

Content-Aware Image Resizing with Seam Carving and ResNets

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Abstract

Image resizing that respects the semantic content of images is an improvement on prior methods of Content Aware Image resizing that don't integrate higher-level knowledge of the image into their resizing processes. We present an algorithm that combines the capabilities of modern, state of the art deep learning techniques with the classical Seam Carving algorithm [2]. By combining the ability of [2] and the advanced image segmentation techniques of Mask R-CNN [3], semantically irrelevant information is removed from the image, while regions featuring subjectively important content is retained. In addition, the image enlarging capabilities of the original seam carving algorithm are enhanced by avoiding distortions of higher level features when they are present in the image.

1. Introduction

Image resizing has historically been done by cropping or scaling images, to shrink or enlarge them respectively. The introduction of the seam-carving operator by [2] allowed for the easy resizing of images while preserving spots of the image according to some energy function. The original paper used the gradient magnitude of the image as the energy function in order to eliminate areas of low change, which is a reasonable proxy for “uninteresting” parts of an image.

Content-Aware image resizing, also referred to as image retargetting, is an interesting problem as it provides quick and immediate feedback regarding the success of an approach. In addition, it is one application of a larger problem of exploring what kinds of content and patterns are visually arresting to the human visual system. The heuristic to determine human interest in the original paper is both simple and effective for many classes of image.

Seam Carving works quite well when applied to landscapes or other images where there are large patches of low and high variation. However, when applied to images with features that people are particularly attentive to (such as

faces) the results can be noticeably bad and distorted. See Figure 1 for a comparison between our method and the original seam carving algorithm (reimplemented for this paper).

By combining the ability to selectively remove “uninteresting” parts of the image with the ability to detect high level features at an accuracy that can’t be matched by a gradient based approach, we demonstrate adaptive image resizing that preserves faces and other high level content in a subjectively more pleasing and natural way.

2. Prior Work

Seam Carving [2] works by selecting seams of the lowest energy in an image, and continuously removing them until a target size is reached. A seam is a connected path leading from one end to the other of an image in a particular dimension. Let \mathbf{I} be an $n \times m$ image. Using the notation of the original paper, a vertical seam is:

$$\mathbf{s}^x = \{s_i^x\}_{i=1}^n = \{(x(i), i)\}_{i=1}^n, \text{s.t } \forall i, |x(i) - x(i-1)| \leq 1 \quad (1)$$

where x is a mapping of: $[1, \dots, n] \rightarrow [1, \dots, m]$. This is a connected path of pixels running from top to bottom of the image, with exactly one mapping between a row $x(i)$ and the horizontal location of the seam at that row. In the same way, a horizontal path consists of a mapping $y : [1, \dots, m] \rightarrow [1, \dots, n]$, and:

$$\mathbf{s}^y = \{s_j^y\}_{j=1}^m = \{(y(j), j)\}_{j=1}^m, \text{s.t } \forall j, |y(j) - y(j-1)| \leq 1 \quad (2)$$

The pixels of the seam are therefore:

$$\mathbf{I}_s = \{\mathbf{I}(s_i)\}_{i=1}^n = \{\mathbf{I}(x(i), i)\}_{i=1}^n \quad (3)$$

Since seams are always of $1 \times n$ or $m \times 1$, their removal from an image will cause a reduction of exactly one pixel in either the width or height of the target image.

