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Seam Carving

Abstract

The current paper discusses seam carving: the new content-aware approach for image resizing. Seam carving, introduced by Avidan and Shamir, is a way to reduce or enlarge dimensions dynamically through the removal and addition of seams—contiguous low-energy pixel paths in the image. Seam carving applies broadly to adaptive resizing, retargeting of images, amplification of contents, and object removals and therefore plays a great role in modern image processing and design. The report covers the seam carving algorithm, a literature review of related work, in-depth implementation and results analysis, and its potential for future advancements in video processing. *(Avidan and Shamir, 2007)*

Introduction

With this variety of modern digital world display devices-including mobile screens, larger monitors with high resolutions-comes the challenge of upholding the quality and integrity of images across formats without distortion or loss of coherence. It has been prompted by a growing demand in adaptive and flexible image resizing techniques to preserve important content without causing distortion or the loss of visual coherence. Pictures play a vital role in new media, and content-aware resizing is needed since new media consumers expect clear picture quality that will appropriately show on various screen sizes and orientations, something which earlier methods of resizing like scaling and cropping cannot offer.

Scaling typically resizes the entire image uniformly, but it can lead to stretched or compressed visuals that distort the image's structure. For example, in portrait pictures, facial features might appear distorted by stretching, or important objects in the landscape could seem unnatural due to some detail missing its original ratio because of cropping. It has a tendency to leave off some essential parts in an image if they fall very close to the picture boundaries. Due to this factor, important content may be cropped, and the visual appeal as well as the information carried by the image is decreased. To overcome these drawbacks, Avidan and Shamir introduced seam carving in 2007 as a revolutionary content-aware resizing approach. *(Avidan and Shamir, 2007)*

Unlike traditional techniques, seam carving resizes or crops the image based on fixed geometric parameters, such as cropping the middle seam or all the vertical seams.

This technique identifies and manipulates "seams," paths of connected pixels that carry minimal visual importance, or low energy. By strategically removing or adding these low-energy seams, seam carving dynamically adjusts the image's dimensions while preserving essential high-energy areas that contribute most to the visual structure and message of the image.

The seam carving technique allows for aspect ratio changes without distortion to critical content, which means it is displayed optimally across devices and their orientations. Therefore, seam carving offers a non-uniform resizing method whereby the more important parts of the image—be it faces or objects of interest or high detail regions—are preserved without distortion that makes it highly useful for content-preserving applications. This content-aware resizing is useful in the following scenarios, such as responsive web design, in which images are scaled both for desktop and mobile layouts; mobile applications that will display images on a number of screen sizes; and real-time media, in which images have to be resized on the fly with no manual intervention. Seam carving, as a tool to be used in adaptive, high-quality visuals, provides an effective means of flexible, visually coherent image resizing, meeting the needs of end-users and designers alike. This report delves into the mechanics of seam carving, its applications, and its performance compared to traditional resizing methods, highlighting its strengths and limitations in various real-world scenarios.

Literature Survey

The approaches developed by the researchers during the last couple of decades focused on the visual importance of key elements within an image while resizing in a content-preserving way to different display formats and aspect ratios. The subsequent literature review covers some important contributions made in the area, starting with foundational work as well as innovative solutions leading to the advanced content-aware resizing techniques like seam carving.

Suh et al. discussed an early approach toward content-aware resizing in 2003. They introduced an automatic visual saliency-based method for thumbnail cropping, which emphasizes the most prominent or "attention-grabbing" regions of an image. Their technique focused on automatically determining and cropping thumbnails to include regions of high visual importance, such as faces or distinctive objects, without user intervention. This approach introduced the idea that image resizing could be guided by perceptual importance rather than simple geometric constraints, providing a basis for content-aware resizing that would later be expanded in more sophisticated techniques. *(Suh et al., 2003)*

An example of notable development comes with the work done by Liu et al. in the year 2003 in their adaptation for images over mobile devices. In general, mobile devices are normally endowed with small displays hence; they investigated adaptive techniques on browsing to determine Regions Of Interest (ROI) from any image and change their contents dynamically according to this aspect to fit in this region. This method realized and prioritized regions of interest in an attempt to match the requirements for preserving image meaning with the constraints imposed by limited size. It constitutes an important step toward countering the problems of handling small-screen devices in such a unique way that goes beyond scaling uniformly. *(Liu et al., 2003)*

