Seam Segment Carving: Retargeting Images to Irregularly-Shaped Image Domains

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Abstract. Image retargeting algorithms aim to adapt the image to the display screen with the goal of preserving the image content as much as possible. However, existing methods and research efforts have mostly been directed towards retargeting algorithms that retarget images to rectangular domains. This significantly hampers its application to broader classes of display devices and platforms for which the display area can be of any origins and shapes. For example, seam carving-based methods retarget images by carving out seams that run from the top to the bottom of the images, and this results in changing the width and therefore aspect ratio of the image without changing the shape of the image boundary in any essential way. However, by carving out appropriately-chosen seam segments, seams that are not required to cut across the entire image, it is then possible to retarget the images to a broader array of image domains with non-rectangular boundaries. Based on this simple idea of carving out the seam segments, the main contribution of this paper is a novel image retargeting algorithm that is capable of retargeting images to non-rectangular domains. We evaluate the effectiveness of the proposed method on a number of challenging indoor and outdoor scene images, and the results demonstrate that the proposed algorithm is both efficient and effective, and it is capable of providing good-quality retargeted images for a variety of interesting boundary shapes.

Keywords: Image Retargeting, Seam Carving.

1 Introduction

As digital images are now displayed on an increasing variety of display devices and platforms, content-aware image retargeting has attracted considerable amount of attention recently, e.g., [1–4]. With the state-of-art image retargeting algorithms, an image can now be resized without much loss of information around the salient areas. Recent image retargeting methods have mostly been studied with the implicit assumption that the images will always be retargeted to a rectangular image domain. However, there are many instances where an irregularly-shaped output, such as a circle, an oval or a heart, is preferred (e.g., Figure 7), and for these applications, existing image retargeting methods are

A. Fitzgibbon et al. (Eds.): ECCV 2012, Part VI, LNCS 7577, pp. 314–326, 2012.

inadequate and insufficient for providing satisfactory results. To address this shortcoming, this paper proposes a novel algorithm for retargeting images to irregularly-shaped image domains based on the simple idea of carving out seam segments.

Seam carving is a simple yet efficient image retargeting algorithm first proposed in [1]. To retarget an image, the algorithm iteratively removes seams from the image until the targeted size (image width) has been reached. A seam as defined in [1] runs across the image from the top to the bottom such that each row of the image has precisely one pixel in the seam. By repeatedly deleting seams from the image, the algorithm constantly reduces the width of the image. In particular, while the aspect ratio of the image boundary keeps changing, its shape is nevertheless always rectangular. Therefore, existing seam carving-based methods cannot retarget images to non-rectangular domains without substantial modifications, and the main technical contribution of this paper is to show that with appropriate modifications, it is possible to design an algorithm that can retarget images to non-rectangular domains while maintaining most of the beneficial features of the seam carving approach, such as its simplicity in concept and implementation.

Because of the non-rectangular image boundary, the number of pixels to be removed from each row of the image is no longer constant, and in fact, it depends on the targeted shape. In particular, the criteria for pixel removals not only have to consider image saliency but also the boundary shape. This new *boundary effect* (or constraint) is the most distinguishing feature of the retargeting problem studied in this paper, and the main idea in our solution is to carve out seam segments instead of seams, where a seam segment is a seam that could start and end in any two rows of the image. Because seam segments do not have to run across the image vertically, by removing seam segments of various lengths with different starting and ending rows, we can delete different numbers of pixels from different rows and therefore, effectively carve out a variety of non-rectangular shapes. Furthermore, since a seam segment can start and end in the middle of the image, the criterion for evaluating the distortion caused by removing a seam segment requires the inputs from the seam segment's two endpoints, and this translates into additional terms in the objective function (section 3.3). Once the objective function is defined, the proposed algorithm proceeds similar to any seam carving-based method by greedily search for the optimal seam segment at each iteration and remove it from the image.

The second contribution of this paper is the two novel image retargeting applications reported in the experimental section, aesthetic image editing and adaptive camera-projector system. For the former, the retargeted images have specific shapes that are task-dependent and often non-rectangular. Once the targeted image domain is given, the proposed algorithm is able to automatically retarget the image based on image saliency and boundary shape. For the later and especially in the context of ubiquitous display, the camera-projector system can automatically detect the shape of the display area and accordingly, retarget the image in order to obtain better display of the image. These two applications demonstrate the value of having a flexible image retargeting algorithm that can retarget images to a wide variety of display domains and at the same time, they broaden the current scope and applicability of image retargeting.

