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Image Retargeting by k-seam removal

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Abstract

In this document we present a methodology for image retargeting based on seam removal that preserves the important content of a resized picture. So we will describe what is a seam and on the base of this concept we'll define 1-seam and k-seam. Then we will present two different approaches for finding a seam in a picture: min energy and min variation. Finally we analyze and compare the four possible combinations of the above operators to resize an image:

- removing 1-seams minimizing the energy of the seam
- removing k-seams minimizing the energy of the seam
- removing 1-seams minimizing the variation of energy of the picture
- removing k-seams minimizing the variation of energy of the picture

We conclude stating which one of these algorithms performs better.

Introduction

Aim of this project is to implement the method described in [1], in which a simple image operator called *seam carving* supporting content-aware image resizing for both reduction and expansion is presented. A seam is an optimal 8-connected path of a single image from top to bottom or left to right, whose optimality is defined by an image energy function. The goal is to remove (or to add) unnoticeable pixels that blend with their surroundings.

Our approach focus on single dimension reduction: this means that we resize the image only on vertical or horizontal dimension instead of resizing the two dimensions at the same time. Enlarging image is a more complicated problem, so we focus on reduction. Infact, the reduction process is based on the removal of the seam minimizing an appropriate energy; but the enlarging process cannot be based only on this consideration, becaudraftlyse repeating this method (adding a seam minimizing the energy) will most likely create a stretching artifact by choosing the same seam. So, to achieve effective enlarging it is important to balance between the original image content and the artificially inserted parts, while in the reduction case it is sufficient to remove the seam without any more consideration.

Moreover since we want to evaluate the performance of such a method, we try to resize image in only one dimension to simplify the computation. Actually in some real applications there is no need for multi dimensional resizing: think about a 4:3 video, the goal is to resize the video to 16:9 format, so it is sufficient to operate in one dimension.

We try two different approaches: the first is based on the seam correspondent to the minimum energy path in the image (as described in [1]); the second find the seam that causes the minimum energy variation.

This document is organized as follows:

- section 1 describes the methodology used in this work
- section 2 describes the first approach (minimum energy path) and it compares this approach with the original one
- section 3 describes the second approach (minimum energy variation) and it compares this approach with the original one
- section 4 compares the two approaches
- section 5 presents the conclusion of this work

1 Methodology

Figure 1 shows the methodology we used for this project.

Basically our implementation finds only vertical seams. In order to find horizontal seams (this allows vertical resizing) the original image is transposed, then the seams are found as they were vertical and the resulting image is transposed again. In this way we obtain vertical resizing.

The energy function is characteristics of the implementation: the first method (Section 2) is based on the sum of horizontal and vertical derivatives; the second one (Section 3) is based on the same energy, but in order to find the seam we don't look for the minimum energy path, but we look for the seam that minimize the energy variation in the image. Since this last task is more difficult, we have simplified the mask used to compute the energy respect to the first method.

An important difference between [1] and our work is that we don't work only with 8-connected path of pixels: we allow the distance between two pixels in adjacent rows belonging to the same seam to be greater than one. In this way the seam path is less constrained. So it's possible to extend the definition of seam taking in account the maximum allowed distance between a pixel and its subsequent:

- 1-seam: each pixel of the seam is at distance 1 or 0 from the previous pixel
- k-seam: each pixel can be at distance greater than 1, tipically 4 or 5, from the previous pixel

The difference between 1-seam and k-seam is shown in the next section.

