Mid-Semester Report (ECE501): Content-Aware Image Retargeting Using Seam Carving: Implementation and Analysis – Group 16

Kushal Rathod*, Shayan Pariyal†, Deep Suthar‡, and Ura Modi§
School of Engineering and Applied Science, Ahmedabad University, Ahmedabad, India

*AU2340189, †AU2340107, ‡AU2340232, §AU2340031

***Abstract*—Content-aware image retargeting is essential for resizing digital media to a wide range of display sizes. This paper presents a comprehensive implementation and analysis of the seam carving algorithm, a powerful method for content-aware image resizing. We developed an optimized Python implementation that utilizes NumPy and SciPy for efficient computation of the core components: the image energy function, optimal seam identification via dynamic programming, and iterative seam removal. Furthermore, we implemented the technique for finding the optimal order of vertical and horizontal seam removals using a transport map, ensuring minimal content distortion during two-dimensional resizing. The methodology is validated through visualizations of intermediate steps, including the energy map and cumulative path maps, demonstrating the algorithm's intelligent decision-making process.**

***Index Terms*—Image retargeting, seam carving, content-aware resizing, dynamic programming, energy function, optimal ordering.**

I. INTRODUCTION

The ability of display devices to vary aspect ratios and resolutions has underscored the limitations of traditional image resizing techniques. Standard methods like uniform scaling and cropping are content-oblivious; scaling distorts important objects, while cropping indiscriminately discards peripheral information. To address this, content-aware image retargeting has emerged as a critical field of study.

A foundational technique in this area is seam carving, introduced by Avidan and Shamir [1]. This discrete method intelligently resizes an image by iteratively removing or inserting "seams"—optimal 8-connected paths of pixels that span the image. The optimality of a seam is defined by an energy function that assigns an importance value to each pixel. By removing low-energy seams, the algorithm gracefully carves out pixels from visually insignificant regions while preserving the structure of important, high-energy content.

This work details a complete and optimized implementation of the seam carving algorithm. We present a methodology that not only performs basic seam removal but also incorporates the advanced optimal ordering strategy for two-dimensional retargeting. The implementation is designed for efficiency and clarity, leveraging Python's scientific computing libraries to provide a practical framework for understanding and applying this powerful algorithm.

II. THE SEAM CARVING ALGORITHM

The implemented algorithm can be deconstructed into four primary stages: 1) defining pixel importance via an energy function; 2) identifying the single optimal seam using dynamic programming; 3) iteratively removing seams for one-dimensional resizing; and 4) determining the optimal order of removals for two-dimensional retargeting.

A. The Image Energy Function

The basis of content-aware resizing is the ability to quantify the importance of each pixel. This is achieved through an energy function based on the gradient magnitude. Using Sobel operators, the energy $e(i, j)$ of pixel (i, j) is computed as:

$$e(i,j) = \left|\frac{\partial I}{\partial x}\right| + \left|\frac{\partial I}{\partial y}\right|.$$

B. Optimal Seam Identification via Dynamic Programming

A vertical seam is an 8-connected path from the top to the bottom of the image with one pixel per row. The cumulative energy map M is computed as:

$$M(i,j) = e(i,j) + \min\big(M(i-1,j-1), M(i-1,j), M(i-1,j+1)\big).$$

Backtracking through M provides the lowest-energy seam. Horizontal seams are found similarly by rotating the image.

C. Iterative Seam Removal

To reduce width by k pixels, the algorithm iteratively finds and removes k vertical seams. The same applies to horizontal seams for reducing height.

D. Optimal Ordering for 2D Retargeting

When resizing in both width and height, the order of seam removals significantly impacts quality. We use a transport map $T(r, c)$:

$$T(r,c) = \min\big(T(r-1,c) + E(s_y^r),\ T(r,c-1) + E(s_x^c)\big),$$

where $E(s_y^r)$ is the cost of the r-th horizontal seam and $E(s_x^c)$ the cost of the c-th vertical seam.

III. ALGORITHM

The pseudocode below outlines the seam carving procedure:

Algorithm 1 Seam Carving Algorithm with Vertical and Horizontal Seams

Require: Image I, target width w_{target}, target height h_{target}
Ensure: Resized image I'