Liu and Gleicher proposed the method of fisheye-view warping in 2005, which is a non-linear resizing method trying to keep the essential content while compressing less important areas. In this manner, significant scaling of significantly less important areas can help preserve the general structure of important regions, such as faces or objects. Therefore, a "focus-plus-context" effect is observed for fisheye-view warping where the focus area is not distorted and context areas are compressed or warped. This method allowed a better control over which part of the image was able to keep its original size, providing an early kind of content-preserving resampling that matched the need for adaptation in those contexts where key elements of the content must remain invariant. *(Liu and Gleicher, 2005)*

Setlur et al. contributed their knowledge to the domain of content-aware resizing work done by targeting large images toward small-displays by Setlur et al. (2005). They proposed a technique where the image was divided into layers and then resized, independent of their importance. This layer-based segmentation made it possible to resize parts of the image selectively: the foreground objects or main areas of interest would be favored, while the background or the less important parts of the image would be more severely resized or even eliminated. Their approach furnished a method to image space adaptation, and in application, was suited for smaller display requirements and demonstrated the applicability of multi-layer approaches to the finer-grained task of resizing images with the visual hierarchy. *(Setlur et al., 2005)*

In the seminal work of Jacobs et al. in 2003 on adaptive document layout, it though was not exactly image size resizing but rather concentrated on media display problems, including displaying different formats within contexts. *(Jacobs et al., 2003)*

This grid system was able to make the layout adaptive towards documents since it auto-formed into any template considering dimensions and images placement. Their innovative work has been on how designs respond, considering the aspect wherein images adjust to layouts created, thereby making designs quite coherent visually. Jacobs et al's work was influential for later works in methods considering an image or document structure at a larger scale instead of element-by-element scaling; these would later shape flexible designs and inform the concepts that later led to seam carving and other content-aware techniques.

Along this line, Setlur et al. (2005) have focused on the automatic image retargeting work in the context of resizing images to fit a mobile or compact display. The technique proposed involves a combination of background segmentation and foreground object preservation that would make the image size adjusted without losing the most important parts but compressing the less important areas. This was useful in the application, particularly where the size of display is a constraint, but their method allowed them to segment the image and resize according to content significance, therefore making the resizing more targeted. It introduced concepts later refined in seam carving by selective resizing based on the energy or importance of areas in the image. *(Setlur et al., 2005)*

Gal et al. (2006) further developed the adaptive image manipulation concept by introducing a feature-aware texturing approach that could warp or alter images while preserving specific user-defined features. Their work was based on local constraints and a global optimization process that maintains the integrity of chosen areas within the image, providing a flexible framework for resizing that can prioritize certain features. This method opened up the path for other later techniques, which involved integrating user input into the resizing process so that a user could identify parts of the image to be untouched or prioritized, something that has been explored with user-defined regions of interest in seam carving. *(Gal et al., 2006)*

More recently, Wang and Cohen (2006) came up with a simultaneous method of image matting and compositing where the foreground elements are allowed to be resized independently from the background. This provides the basis for object-aware resizing, which is used for segmenting certain elements that have to be resized independently for better detail preservation. This method addressed one of the main limitations of traditional resizing: both background and foreground are scaled uniformly, which can lead to distortion or unnatural results. Their work has influenced modern content-aware resizing methods that aim to balance the resizing of different image layers based on content significance. *(Wang and Cohen, 2006)*

Seam carving was developed by Avidan and Shamir in 2007 by synthesizing many of these ideas into a single, unified approach that has since become one of the most widely used content-aware resizing techniques. The authors defined a "seam" as a connected path of low-energy pixels and thereby achieved a dynamic resizing process that adapts to image content in ways that traditional scaling or cropping cannot. With an energy map, such as a gradient or saliency measure, the seam carving approach allows for a nuanced resizing that will preserve details while compressing less significant areas. Building on prior research in content preservation, this method not only creates a flexible algorithm but can also be used for image, video, and any other visual media. Through exploring these groundworks, one should establish that the concept of content-aware resizing has evolved through numerous innovations, which address some aspects of maintaining visual coherence. *(Avidan and Shamir, 2007)*

Techniques like saliency-based cropping, fisheye warping, layer segmentation, and seam carving have together advanced image adaptation capabilities while preserving integrity of content in different forms. This literature survey lays a solid foundation for understanding how seam carving integrates and expands on previous techniques to establish itself as a highly effective solution in content-aware image resizing..

