed and high-energy columns being duplicated. It operates in a structured manner by evaluating columns as a whole rather than individual pixels. This technique respects the vertical continuity of the image. As columns are treated as a single unit, this method avoids the chaotic distortions seen in pixel-wise approaches. By summing up energies for entire columns, the method has a limited form of content awareness, allowing it to prioritize removing less significant areas. For example, areas with uniform colors or textures (like the sky or water in the image we used) were more likely to be modified than complex areas with high energy.

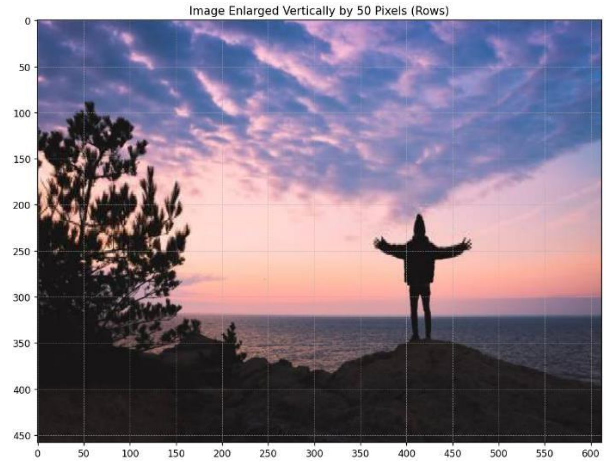


Figure 16: Image Enlarged Vertically by 50 pixels using column modification

iv. **Resizing by row-wise modification of pixels:** This method refines the resizing process by performing energy-based pixel removal and duplication on individual rows. It removes or duplicates pixels with the least or highest energy based on reduction or enlargement operation. It preserves the rectangular shape of the image but destroys the image content by creating a zigzag effect, and breaking image continuity [1]. It created jagged distortions or abrupt transitions, as seen in the uploaded results. This technique was indeed faster but sacrifices quality for efficiency.

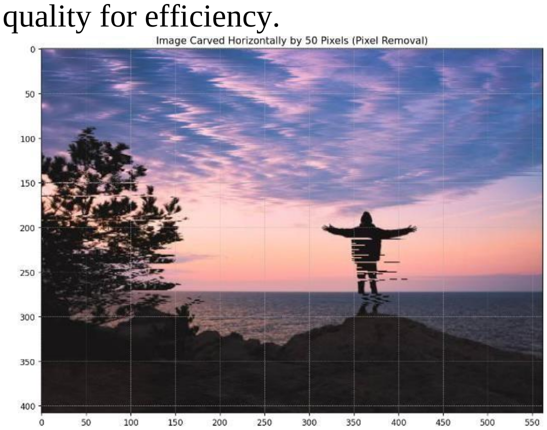


Figure 17: Image Carved Horizontally by 50 pixels using row-wise pixel modification

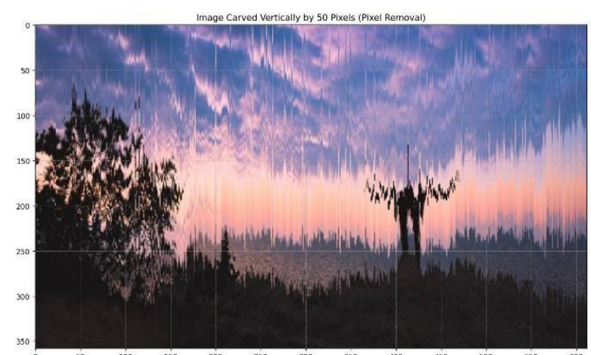


Figure 18: Image Carved Vertically by 50 pixels using row-wise pixel modification

v. **Resizing by modification of pixels globally:** The overall method of user-controlled pixel removal and pixel duplication remove the pixel according to the energy of the pixel over the image. It does not select specific areas or lines, instead, it looks at the energy map of the entire image and chooses pixels to delete or duplicate for the target image. It distorts the image's overall structure, as seen in the artifacts and warping in the uploaded images. It disrupted patterns and continuity, especially in areas like the sky or water in our input image where gradients are smooth. Unatural repetitions were visible leading to distortions in textured areas.

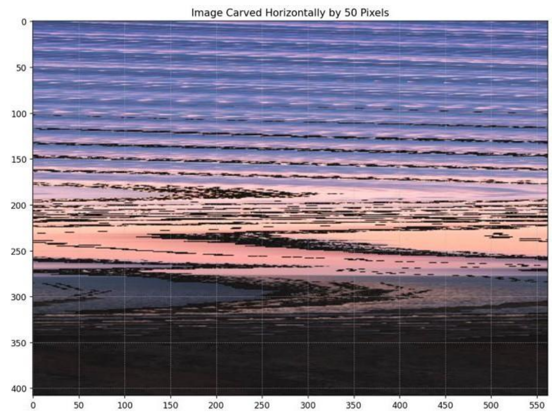


Figure 19: Image Carved Horizontally by 50 pixels using global modification of pixels

