

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 [1]. By combining the ability of [1] and the advanced image segmentation techniques of Mask R-CNN [?], 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 [1] 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 retargeting, 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 [1] 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:

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

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:

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

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:

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

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 [1])

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

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.

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Papers, excluding the references section, must be no longer than eight pages in length. The references section will not be included in the page count, and there is no limit on the length of the references section. For example, a paper of eight pages with two pages of references would have a total length of 10 pages. **There will be no extra page charges for CVPR 2018.**

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2.3. The ruler

The L^AT_EX style defines a printed ruler which should be present in the version submitted for review. The ruler is provided in order that reviewers may comment on particular lines in the paper without circumlocution. If you are preparing a document using a non-L^AT_EX document preparation system, please arrange for an equivalent ruler to appear on the final output pages. The presence or absence of the ruler should not change the appearance of any other content on the page. The camera ready copy should not contain a ruler. (L^AT_EX users may uncomment the `\cvprfinalcopy` command in the document preamble.) Reviewers: note that the ruler measurements do not align well with lines in the paper — this turns out to be very difficult to do well when the paper contains many figures and equations, and, when done, looks ugly. Just use fractional references (e.g. this line is 095.5), although in most cases one would expect that the approximate location will be adequate.

2.4. Mathematics

Please number all of your sections and displayed equations. It is important for readers to be able to refer to any particular equation. Just because you didn't refer to it in the text doesn't mean some future reader might not need to refer to it. It is cumbersome to have to use circumlocutions like "the equation second from the top of page 3 column 1". (Note that the ruler will not be present in the final copy, so is not an alternative to equation numbers). All authors will benefit from reading Mermin's description

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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 frobnicable 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

An example of an acceptable paper:

An analysis of the frobnicable 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 frobnicable foo filter, a fundamental contribution to human knowledge". Nature 381(12), 1-213.

If you are making a submission to another conference at the same time, which covers similar or overlapping material, you may need to refer to that submission in order to explain the differences, just as you would if you had previously published related work. In such cases, include the anonymized parallel submission [?] as additional material and cite it as

[1] Authors. "The frobnicable foo filter", F&G 2014 Submission ID 324, Supplied as additional material `fg324.pdf`.

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technical report. For conference submissions, the paper must stand on its own, and not *require* the reviewer to go to a techreport for further details. Thus, you may say in the body of the paper “further details may be found in [?]”. Then submit the techreport as additional material. Again, you may not assume the reviewers will read this material.

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

As you can see, the above text follows standard scientific convention, reads better than the first version, and does not explicitly name you as the authors. A reviewer might think it likely that the new paper was written by Zeus *et al.*, but cannot make any decision based on that guess. He or she would have to be sure that no other authors could have been contracted to solve problem B.

FAQ

Q: Are acknowledgements OK? **A:** No. Leave them for the final copy.

Q: How do I cite my results reported in open challenges? **A:** To conform with the double blind review policy, you can report results of other challenge participants together with your results in your paper. For your results, however, you should not identify yourself and should not mention your participation in the challenge. Instead present your results referring to the method proposed in your paper and draw conclusions based on the experimental comparison to

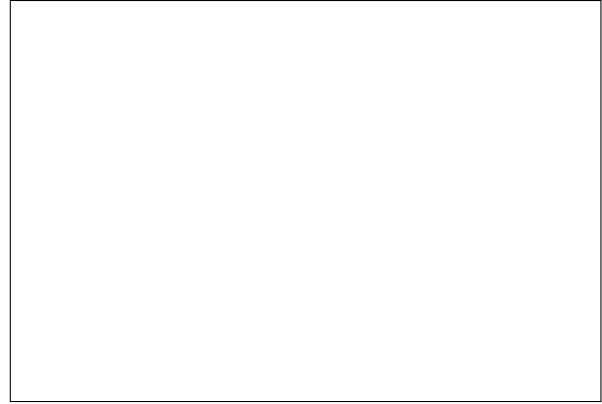


Figure 3: Example of caption. It is set in Roman so that mathematics (always set in Roman: $B \sin A = A \sin B$) may be included without an ugly clash.

other results.