With this idea, the optimal seam to remove from an image will be the one that minimizes the cost, where the cost is defined as the sum of the energy of the seam, where the



(a) Original



(b) Seam-Carving



(c) Our Method

Figure 1: Comparison between the original method and our own. The bottom two images are 80% of the size of the original image.

energy can be an arbitrary function. The optimal seam s^* is the one that minimizes this energy over the range of possible seams for a given dimension of the image:

$$s^* = \min_s(E(s)) = \min_s \sum_{i=1}^n e(\mathbf{I}(s_i)) \quad (4)$$

The optimal seam can be found through a bottom-up dynamic programming approach, where we can create a scoring matrix M by computing the minimum energy for all possible connected seams at a point by:



(a) Optimal Seam Insertion



(b) Seams Inserted in order of Removal

Figure 2: The result of inserting the optimal seam repeatedly and in order of removal. (Figures taken from [2])

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

After the scoring matrix is constructed, we can find the optimal seam by tracing up from the bottom and picking the minimum value of the three connected elements on the row above. The process is identical for horizontal seams, using the transpose of the original image.

After the seam is found, it can be removed from the image and the whole process can be repeated until the desired image size in the specified dimension $n' \leq n$ is reached. A simplification from the original paper is made here. The authors propose a scheme for finding the optimal removal order of seams, but the qualitative difference in the modified image was negligible. A simpler approach was taken by simply applying horizontal seam removal to an image, and then transposing the resulting image and performing the process again, until the desired size was reached in each dimension.

To enlarge an image from $n \times m$ to $n' \times m'$, it is not sufficient to simply add the optimal seam repeatedly, as this will most often insert the same seam repeatedly, causing obvious banding effects as seen in Figure 2.

To avoid this issue, it suffices to first shrink the image by $(n' - n, m' - m)$ and then save the seams in the order of removal. After the image is fully resized, you then insert the removed seams back into the original image.

The energy function is generally the gradient magnitude of the image, as the original authors experimented with different functions but all provided qualitatively similar results.

2.1. Limitations of Prior Work

The Seam Carving method described above works very well for images with clearly separated regions of high and low energy, and especially those without faces or other features that human minds are particularly sensitive towards. An example of a good image to perform seam carving on is seen in Figure 3.

However, when seam carving is applied to images with faces or other high level semantic features, the results are often wildly distorted. This is because the idea of gradient magnitude being a perfect measure of human attention in an image is inaccurate at best. An example of this can be seen in Figure 4.

Other limitations include only being able to enlarge an image by a factor of 2 as seams have to be removed first before they can be added back to the original.

2.2. Addressing the Limitations

This paper seeks to address the inability to resize images containing human images and other recognizable object categories. By utilizing the neural network defined in [3, 1], the high level feature knowledge embedded in the pretrained network weights allow our algorithm to preserve the semantic content of the images being resized. This not only allows for better shrinking of images, it also allows for better enlarging by the same strategy. We enhance the energy function by introducing the masks generated by Mask R-CNN as a measure of greater importance to the areas belonging to high level features.

2.3. Datasets

A selection of images have been taken from Flickr, which contain a Creative Commons fair use license. These images have been selected for evaluation as they present the kinds of features the original seam carving algorithm did not perform well on.

2.4. System Description

The seam carving system described in the original paper was entirely reimplemented in the Julia programming language. This language was chosen for its greater ease of use and speed over Matlab, and chosen over Python for its increased speed. The metaprogramming and extensive linear algebra and image filtering features of Julia made several aspects of the reimplementation easier and faster than an equivalent Matlab or Python implementation. The high level image filtering features of Julia used were only the image gradient calculation. Otherwise, the seam-carving por-



(a) Original Image



(b) Shrunk by 20%



(c) Grown by 20%

Figure 3: An image with good results shown with classical seam carving.

tion of the algorithm has been entirely written based off of [2].

Mask-RCNN is used to calculate the mask overlays of the high level objects in the image. As there is a separate overlay for each specific mask, these are summed and normalized into a single image with pixels inside the mask being α and those outside being 1. The mask sum is computed by:

$$\mathbf{R} = \alpha \sum_{i=1}^N R_i + \mathbf{1} \quad (5)$$



Figure 4: Seam Carving gone wrong.

where $\mathbf{1}$ is a matrix of ones the same size as R_i , and α is a hyperparameter chosen experimentally to improve the preservation of semantic content in the image. Unless otherwise stated, $\alpha = 20$ for images using our algorithm.