2 Related Works

Image retargeting is naturally related to image resizing that has a long history in image processing. To display an oversized image on mobile devices that often carry only small display areas, [5] introduces the notion of automated image retargeting based on uniform warping and cropping (resizing) of parts of the image [6]. While providing reasonable solutions for the time, these earlier approaches cannot be classified as content-aware methods due to the minimal input from the image in determining the image transform and their lack of non-uniformity in scaling the images. In contrast, the new generation of image retargeting algorithms that has emerged in the past few years emphasizes the preservation of the image content, and these methods often uses non-uniform image transforms to produce more informative and revealing retargeted images.

The current existing image retargeting methods can be broadly classified into two main categories, the discrete and continuous methods. The former category can be represented by the family of retargeting algorithms based on seam carving, an idea first introduced in [1]. The method defines an objective function that evaluates the quality (energy) of the seams that usually based on the image gradient and other criteria for image saliency, and low-energy seams are determined and removed from the image repeatedly until the desirable size has been reached. The idea is simple and effective and it has been extended in various different directions. Seam carving-based video retargeting algorithms have been studied in [7, 8] with additional terms added to the original objective function that measure the temporal distortion. Discontinuous seams have also been proposed for image and video retargeting in [9], and [10] has developed a multi-operator method that combines seam carving, cropping and uniform scaling together.

The continuous method can be exemplified by warping-based methods that include [2, 3, 11, 12]. In this approach, retargeting is accomplished by determining a non-uniform warp (transform) and the warp is computed by minimizing an objective function that aims to preserve salient regions in the image. For example, the algorithm proposed in [2] first divides the image into quads and computes the new position of the pin-points at the four corners of each quad by minimizing an objective function that penalizes distortions incurred in salient areas. [12] has investigated different way of determining the warping function for video sequences by setting up a linear system for computing the non-linear mappings. Finally, shift-map-based image retargeting, first introduced in [13], uses a shift-map to represent the new position of each retargeted pixel. The objective function proposed in [13] allows efficient optimization using graph-cut. A more elaborated shift-map-based method is proposed in [4] that uses a novel 'importance filter' to compute the shift-map by integrating the gradient map. For these continuous methods, the retargeted images are computed using interpolation once the transform (warping or shift-map) has been determined. Compared

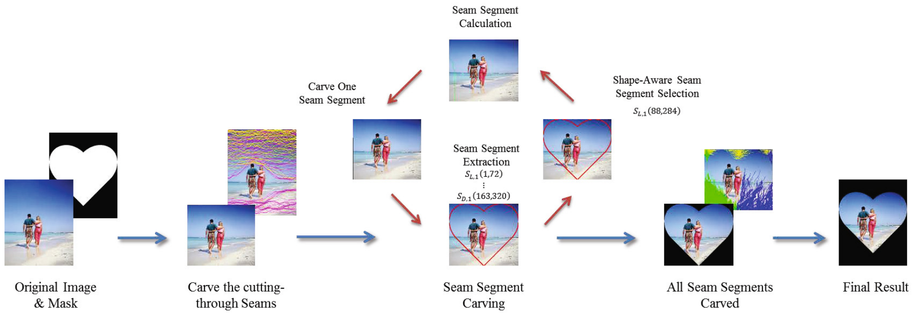


Fig. 1. Schematic Illustration of the Algorithm Pipeline

with the discrete method such as seam carving, the continuous methods generally provide smoother results, with the expense of longer running time.

Finally, we remark that compared with the carving-based method, it is more difficult to extend or modify the continuous methods such as warping-based or shift-map-based approach to handle non-rectangular image domains. For example, it is not trivial to use a mesh to represent an arbitrary boundary shape in this setting as a dense mesh would invariable increase the running time while a sparse mesh tends to render numerical instability. In addition, existing shift-map-based algorithms can only move the pixels in one dimension, which can be inefficient for carving out shapes (section 3.2).

3 Seam Segment Carving

In this section we detail the proposed image retargeting algorithm based on seam segment carving. The algorithm pipeline is schematically illustrated in Figure 1. The algorithm takes two inputs: an image I with height H and width W, and a mask M_{Bound} that highlights the target shape. The output is a retargeted image I' with the shape defined by M_{Bound}. The algorithm first, if necessary, removes all the through-seams in order to fit the bounding box of the target shape. Next it repeatedly selects and carves out one optimal seam segment from the extracted seam segments, both vertical and horizontal segments, until the retargeted image reached the desired shape. For the final step, it pastes the retargeted image back to the original mask to obtain the retargeted image I'.