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Compute Energy Map:
    For each pixel (i, j), compute
    e(i,j) = |∂I/∂x (i,j)| + |∂I/∂y (i,j)|
Vertical Seam Identification:
for each row i = 2 → h do
    for each column j = 1 → w do
        Update cumulative cost:
            M(i,j) = e(i,j) + min{M(i−1, j−1), M(i−1, j), M(i−1, j+1)}
        Store backtrack pointer to predecessor pixel
    end for
end for
Backtrack from argmin_j M(h, j) to obtain vertical seam s_v*.
Horizontal Seam Identification:
Rotate I by 90° to obtain I_rot.
Apply vertical seam algorithm on I_rot to obtain seam s_h*.
Rotate seam coordinates back to recover horizontal seam.
Seam Removal / Insertion:
while width(I) > w_target do
    Find and remove vertical seam s_v* from I.
end while
while width(I) < w_target do
    Insert low-energy vertical seams by averaging neighbors.
end while
while height(I) > h_target do
    Find and remove horizontal seam s_h* from I.
end while
while height(I) < h_target do
    Insert low-energy horizontal seams by averaging neighbors.
end while
return I' (resized image).
```

IV. Results

Our implementation of the seam carving algorithm produces several key visual outputs that demonstrate its decision-making process. These results include the intermediate energy and path maps, the identified seams, and a comparison with other resizing strategies.

First, the algorithm computes the necessary maps to guide the seam identification process. The original image (Fig. 1a) is analyzed to produce an energy map (Fig. 1b), which quantifies pixel importance. This energy map is then used to generate the vertical and horizontal cumulative path maps (Fig. 1c and 1d), which reveal the lowest-cost paths across the image.

Using the path maps, the algorithm backtracks to find the optimal vertical (red) and horizontal (cyan) seams, as shown in Fig. 2. These paths represent the pixels that will be removed in the first iteration of width and height reduction, respectively.

To demonstrate the superiority of seam carving, we compare it against several other resizing strategies in Fig. 3. The visual results highlight the artifacts introduced by naive methods versus the structure-preserving nature of seam carving.

Finally, the result of iteratively applying the seam carving process is shown in Fig. 4. The image is successfully retargeted to a new aspect ratio while preserving the integrity of the main objects.

V. Discussion

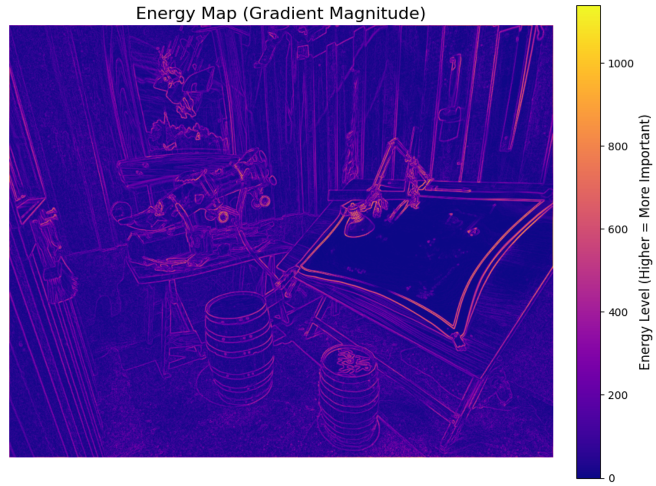
The results confirm the effectiveness of the seam carving algorithm for content-aware image retargeting. The energy map shown in Fig. 1b successfully identifies the contours of the airplane, barrels, and drawing board as high-energy (bright yellow) regions. Consequently, the low-energy areas correspond to the plain wooden walls and the empty space on the drawing paper.

This intelligent cost mapping is directly reflected in the identified seams shown in Fig. 2. The vertical seam correctly navigates the visually unimportant wooden panels on the left, while the horizontal seam follows the blank areas of the blueprint and the space between the desks. This demonstrates the algorithm's ability to find a "path of least resistance" that avoids damaging key objects.

