Faster Seam Carving With Minimum Energy Windows

César L. Blum Silveira *
Computer Science
University of Vale do Rio dos Sinos (Unisinos)
São Leopoldo, Rs, Brazil
cesarbs@gmail.com

Luiz Gonzaga Jr
Advanced Visualization Lab (VIZLab)
Applied Computing Graduate Program (PIPCA)
University of Vale do Rio dos Sinos (Unisinos)
São Leopoldo, RS, Brazil
lgonzaga@unisinos.br

Kleinner Farias
Applied Computing Graduate Program (PIPCA)
University of Vale do Rio dos Sinos (Unisinos)
São Leopoldo, RS, Brazil
kleinnerfarias@unisinos.br

Fabio de Oliveira Mierlo
V3D::Innovative Visualization Company
São Leopoldo, RS, Brazil
fabio@v3d.com.br

Cristiano André da Costa
Applied Computing Graduate Program (PIPCA)
University of Vale do Rio dos Sinos (Unisinos)
São Leopoldo, RS, Brazil
cac@unisinos.br

Rodrigo da Rosa Righi
Applied Computing Graduate Program (PIPCA)
University of Vale do Rio dos Sinos (Unisinos)
São Leopoldo, RS, Brazil
rrrighi@unisinos.br

ABSTRACT

Content-aware image retargeting is the problem of adapting images to different display sizes and aspect ratios while minimizing distortions to the most important regions of those images. Seam carving is an operator for content-aware image retargeting that iteratively removes 8-connected pixel paths (seams) from an image until a target resolution is reached. Finding optimal seams for seam carving is computationally expensive. We have proposed the concept of minimum energy windows as an approach to reduce the computational load of seam finding. Our results demonstrate that it is possible to find nearly-optimal seams and obtain high quality results with a significant performance improvement.

Categories and Subject Descriptors

I.3.0 [**Computing Methodologies**]: Computer Graphics – General; I.4.10 [**Image Processing and Computer Vision**]: Image Representation

Keywords

Image resizing, Content-aware image retargeting, Minimum energy windows, Seam carving, Image seams, Dynamic programming.

*César developed this work while he was undegraduate student at Unisinos. Currently, he is working at Microsoft, Redmond - WA - USA.

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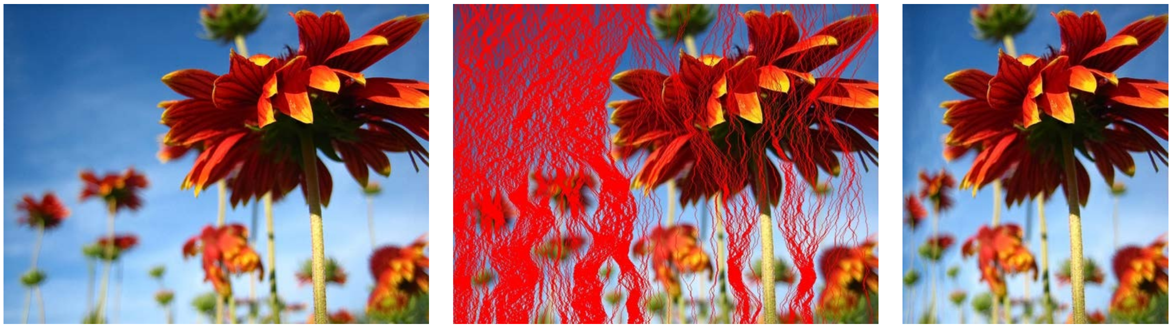
1. INTRODUCTION

The widespread adoption of mobile devices such as smartphones gives rise to the need of adapting existing visual content to the smaller display sizes of those devices. Content-aware image retargeting is concerned with adapting images to different display sizes and aspect ratios while minimizing distortions to the most important regions within such images. Only cropping or uniformly scaling content may not be sufficient for that purpose. Cropping potentially excludes important visual data from the scene. Scaling might shrink important content to an extent that it becomes hard for the user to understand it. Besides, uniform scaling damages the proportions of scene objects if there is a change in aspect ratio.