We then element-wise multiply (sometimes known as the “Hadamard Product” denoted by \oplus) our gradient magnitude by \mathbf{R} to produce our energy matrix:

$$E(\mathbf{I}) = \left| \frac{\delta \mathbf{I}^2}{\delta x} + \frac{\delta \mathbf{I}^2}{\delta y} \right| \oplus \mathbf{R} \quad (6)$$

2.5. Blind review

Many authors misunderstand the concept of anonymizing for blind review. Blind review does not mean that one must remove citations to one’s own work—in fact it is often impossible to review a paper unless the previous citations are known and available.

Blind review means that you do not use the words “my” or “our” when citing previous work. That is all. (But see below for techreports.)

Saying “this builds on the work of Lucy Smith [1]” does not say that you are Lucy Smith; it says that you are building on her work. If you are Smith and Jones, do not say “as we show in [7]”, say “as Smith and Jones show in [7]” and at the end of the paper, include reference 7 as you would any other cited work.

An example of a bad paper just asking to be rejected:

An analysis of the frobnicatable foo filter.

In this paper we present a performance analysis of our previous paper [1], and show it to be inferior to all previously known methods. Why the previous paper was accepted without this analysis is beyond me.

[1] Removed for blind review

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An analysis of the frobnicatable foo filter.

In this paper we present a performance analysis of the paper of Smith *et al.* [1], and show it to be inferior to all previously known methods. Why the previous paper was accepted without this analysis is beyond me.

[1] Smith, L and Jones, C. “The frobnicatable foo filter, a fundamental contribution to human knowledge”. *Nature* 381(12), 1-213.

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We describe a system for zero-g frobnication. This system is new because it handles the following cases: A, B. Previous systems [Zeus et al. 1968] didn’t handle case B properly. Ours handles it by including a foo term in the bar integral.

...

The proposed system was integrated with the Apollo lunar lander, and went all the way to the

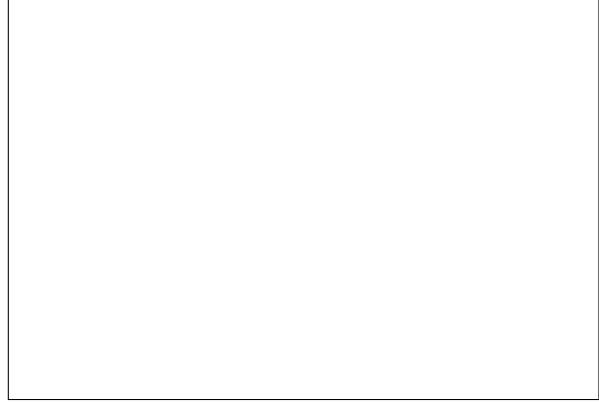


Figure 5: Example of caption. It is set in Roman so that mathematics (always set in Roman: $B \sin A = A \sin B$) may be included without an ugly clash.

moon, don't you know. It displayed the following behaviours which show how well we solved cases A and B: ...

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2.6. Miscellaneous

Compare the following:

```
$conf_a$           confa
$\mathit{conf}_a$    confa
```

See The TeXbook, p165.

The space after *e.g.*, meaning “for example”, should not be a sentence-ending space. So *e.g.* is correct, *e.g.* is not. The provided \eg macro takes care of this.

When citing a multi-author paper, you may save space by using “et alia”, shortened to “*et al.*” (not “*et. al.*” as “*et*” is a complete word.) However, use it only when there are three or more authors. Thus, the following is correct: “Frobnication has been trendy lately. It was introduced by Alpher [?], and subsequently developed by Alpher and Fotheringham-Smythe [?], and Alpher *et al.* [?].”