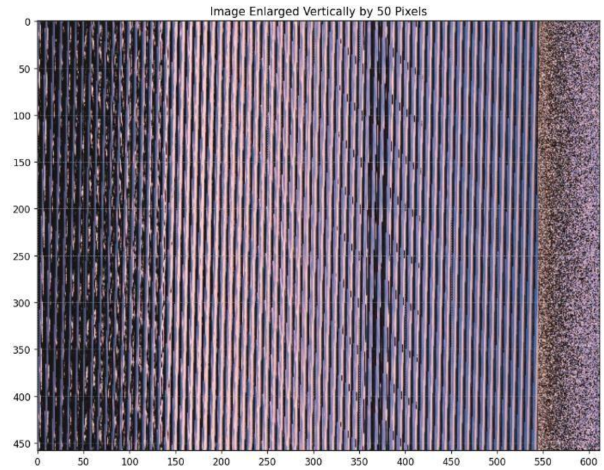


Figure 20: Image Enlarged Vertically by 50 pixels using global modification of pixels

5.4. Reflection on the Implemented Method

Advantages:

- **Flexible Resizing**: The algorithm fine-tunes cropping and scaling after determining the type of the image. Handling parameters such as resizing of image also performs resizing with reasonable quality loss, which allows to adjust to a wide range of content.

- **Content Preservation:** Seam carving prioritizes important visual content by removing or duplicating pixels in less significant areas, such as backgrounds or uniform regions. Unlike traditional scaling, which uniformly stretches or shrinks all parts of an image, seam carving maintains the proportions and shapes of important objects.

- **Flexibility in Aspect Ratio Changes:** Allows for changing the aspect ratio of an image without cropping or distorting essential content. It supports both reduction and enlargement of images in horizontal and vertical dimensions.

- **Minimal to no Visual Artifacts:** By selectively removing or adding seams, seam carving minimizes the introduction of visual artifacts compared to standard resizing methods. It maintains the continuity of textures and patterns, leading to more natural-looking resized images.

Disadvantages:

- **Scaling Can Add Artifacts**: As in enlarging functions, upscaling can sometimes be accompanied by blurriness or other types of artifacts, particularly in regions with a tight structure. If the energy function doesn't work properly, it can alter the spatial relationship between objects, changing the meaning of the image.

- **Performance Impact**: Not all available functions, such as the used for enlarging images cv2.resize, are light; this emphasizes limitations in performance when dealing with larger images or a considerable number of requests.

- **Not Universally Applicable:** Images with uniform importance throughout, such as detailed patterns or artworks, may not benefit from seam carving. Symmetrical objects or patterns may appear distorted if seams are not uniformly applied.

5.5 Difficulties in Reimplementation:

Qualitative enhancement: It was difficult to balance cropping and scaling for the intended goals. For instance, the method to carve horizontally and that to carve vertically required some painstaking calculations to ensure that it was possible to carve out the user-defined areas equally from both sides to keep the image symmetrical. In the same regard, the enlargement methods had to be used very loosely with interpolation to avoid distortions or artifacts when changing the dimensions.

User flexibility: It was quite challenging to develop a set of experiments to comprehensively test the function to resize based on target height and width and ensure seamless integration of such opposite functions as cropping and zoom. For instance, when images were too dissimilar in their widths to heights or vice versa, there were issues associated with detail and scale factors.

Algorithmic Challenges: Seam carving relies heavily on dynamic programming to calculate the cost matrix and find the optimal seams. Errors in implementation can lead to inefficient processing or incorrect seam selection, causing distortions. Moreover, Ensuring the algorithm correctly handles edge cases (e.g., first and last columns/rows, very small images) was tricky.

Computational Complexity: Processing large images or resizing by a significant number of pixels can be computationally expensive. Recomputing energy maps and cost matrices for each seam adds to the time complexity. Balancing between quality and speed was challenging for real-time and batch processing scenarios.

Visual Quality: Distortions in sensitive regions, such as faces, text, or non-linear objects, may degrade image quality. Seam interference, where the removal or insertion of multiple seams interacts poorly, can lead to compounded artifacts. Visual quality is subjective, so ensuring that resized images look "natural" to a wide audience can be hard to validate quantitatively.

Generalization Issues: Seam carving works better on certain types of images (e.g., landscapes) and struggles with others (e.g., cluttered or text-heavy images). Low-contrast or high-detail images produced poor results.

References

[1] S. Avidan and A. Shamir, “Seam carving for content-aware image resizing,” ACM Trans. Graph., vol. 26, no. 3, Jul. 2007, Art. no. 10. doi: 10.1145/1239451.1239461.

[2] J.-W. Han, K.-S. Choi, T.-S. Wang, S.-H. Cheon, and S.-J. Ko, "Wavelet based seam carving for content-aware image resizing," in 2010 IEEE International Conference on Image Processing, 2010, pp. 3989-3992.