Problem Statement

Seam carving addresses one of the most fundamental issues in digital media, where resizing images should not perturb the content they embody inside. Seam carving contrasts with most other scaling and cropping operations since it relies on knowledge about the content carried within the image and thereby can favor some objects while penalizing others based upon their importance. Simple scaling for simple changes in dimension sometimes produces unexpected distortions on the structure of the image, or even removes very crucial details. For example, the expansion of the dimensions of an image will stretch the important areas and shrink other areas and therefore do not look natural or seem out of place. In comparison, cropping removes the surrounding areas of an image into a size that is within the preferred dimensions, with the potential to miss on critical information, especially those near the edges of a frame. Both methods then do not offer the desired flexibility and adaptability especially in applications that require utmost preservation of content.

The challenge of content-preserving resizing is particularly relevant because images increasingly often appear on a host of systems and in various formats. For example, an image that appears across a large desktop monitor must be resized for viewing on a mobile screen, which has an entirely different aspect ratio and much less space. The image should thus be transformed in such a way that the more pronounced features are preserved, including both visual and contextual kind, but less important may change. Obviously, in practice it is very complicated to manage this delicate equilibrium manually for each image when rather drastic or even dynamic adjustment/resize has to be applied.

One promising adaptive solution through the energy map is devised to aid the resizing with guidance throughout the process of reduction in size, while energy map can somehow be construed as a means of measures of the amount of 'importance' of any pixel in terms of where more energy reflects areas significant to the visibility and understanding of the particular image of interest. So low-energetic points would constitute lesser importance related to this type of generalized structure along with the implied meaning contained within the original image.

Seam carving, for instance, can identify low-energy regions and strategically remove or duplicate connected paths of pixels, referred to as seams, that have the lowest cumulative energy. This way, it only changes the least important pixels while protecting the important areas with high energy and preserving visual coherence.

To compute the energy map in seam carving, gradient-based techniques such as the Sobel operator are often used. These compute variations in intensity between adjacent pixels, with objects having large variations in their intensity around the edges and other regions of smaller variations. The result is that seams are automatically found through areas of the image that do not carry much noticeability. It will gradually resize the image without any loss of its coherence by removing these low-energy seams in a sequence.

Huge application of this content-aware resizing is found in digital design, media, and web development; images are required to be optimized for different screen sizes and orientations. For example, the very same image may need to fit a wide desktop screen versus a narrow mobile viewing area, responsive web design. This ability of seam carving, adapting dimensions sensitively, can easily warrant that the critical contents need not get distorted but will be maintained regardless of their format. Finally, seam carving proves itself to be an ideal way of image resizing when applied in cases where display space is much tighter, particularly in mobile applications without sacrificing any image quality or content integrity.

Adaptive resizing in seam carving removes the need for human intervention, which is suitable for real-time applications and automated workflows.

Application-specific, such as video processing, where resizing of the individual frames may occur on-the-fly, makes it highly desirable to use seam carving for maintaining continuity of view across frames. On top of that, seamless regions of interest defined by the user can be made part of the seam-carving algorithm to further qualify which parts of the image is being preserved during a resize operation. For instance, a user can define a certain object or region of an image that should not be resized; the rest of the image is resized around it. The flexibility in seam carving can make it more useful in any application where both automated resizing and customized resizing are demanded.

Overall, seam carving overcomes the main difficulty of content-preserving resizing, as it changes the dimensions of images adaptively in response to the content's importance. It ensures important structures and details in an image remain visually coherent and undistorted by changing selectively only low-energy areas. Thus, seam carving is a very powerful tool for modern digital media where images are presented in many different formats and need to be adapted to each other without degrading quality or content.

Proposed System

The seam carving operation is structured in a careful step-by-step process as follows to achieve content-aware image resizing. It heavily depends on three primary stages that are calculating the energy map, identifying the optimal seam, and removing or adding seams according to the resizing intended. Each of these stages does have a significant role towards making sure that the size changing operation will adapt within the content of the given image rather than applying a change with uniformity that distorts or omits several details.

The first stage, energy map calculation, involves analyzing the image to determine the importance of each pixel. This is done by assessing the gradients across the image, typically using a gradient-based filter like the Sobel operator. The Sobel operator calculates the rate of change in pixel intensity across horizontal and vertical axes, effectively capturing the edges and boundaries within the image. High gradients are given by edges and, visually speaking, represent those significant transitions or structures rich in energy. Smoother regions that have less changes in intensity imply the low gradient values and so, comparatively lower energy. This energy map is thus the basis on which the entire seam carving process hinges, showing which parts of the image need to be preserved while which parts might be arbitrarily changed or deleted without drastically diminishing visual value.