Seam carving [2] is a discrete approach to content-aware image retargeting. The seam carving operator works by iteratively removing monotonic vertical or horizontal 8-connected single-pixel paths from an image, until target dimensions are reached. Seams are found based on an energy function for the image, which gives an importance value for every pixel. An optimal seam is a seam whose path has the minimum possible energy i.e. whose accumulated pixel energies are the minimum among all possible paths. Figure 1 shows an original image, the removed seams and resized image.

Numerous extensions have been proposed to the seam carving operator. In [6], it is extended to video retargeting, and an improved energy metric is introduced. This new energy metric, called forward energy, alters the definition of the operator so that is removes seams that cause the smallest introduction of new energy in the image, as opposed to the original formulation where seams of minimum energy are chosen for removal. Other works aim to improve the seam carving operator by introducing additional energy information from human skin detectors [8], line detectors [4] and visual saliency maps [1]. in order to visually improve its results. On the computational efficiency front, also a number of approaches have been proposed to reduce the time



(a) (b) (c)

Figure 1: Seam carving technique. (a) Original image. (b) Image with vertical seams. (c) Image resized

required for an image to be retargeted with the seam carving operator. In [7], the authors propose partitioning the images in order to find more than one seam per retargeting step. A very fast approach is proposed in [3] where all seams are computed at once. A partial energy update along with a divide-and-conquer method is proposed in [5], reducing the computational load for seam carving.

In this paper, we have proposed a new approach to improving the computational efficiency of the seam carving operator. Our approach, realized by what we call minimum energy windows, restricts the span of seams, limiting energy computation to a restricted area of the image and consequently requiring less computations to be carried out. Despite the limitation imposed on seam span, out technique leads to results very similar to those obtained with canonical seam carving.

2. SEAM CARVING

The approach taken by the seam carving operator is to iteratively remove monotonic vertical or horizontal 8-connected single-pixel paths from an image, until target dimensions are reached. In this section, we provide a brief overview of its definition.

Given an image $I(x, y)$ of width w and height h, the seam carving operator iteratively removes monotonic vertical and horizontal 8-connected pixel paths from I until target dimensions $w' \times h'$ are reached. Formally, a vertical seam s^x is defined as the set

$$s^x = \{s^x_y\}_{y=1}^{h} = \{(x(y), y)\}_{y=1}^{h}, t.q.\forall y, |x(y) - x(y-1)| \leq 1 \quad (1)$$

where $x(y)$ is a mapping $x : [1, ..., h] \rightarrow [1, ..., w]$. Likewise, a horizontal seam s^y is defined as the set

$$s^y = \{s^y_x\}_{x=1}^{w} = \{(x, y(x))\}_{x=1}^{w}, t.q.\forall x, |y(x) - y(x-1)| \leq 1 \quad (2)$$

where $y(x)$ is a mapping $y : [1, ..., w] \rightarrow [1, ..., h]$. Removing a vertical seam from an image decreases its width by 1 pixel, while removing a horizontal seam decreases its height by 1 pixel.

Seam carving with forward energy aims to find seams whose removal cause the least introduction of new energy in I. Considering the removal of vertical seams, in order to find those, a cumulative energy map M is computed by dynamic programming for every pixel (x, y) in I:

$$M(x, y) = P(x, y) + min \begin{cases} M(x-1, y-1) + C_L(x, y) \\ M(x, y-1) + C_U(x, y) \\ M(x+1, y-1) + C_R(x, y) \end{cases} \quad (3)$$

where $P(x, y)$ is a user-provided energy bias and C_L, C_U and C_R are factors that account for the creation of new edges i.e. introduction of new energy after pixel (x, y) is removed:

$$\begin{aligned} C_U(x, y) &= |I(x+1, y) - I(x-1, y)| \\ C_L(x, y) &= C_U(x, y) + |I(x, y-1) - I(x-1, y)| \\ C_R(x, y) &= C_U(x, y) + |I(x, y-1) - I(x+1, y)| \end{aligned}$$

Once M is computed, the optimal seam can be found by searching for the minimum value in row h and following an 8-connected path up to row 1, choosing at each step pixel $(x, y-1)$ such that $M(x, y-1)$ is minimal among the three neighbours above the current pixel. By transposition, the same definitions apply to horizontal seams.