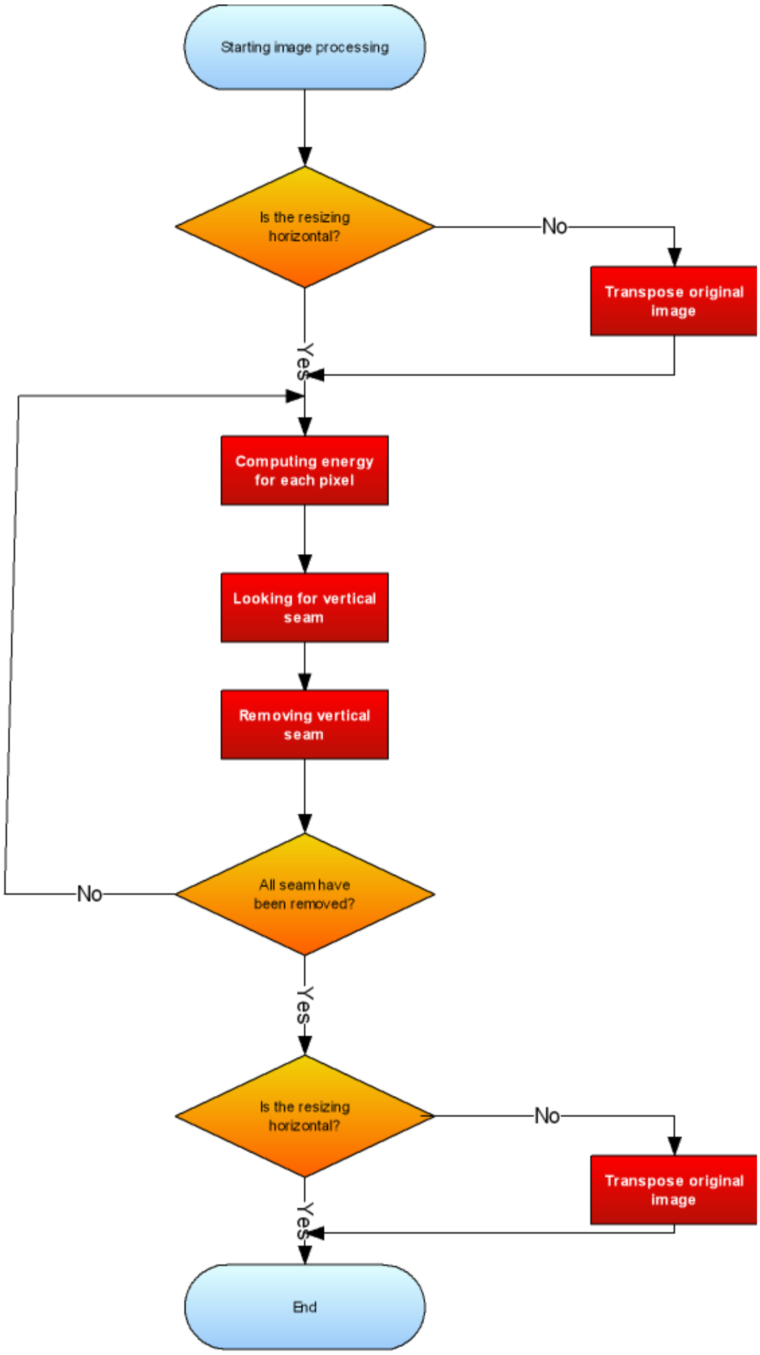


Figure 1: Methodology

2 First method: minimum energy path seam

The first method implements the one described in [1], extending it with the possibility of non-connected paths (k-seams). From now on we'll refer to this method as *min energy*.

The used energy function is

$$E = |\frac{\partial I}{\partial x}| + |\frac{\partial I}{\partial y}|$$

where the differential is calculated through the image convolution with the following mask:

$$dx = \begin{pmatrix} -1 & 0 & 1 \end{pmatrix} \qquad dy = \begin{pmatrix} -1 \\ 0 \\ 1 \end{pmatrix}$$

After the computation of the energy for each pixel, the optimal seam that minimizes the energy is found using dynamic programming. That seam is then removed from the image.

Our method differs from the original one because we use both 1-seams and k-seams. The differences between the two methods can be more clear looking at Figure 2 and 3.

Figure 2: Original image

In Figure 3 the results coming from the application of the method used in [1] and our approach are shown. It is possible to see that with an 1-seam it is not possible to avoid the removal of pixel belonging to the image (the seam is in blue, on the left); incrementing the maximum distance between pixels of adjacent rows to 5 (so using a 5-seam), the algorithm is able to avoid cutting pixels belonging to the image content.