After developing the energy map, another process called seam identification begins. A seam is a connected path of pixels that spans from one side of an image to the opposite side. For vertical seams, this would be from top to bottom, and for horizontal seams, from left to right. The idea is to find the seam with the lowest cumulative energy, which is the path through the least significant pixels in terms of visual content.

This seam identification is crucial because the algorithm will attack the low-energy regions and avoid important structures and details in the image. Dynamic programming can be used to find this optimal seam. This approach is advantageous in computing the minimum-energy path efficiently by considering the cumulative energy at each pixel along with the energy values of the neighboring pixels along the path.

Dynamic programming initializes the first row (or column) of image energy values and then proceeds to calculate the cumulative energy for each subsequent row or column by choosing the minimum cumulative energy at each step. A dynamic programming algorithm tracks the optimum seam path all over the entire image effectively, with no redundant computation and cumulative energy values updated and stored that make certain the path costs the least that is to significant visual areas selected.

The final stage is seam removal or insertion. Depending on the need for resizing reduction or expansion, the identified seam may either be removed or duplicated. To reduce the image width or height, the seam is removed and this is reduced by one pixel line of the total dimension. Low-energy seams are progressively removed so that key areas do not distort or compress in the process. The expansion involves duplication of the detected seam thus making a new seam with the same pixel values as of the previous seam.

This seam insertion process preserves the image's visual continuity as it increases in size, since the duplicated pixels integrate seamlessly with neighboring pixels.

All of these phases-seam identification, energy map calculation, and removal/insertion of seam, therefore will contribute towards such a flexible, content aware resizing process. In case only the lowest energy area is targeted, then it thus maintains the high-energy region that consequently retains all details, therefore this resizing is implemented on an image such that it honors the visual content. Hence, such adaptation of image transformation so that visually coherent happens to make seam carving a pretty fine application for applications with adaptation.

Working/Implementation

The seam carving algorithm is built upon several core elements, which give it the functionality of resizing images in a content-aware manner. Each part contains a certain task from the review of pixel importance to the identification of areas where the image might be resized further or eliminated. Major parts include calculation of energy map, finding seams, removal or insertion of seams, and also application for object removal.

The first component is Energy Map Calculation. This determines what parts of the image are visually significant. It is computed by calculating the gradient of the image with the use of Sobel operators. Sobel operators are filters that measure changes in pixel intensity along the x (horizontal) and y (vertical) axes. Applying these filters will activate edge and structural cues within the image since high intensity changes typically happen there. The energy map that is produced highlights the high-energy regions that are possibly edges or otherwise the details significant for visual perception within the image. Low-energy regions, on the other hand, are less critical where minimal variation of intensity takes place. These low-energy regions are candidates for resizing or removal because variations in these regions less affect the image's overall appearance.

Once the energy map is established, the algorithm proceeds to Seam Identification. A seam is defined as a connected path of pixels that extends either vertically from the top to the bottom of the image or horizontally from left to right. The seams are selected according to their accumulated energy. Here, the minimum-energy seam is to be found. The minimum visually noticeable path in the image is known as the minimum-energy seam. It is optimum for being removed or duplicated. Dynamic programming is utilized for efficiently calculating the minimum cumulative energy path throughout the image for seam identification. This process will accumulate energy at every pixel by adding up the energies from a neighboring pixel along a seam path. Storing all these values, the algorithm could very quickly trace its way back to what are the paths that are going to be the lowest total energy that will ensure areas modified are of low impact.

The second feature is Seam Removal or Insertion, depending on whether one wants to resize up or down. If the objective was to shrink the dimensions of the image, eliminate the seam that was located. Eliminating this seam decreases the dimensions of the image by one row of pixels in width and height. This is repeated for every seam until one has the desired size, then every elimination is aimed at the next least significant seam based on the energy map that has been modified. On this account, seam removal gives way to low-energy portions, and the image now shrinks gradually without having any distortion in the importance structures. On the opposite end, seam insertion can be applied for image enlargement. In this case, the algorithm duplicates the found seam by inserting a row or column of pixels mirrored for original values. This enables the expansion of image size without stretching high-energy areas because newly inserted pixels blend with surrounding content. Seam insertion can be used to expand an image to a larger dimension while still preserving its natural appearance.