3. PROPOSED APPROACH

The minimum energy map computation described in Equation 3 has a high computational cost. Since M has to be computed for every seam that is to be removed from an image, that constitutes the biggest bottleneck in seam carving. It is clearly disadvantageous computing M for an entire image so that a single seam can be removed from it.

The discussion that follows applies to altering the width of an image. However, the same concepts and ideas apply to height reduction by transposition, without loss of generality.

We observed that vertical seams rarely have a large horizontal span. Therefore, we propose the concept of minimum energy windows. When using minimum energy windows in seam carving, M is computed only for a restricted region of the image consisting of a column interval. Consequently, seams are restricted to that column interval.

A minimum energy window is an interval $[x_0, x_1]$ in the columns of an image where

$$\sum_{x=x_0}^{x_1} M(x, h) \quad (4)$$

is minimum. The size $(x_1 - x_0) + 1$ of a minimum energy window is arbitrary. In order to retarget an image with seam carving and minimum energy windows, we devised the following sequence of steps:

1. Compute $M(x, y)$ for the entire image.
2. Find a minimum energy window in M according to Equation 4.
3. Remove half of the seams in the minimum energy window; if the target width is reached before half of the seams are removed, halt. During the process, update M only within the bounds of the window.
4. If the target width hasn't been reached, go to step 1.

Evidently, if the minimum energy window size is larger than the target width, the process reverts to canonical seam carving. Removing half of the seams was empirically determined to be an appropriate quantity before starting to introduce significant distortions in the images.

4. EXPERIMENTAL RESULTS

We have evaluated two aspects concerning the usage of minimum energy windows with the seam carving operator:

1. Computational performance.
2. Impact on the quality of results.

Regarding computational performance, our tests indicate that there is a performance gain inversely proportional to the size of minimum energy windows. Table 1 presents average times in seconds for retargeting 1024×768 images to new widths of 512, 640 and 720 pixels using canonical seam carving i.e. no minimum energy windows and using 512-, 256- and 128-pixel minimum energy windows. As can be observed, retargeting time decreases as window size decreases. Our tests were performed on a desktop computer equipped with an Intel® Core™2 Duo CPU clocked at 2.2GHz with 2 GB RAM and a Linux 2.6.32 system. A set of 20 images was employed in order to measure the average values.

Target width	Window size			
	No window	512	256	128
512	5.66	3.92	2.23	1.35
640	4.57	2.96	1.70	1.04
720	3.78	2.38	1.36	0.83

Table 1: Average retargeting times (in seconds) for different minimum energy window sizes when retargeting 1024×768 images to new widths of 512, 640 and 720 pixels.

When considering the impact on the visual quality of results caused by the usage of minimum energy windows, our observations did not lead to precise conclusions such as that for computational performance. In general, we observed that larger minimum energy windows lead to results with greater similarity to those obtained without using them. However, there is no precise relation between window size and canonical result similarity. Different window sizes yield different outputs but, in general, those are all visually acceptable.

Figure 2 displays a visual comparison of images retargeted with seam carving with and without minimum energy windows. All images were retargeted from an original width of 1024 pixels to a new one of 640 pixels. Three different minimum energy window sizes were used: 512, 256 and 128 pixels.

In all cases, results were very similar to those obtained without minimum energy windows. We have noticed that a windows size of 256 pixels led to the most significant distortions. Our conclusion is that a large (512) window size allows for a greater seam span, while a small (128) one causes less seams to be removed and new windows are looked for more frequently, lessening the impact caused by narrowing seams. A medium window size of 256 pixels does not allow seams to span too much and causes the window to be repositioned less frequently, thus introducing greater distortions.

5. CONCLUSIONS AND FUTURE WORK

We presented a technique to reduce the number of computations required to find seams for removal in seam carving. We denoted the object of this technique a minimum energy window. While seams found in minimum energy windows are not optimal as those found according to the canonical formulation of the seam carving operator, the results yielded by the use of our technique are very similar to those obtained without it. Furthermore, there is a significant performance gain that is achieved by the reduction in the number of computations required for the minimum energy map.