(a) not connected

(b) connected

Figure 3: Comparing connected and not connected seams

Obviously the maximum distance (k) must be a reasonable number, since a high distance (in example, the whole image width) can produce a zig-zag effect on the image (see Figure 4 and 5).

Figure 4: Original Image

(a) maximum distance = 10 pixels

(b) maximum distance equals to image width

Figure 5: Figure 4 resized of 100 pixels

3 Second method: minimum energy variation seam

In this part, seams are defined with a different approach in order to optimize the previous method. From now on we'll refer to this method as *min variation*. With the new approach a seam is a sequence of pixel such that when removed causes the minimum variation in the energy of the picture. In other words, if I is the original image and $I'(v)$ is the image after the removal of a generic seam v, the seam which minimizes the energy variation is:

$$\operatorname*{argmin}_{v}(E_I - E_{I'(v)})$$

As before, it's possible to use this approach both with k-seams and 1-seams. The difference with the previous method become very clear when using k-seams. An example is in figure 6 where seam pixel are those in solid black.

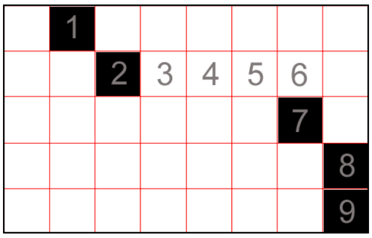


Figure 6: Disconnected seam

With the first method the seam contains the pixels with lowest energy, but it doesn't take in account that all the pixels from 3 to 6 will vary their energy (because in I' they will be moved and its energy will vary consequently), and such variation can be very big.

When a seam is selected for the removal, pixels that vary their energy depend on the kind of mask used to compute the vertical and the horizontal derivatives. In the first step we tried to use the following mask:

$$dx = \begin{pmatrix} -1 & 0 & 1 \end{pmatrix} \qquad dy = \begin{pmatrix} -1 \\ 0 \\ 1 \end{pmatrix}$$

Given a seam, it was simple to find an algorithm computing the energy variation. To compute the best seam turned out to be a more difficult problem. Using the dynamic programming like the first method revealed some problems. Infact after selecting n pixel of the seam, the $n+1$ pixel to choose modifies the values associated with previous pixels. One way of solving this problem is to consider three rows per times, but this can be computational inefficient. Another way of overcoming the problem is to choose a simpler mask:

$$dx = \begin{pmatrix} -1 & 1 \end{pmatrix} \qquad dy = \begin{pmatrix} -1 \\ 1 \end{pmatrix}$$

With these mask, only the next pixel is involved in the energy calculation, so when applying dynamic programming and searching for $n+1$ pixel, no modification to previous n pixel is needed. The pixels that vary their derivatives, and so their energy, are shown in 7 and in 8:

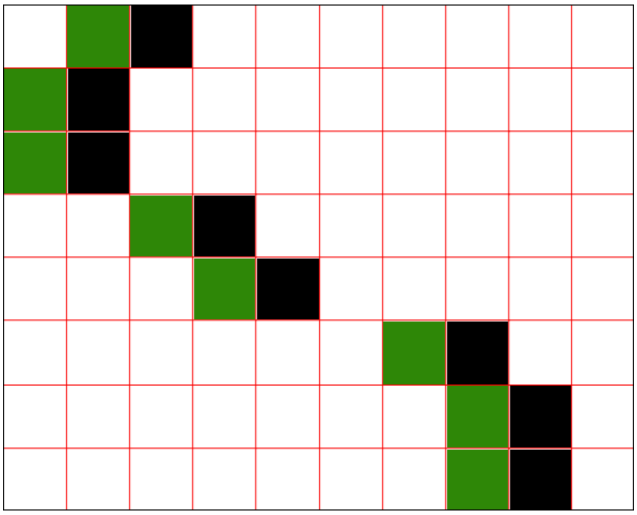


Figure 7: Green pixels are those varying horizontal derivatives

It's possible to see that the pixel varying horizontal derivatives is always the one before the seam pixel. Instead the pixels with vertical variation run along the disconnection between two pixels of the seam. Once defined those pixel that vary their derivatives, it's possible to compute the total variation of energy caused by a seam v:

$$\Delta(v) = \sum_{i \in v} e(i) + \sum_{i \in c} \delta(i)$$

where $e()$ is the energy of a pixel, $\delta()$ the variation of energy of a single pixel and c is the set of all pixels that vary horizontal derivatives or vertical derivatives or both. Upon the definition of the energy variation of a seam the main task is to find that one with minimum variation. This is done using dynamic programming techniques. After this preliminary study we

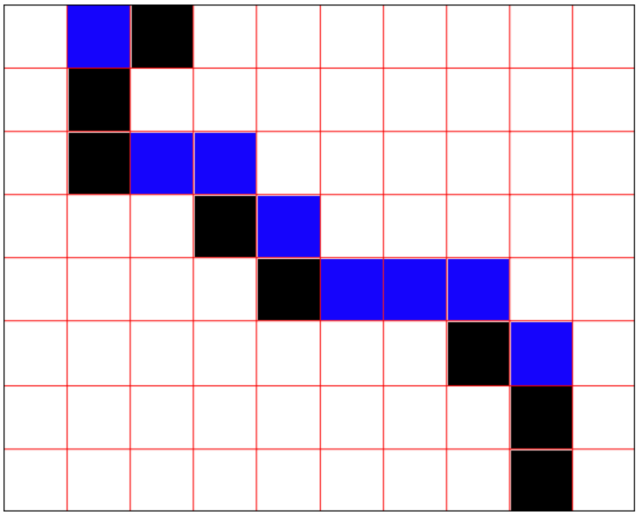


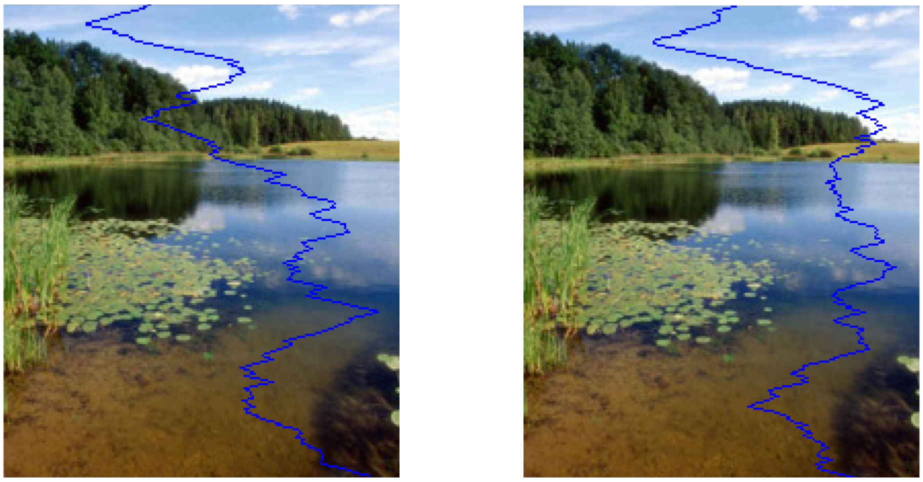
Figure 8: Blu pixels are those varying vertical derivatives

implemented two different algorithms: one using 1-seams and the other using k-seams. The resulting algorithms were applied to different images like 9, and compared with the previous method as shown in next part.

Figure 9: A resized Picture with the min energy variation method

4 Comparison of the two approaches

In this section a detailed comparison between the two approaches is provided. In figure 10 it's possible to see the different paths of the seams computed with the min energy and min variation methods. The important difference to note, is that min variation seam cuts the forest near the middle, while the other seam turns around. After that the path is quite similar.