Besides rescaling, another very powerful application of the algorithm is Seam Carving for Object Removal. By modifying the algorithm to mark the area a user wishes to remove in the image, the removal of an object can be achieved using seam carving by calculating the seams again. This time, paths will avoid the object, removing it from the image without leaving any gaps. It marks the object by reducing the energy of the marked object to a low value so that it becomes part of the identified low-energy seams. As these seams are removed gradually, the marked object is effectively erased from the image, while the content around it moves into the space naturally. It can be used for eliminating unwanted elements or distractions from images because it preserves the visual continuity without any need for manual editing.

All these parts comprise the core of the seam carving algorithm: energy map calculation, finding the seam, its removal or insertion, and object removal. In total, each of these steps is meant to allow the algorithm to carry out the resizing of images or removal of objects in a manner that would retain the visual content of an image. In focus on low-energy paths and adaptation to the image structure, seam carving provides a flexible content-aware manipulation-a powerful tool for modern applications of image processing.

Result Analysis

It has been found to be much more effective for preserving essential content and the quality of images in comparison with traditional resizing techniques. However, uniform scaling or cropping often tend to distort areas of key interest and miss important details while seam carving dynamically adapts to resizing an image by focusing on least important areas of an image for preserving visually significant regions with minimal distortion.

For instance, when resampling a landscape picture with the standard scaling technique, all of the pixels within that image are compressed equally in terms of their dimensions. That would stretch or squish significant elements in the scene such as buildings or trees. Cropping might save the important features but throw away parts of the border of the image that would be very important for the context. Seam carving determines low energy paths, that is the least visually impacting regions and then progressively removes those paths from the image so that most elements in the scene are nearly undistorted: more so than detailed structures in buildings.

In the images resized by this method, structural integrity, overall visual details remain the same even after quite an alteration in the size. Features such as faces and objects continue to be very much viewable, considering how well the algorithm locates areas of low energy while retaining high-energy zones, particularly very important for face-featured portrait images which normally experience distortion with uniformly scaling; seam carving still results in natural proportions.

Various imagery experiments illustrate that seam carving actually is an algorithm highly adaptive to the change of complexity. For less complex images with distinguishable objects, the low-energy region can easily be identified, but for a more complex one containing more textures with overlapping shapes, again it will retain regions of maximum energy while keeping coherence of contents may be managed with some subtle mechanism in this process.

It is also video frames adaptive in its nature. Seam carving frame-by frame maintains the integrity of each frame visually hence with proper resizing. Its ability becomes useful for

any application using adaptive resizing across various different formats.

Figure 1: Input Image

Figure 2: Output Image

Conclusion and Future Work

The effectiveness with which seam carving manages the adjustment of an image's size without distorting its central visual content makes it especially effective for adaptive resizing methods. Seam carving allows selecting low-energy seams: image paths that are critical toward the overall structure while comprising small importance to the rest. So, it is an option that is especially valid to be used in areas or applications where content preservation and maintenance are crucial.

Despite its good qualities, seam carving still has several weak points. Specifically, they do not work all too well in images full of complex patterns or detailed texture-these provide the fewer low energy regions which must be extracted without much visual degradation or loss in looks and display. If that is the scenario, during extremely shrinking and resizing processes of an image, some sections of necessary features would have started getting degraded, considering the lower energy seams may be at a hard bargain. All that should work then best is seam carving with just another rather very conventional one like the one using a control crop and then scale.

Further improvement in seam carving can give better performance and applicability in the future. One direction is the optimization of seam carving for real-time video processing. Seam carving on video frames is a challenging issue because the removal of seams between frames causes visual breaks. For effective real-time resizing, complex algorithms have to be developed that would maintain seam continuity over time.

Another possible enhancement could be the integration of user-defined regions of interest (ROIs). Enabling users to specify the parts of the image they want to be preserved will make the algorithm more versatile. For instance, a group photo can be allowed to have all faces that should not be touched while resizing, and the energy values of the algorithm should be adjusted accordingly.

Ultimately, hybrid approaches combining seam carving with other resizing methods could prove more effective for difficult images and videos. For example, after seam carving to remove low-energy areas, traditional scaling may achieve a much more significant size change while minimizing distortion.

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