This is incorrect: “... subsequently developed by Alpher *et al.* [?] ...” because reference [?] has just two authors. If you use the \etal macro provided, then you need not worry about double periods when used at the end of a sentence as in Alpher *et al.*

For this citation style, keep multiple citations in numerical (not chronological) order, so prefer [?, ?, ?] to [?, ?, ?].

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All text must be in a two-column format. The total allowable width of the text area is $6\frac{7}{8}$ inches (17.5 cm) wide by $8\frac{7}{8}$ inches (22.54 cm) high. Columns are to be $3\frac{1}{4}$ inches (8.25 cm) wide, with a $\frac{5}{16}$ inch (0.8 cm) space between them. The main title (on the first page) should begin 1.0 inch (2.54 cm) from the top edge of the page. The second and following pages should begin 1.0 inch (2.54 cm) from the top edge. On all pages, the bottom margin should be 1-1/8 inches (2.86 cm) from the bottom edge of the page for 8.5 × 11-inch paper; for A4 paper, approximately 1-5/8 inches (4.13 cm) from the bottom edge of the page.

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```
%\ifcvprfinal\pagestyle{empty}\fi
\setcounter{page}{4321}
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where the number 4321 is your assigned starting page.

Make sure the first page is numbered by commenting out the first page being empty on line 46

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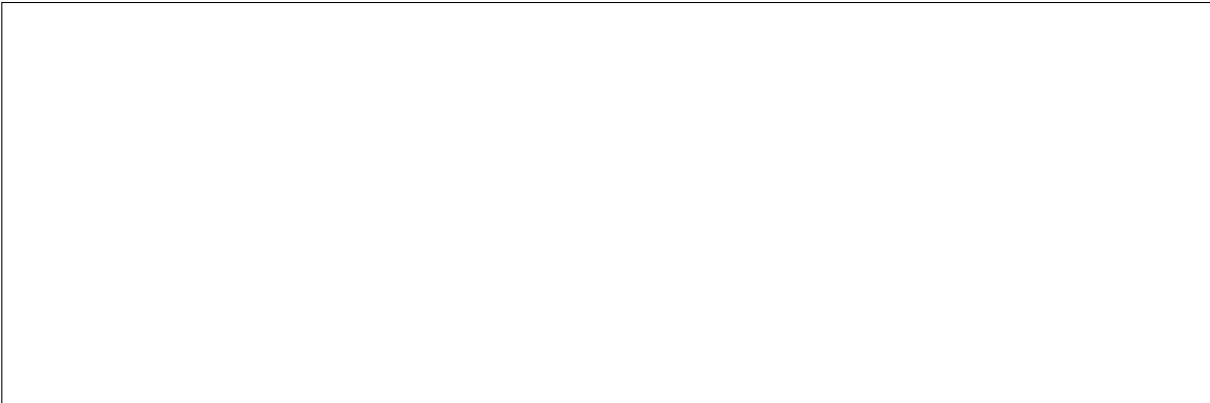


Figure 6: Example of a short caption, which should be centered.

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Method	Frobnability
Theirs	Frumpy
Yours	Frobby
Ours	Makes one's heart Frob

Table 1: Results. Ours is better.

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Please use footnotes¹ sparingly. Indeed, try to avoid footnotes altogether and include necessary peripheral observations in the text (within parentheses, if you prefer, as in this sentence). If you wish to use a footnote, place it at the bottom of the column on the page on which it is referenced. Use Times 8-point type, single-spaced.

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¹This is what a footnote looks like. It often distracts the reader from the main flow of the argument.

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References

- [1] W. Abdulla. Mask r-cnn for object detection and instance segmentation on keras and tensorflow. https://github.com/matterport/Mask_RCNN, 2017.
- [2] S. Avidan and A. Shamir. Seam carving for content-aware image resizing. *ACM Trans. Graph.*, 26(3):10, 2007.
- [3] K. He, G. Gkioxari, P. Dollár, and R. B. Girshick. Mask R-CNN. *CoRR*, abs/1703.06870, 2017.