(a) min variation (b) min energy

Figure 10: Comparison between the two different paths

For a deeper analysis each test picture was resized with all the four combinations of algorithms:

- min energy 1-seam
- min energy k-seam
- min variation 1-seam
- min variation k-seam

In figure 11 there is the original picture, in 12 the result of the application of min energy and in figure 13 the result of min variation. In all the examples k is equal to 5.

It can be noted that min energy 1-seam in this case produce the best result among the four methods applied. If we consider only the min variation, in this case the use of a 1-seam gives a better result than k-seam.

Figure 11: Original picture

Figure 12: Min energy: a) 1-seam b) k-seam

Figure 13: Min variation: a) 1-seam b) k-seam

The next test was performed on figure 4 and the resize applied was vertical. Figure 14 shows the comparison between min energy and min variation both with 1-seam. It's possible to see that the principal problem in this results is that the sea level on the left side of the palace is much more than in the original picture (anyway is more than the level on right side). The results produced with k-seams are not shown because they are even worse: they can be seen in the appendix(6).

(a) min energy

(b) min variation

Figure 14: Vertical resize with 1-seams

Another test was performed on the picture in 15. The results are shown in figures 16 and 17. Again, it's possible to observe that min energy with 1-seam performs better. The other methods in particular damage the shape of the mountain and the red labels.

Figure 15: Original picture

(a) 1-seam

(b) k-seam

Figure 16: Min energy

(a) 1-seam

(b) k-seam

Figure 17: Min variation

Finally we show a test result on which these algorithms do not perform very good. The original picture is in figure 18.

Figure 18: Original Picture

Both the k-seam methods perform very badly. 1-seam methods perform better, but not so much: the head of the horse is too damaged from the resize. The cause of this bad results can be more clear looking at the energy of the picture in 21.

(a) 1-seam (b) k-seam

Figure 19: Min energy

(a) 1-seam (b) k-seam

Figure 20: Min variation

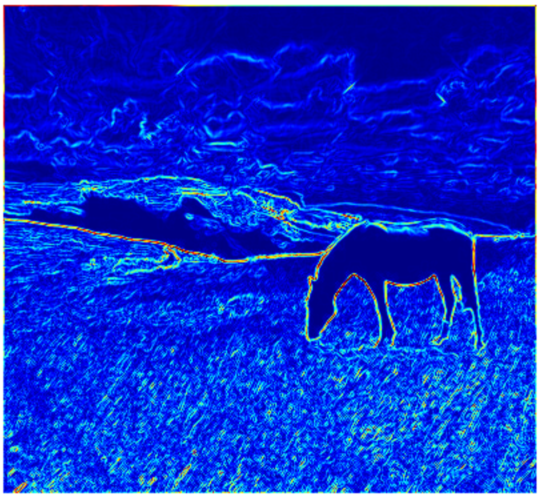


Figure 21: Energy of the picture 18

It's possible to see that the body of the horse is the part of the picture with less energy: even the grass and sky have more energy. In pictures like that what fails is not the algorithm but the idea behind it: it's not always true that the important content of the picture is associated with the areas with highest energy.

5 Conclusion

From the results presented in the section above, and from the other tests visible in 6, it's possible to conclude that min energy method performs better, in particular when it's used with 1-seam. Min variation performs better with 1-seams, except for few examples (6). In general, in landscapes, where no important contents are present, the two approaches performs better, because in the other images they tend to remove pixel image belonging to important image subjects, damaging their contours. Finally, from the point of view of performances, the min energy is faster than min variation. In particular min variation with k-seams is the one that performs worst among these four algorithms. The results of performances evaluation are in the table in appendix 6.
In conclusion from this comparison results that the best choice among these algorithms is the min energy with 1-seam.

6 Appendix

The pictures and the table of this appendix are in the attached files to this document. In these files we refers to 1-seam with connected seam, and to k-seam with not connected seam.

References

[1] Shai Avidan, Ariel Shamir, *Seam Carving for Content-Aware Image Resizing*, International Conference on Computer Graphics and Interactive Techniques, 2007.