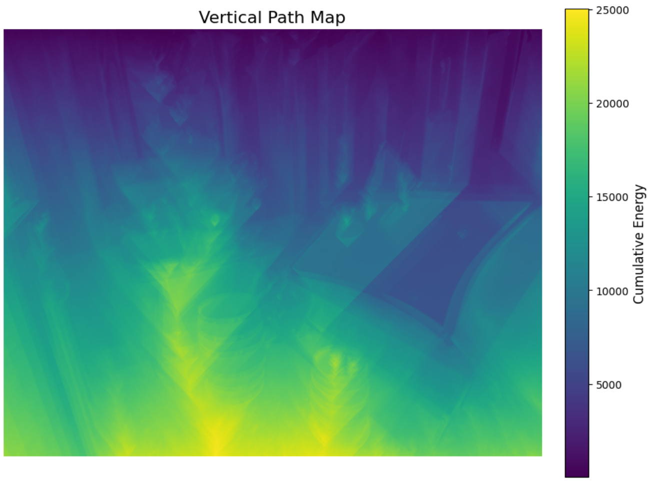
The qualitative comparison in Fig. 3 further validates the approach. Simple cropping (b) and column removal (c) produce abrupt, unnatural results. Per-row pixel removal (e) and global optimal removal (f) completely destroy the image's structural coherence, confirming that spatial connectivity is crucial. Seam carving (d) is the only method that successfully reduces the image width while maintaining the shape and integrity of the objects in the scene.

Fig. 5 compares the average energy of the remaining pixels after resizing using different methods. Seam carving consistently preserves more high-energy content than cropping or simple column removal. While it is surpassed by the globally optimal pixel removal, it does so without the destructive visual artifacts, striking the best balance between energy preservation and visual coherence. This confirms that seam carving is a highly effective strategy for intelligent image retargeting.

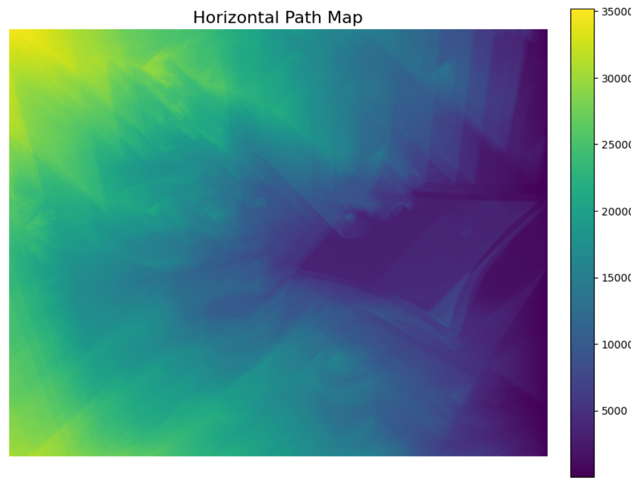
(a) Original Input Image



(b) Energy Map (Gradient Magnitude)



(c) Vertical Cumulative Path Map



(d) Horizontal Cumulative Path Map

Fig. 1: Intermediate maps generated by the algorithm. (a) The original image. (b) The energy map, where bright yellow indicates high energy. (c) The vertical path map, showing low-cost paths from top to bottom. (d) The horizontal path map, showing low-cost paths from left to right.

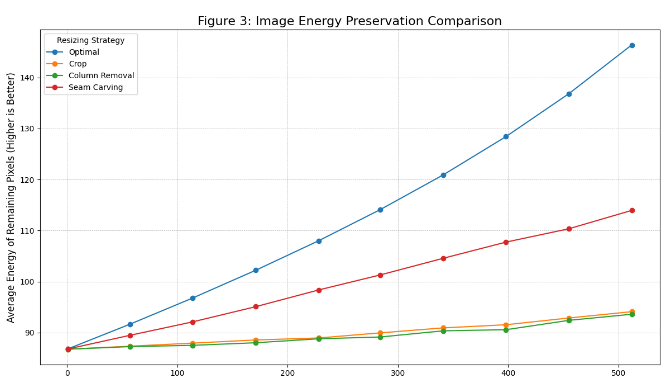


Fig. 5: Image Energy Preservation Comparison. The plot shows that Seam Carving preserves more energy (important content) than Crop or Column Removal, striking a balance between performance and visual quality.

VI. Conclusion

This paper presented a complete and optimized seam carving implementation for content-aware image retargeting. Results confirm that seam carving successfully preserves salient structures while reducing image dimensions, demonstrating its applicability for modern display adaptation.

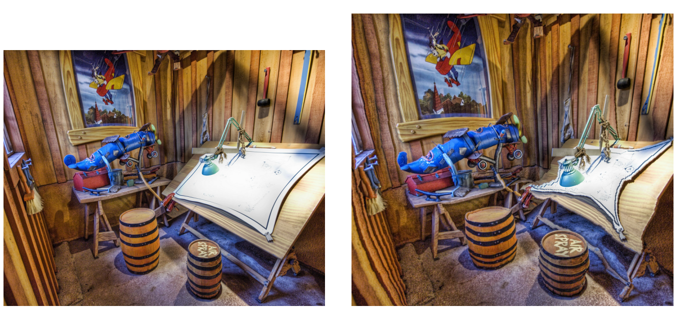
References

[1] S. Avidan and A. Shamir, “Seam carving for content-aware image resizing,” *ACM SIGGRAPH 2007 Papers*, pp. 10–es, 2007.

[2] M. Rubinstein, D. Gutierrez, O. Sorkine, and A. Shamir, “A comparative study of image retargeting,” *ACM Transactions on Graphics (TOG)*, vol. 29, no. 6, pp. 1–10, 2010. [Online]. Available: https://people.csail.mit.edu/mrub/retargetme/

Fig. 2: The first optimal vertical seam (red) and horizontal seam (cyan) identified by the algorithm, overlaid on the original image.

Fig. 3: A comparison of different strategies for reducing image width. (a) Original with energy map overlay. (b) Best Crop, which loses context. (c) Column Removal, which creates abrupt artifacts. (d) Seam Carving, which preserves object structure. (e) Per-row Pixel Removal, which destroys coherence. (f) Global Optimal Removal, which destroys the image shape.



(a) Original Image (b) Final Resized Image

Fig. 4: A before-and-after comparison showing the result of content-aware resizing via seam carving.