2.6. Miscellaneous

Compare the following:

`$conf_a$` $conf_a$

`conf_a` conf_a

See The \TeX book, 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

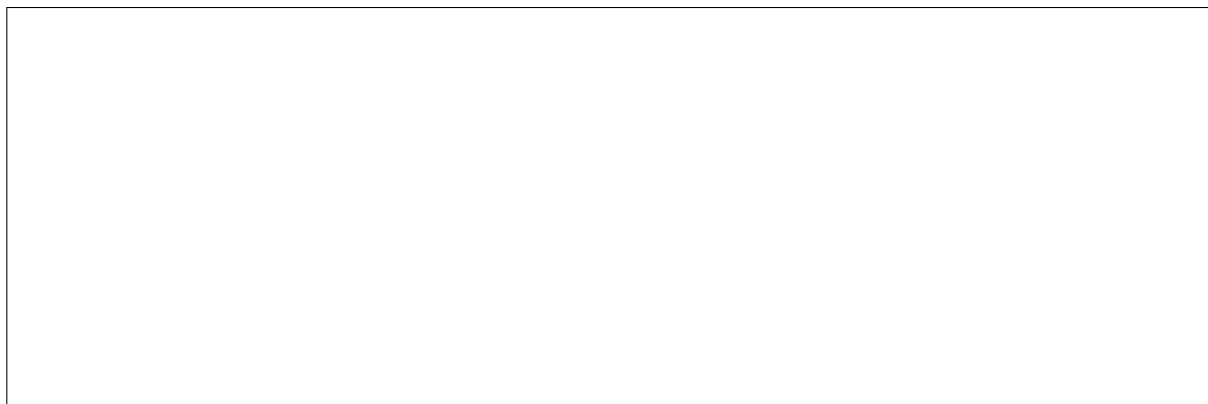


Figure 4: Example of a short caption, which should be centered.

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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All printed material, including text, illustrations, and charts, must be kept within a print area 6-7/8 inches (17.5 cm) wide by 8-7/8 inches (22.54 cm) high. Page numbers should be in footer with page numbers, centered and .75 inches from the bottom of the page and make it start at the correct page number rather than the 4321 in the example. To do this fine the line (around line 23)

```
%\ifcvprfinal\pagestyle{empty}\fi  
\setcounter{page}{4321}
```

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

```
%\thispagestyle{empty}
```

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Wherever Times is specified, Times Roman may also be used. If neither is available on your word processor, please use the font closest in appearance to Times to which you have access.

MAIN TITLE. Center the title 1-3/8 inches (3.49 cm) from the top edge of the first page. The title should be in Times 14-point, boldface type. Capitalize the first letter of nouns, pronouns, verbs, adjectives, and adverbs; do not capitalize articles, coordinate conjunctions, or prepositions (unless the title begins with such a word). Leave two blank lines after the title.

AUTHOR NAME(s) and **AFFILIATION(s)** are to be centered beneath the title and printed in Times 12-point,

non-boldface type. This information is to be followed by two blank lines.

The **ABSTRACT** and **MAIN TEXT** are to be in a two-column format.

MAIN TEXT. Type main text in 10-point Times, single-spaced. Do NOT use double-spacing. All paragraphs should be indented 1 pica (approx. 1/6 inch or 0.422 cm). Make sure your text is fully justified—that is, flush left and flush right. Please do not place any additional blank lines between paragraphs.

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FIRST-ORDER HEADINGS. (For example, **1. Introduction**) should be Times 12-point boldface, initially capitalized, flush left, with one blank line before, and one blank line after.

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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.

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

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

Table 1: Results. Ours is better.

3.4. References

List and number all bibliographical references in 9-point Times, single-spaced, at the end of your paper. When referenced in the text, enclose the citation number in square brackets, for example [?]. Where appropriate, include the name(s) of editors of referenced books.

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All graphics should be centered. Please ensure that any point you wish to make is resolvable in a printed copy of the paper. Resize fonts in figures to match the font in the body text, and choose line widths which render effectively in print. Many readers (and reviewers), even of an electronic copy, will choose to print your paper in order to read it. You cannot insist that they do otherwise, and therefore must not assume that they can zoom in to see tiny details on a graphic.

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References

- [1] S. Avidan and A. Shamir. Seam carving for content-aware image resizing. *ACM Trans. Graph.*, 26(3):10, 2007.