Considering future works, the definition of minimum energy windows is open to improvements. Furthermore, alternative approaches to determining the number of seams to be removed from within minimum energy windows might lead to even better results than our empirically determined half window size. It is important, however, that any such approaches maintain the performance gains offered by the use of minimum energy windows.

6. IMAGE CREDITS

The top image in Figure 2 is available in UGArdener's Flickr photostream at `http://www.flickr.com/photos/ugardener/3274095876/` under a Creative Commons Attribution-NonCommercial 2.0 Generic license. The middle image in Figure 2 is available in Taro Taylor's Flickr photostream at `http://www.flickr.com/photos/tjt195/4440026599/` under a Creative Commons Attribution 2.0 Generic license. The image at the bottom of Figure 2 is available in Brian Wolfe's Flickr photostream at `http://www.flickr.com/photos/mightyboybrian/174194956/` under a Creative Commons Attribution-NonCommercial 2.0 Generic license.

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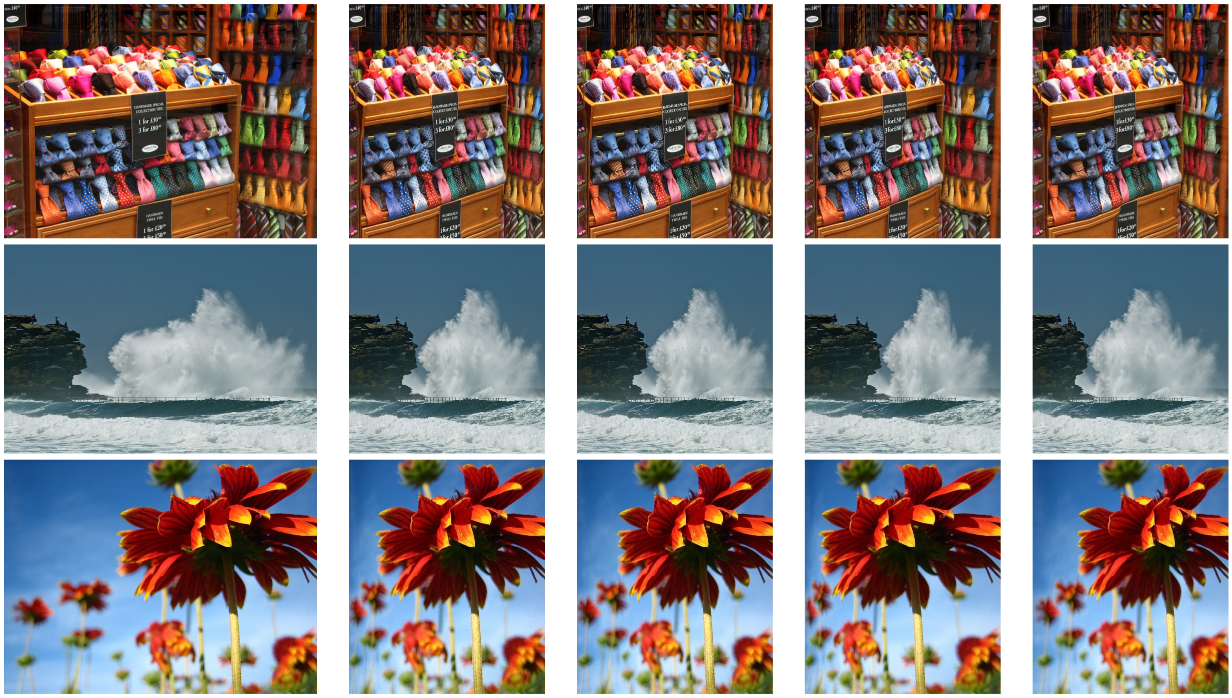

(a) (b) (c) (d) (e)

Figure 2: Visual comparison of images retargeted with seam carving with and without minimum energy windows. (a) Original images. (b) Images retargeted with seam carving without minimum energy windows, (c) with 512-pixel minimum energy windows, (d) with 256-pixel minimum energy windows and (e) with 128-pixel minimum energy windows.

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