3.1 Seam Segments

The advantage of using seam segments is that the shape of the boundary can be directly modified by removing a sequence of properly-chosen seam segments and shifting the corresponding pixels. Figure 3 shows a simple example of forming a specific left boundary by removing two seam segments. Once these seam segments are removed, the left boundary will have the desired shape. The other

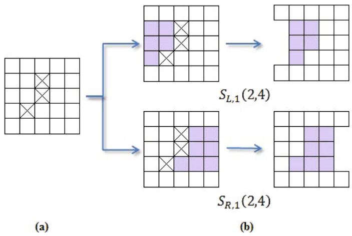


Fig. 2. Direction associated to a seam segment. Each seam segment is associated with one direction indicating the direction of pixel shift. **(a)** In a 5x5 image, a seam segment has been calculated (labelled in 'X'). **(b)***(top)* If the seam segment is to form the left boundary, the pixels on its left (in purple) are moved to the right for one pixel once the seam segment is removed *(bottom)* On the other hand, the pixels (in purple) are shifted to the left when the seam segment is involved in constructing the right boundary.

three boundaries (right, top and bottom) can be reshaped similarly by finding the appropriate seam segments and shifting the correspondent pixels accordingly.

Similar to the seams introduced in [1], a seam segment S is also a set of interconnected pixels, $s_1, s_2, s_3, \cdots, s_n$, with only one pixel in each row (vertical seam segment) or each column (horizontal seam segment), but not necessarily starts and ends on the image boundary. Therefore, a cut-through seam (seam that run across the image) or an isolate pixel can be regarded as a seam segment. However, we will associate each seam segment to one of the four image boundaries and this association will then determine the direction of the pixel shift once the seam segment has been removed (see Figure 2).

In the following sections we will use $S_{X,n}(st,\ ed)$ to denote a seam segment, where X defines the direction (boundary) associated to the seam segment, whose value can be either *L(eft)/R(ight)* (vertical seam segments), or *T(op)/B(ottom)* (horizontal seam segments). n is an integer that labels the given seam segment. $(st,\ ed)$ gives the starting and ending row/column of the seam segment. For examples, $S_{L,5}(4,\ 7)$ denotes the 5^{th} seam segment starting at the 4^{th} row and ending at the 7^{th} row, that is involved in forming the left boundary. $S_{L,n}(st, st)$ indicates that this seam segment contains only one pixel in row st, and $S_{L,n}(1, H)$ denotes a vertical cut-through seam.

3.2 Seam Segment Extraction and Selection

For determining one seam segment to be removed, we will first determine the starting and ending rows/columns (st, ed) and the pixels in the seam segment will be located only between these rows/columns. To efficiently extract the seam segments, we use an auxiliary array A_X, where X denotes the corresponding boundary. For example, the auxiliary array A_L, used for extract a seam segment for forming the left boundary, is an $1 \times H$ vector, and $A_L(j)$ denotes the number of pixels remained to be removed in row j (Figure 3(b,c)). Once A_L is computed,

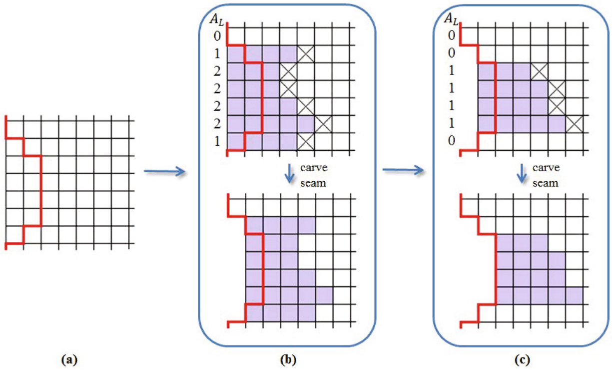


Fig. 3. Boundary construction and seam segment extraction. (a) The red line highlights the desired new boundary. **(b)***(top)* Determine the first seam segment (labelled in 'X'), and *(bottom)* remove the seam segment by shifting all the purple pixels to the right. **(c)** After determining and removing the second seam segment, the new boundary is successfully formed. An example of the auxiliary array A_L for seam extraction is also shown in this figure.

we can extract all seam segments for the left boundary as follows: for a given auxiliary array A_L, we scan from $A_L(1)$ to $A_L(H)$ to find all the intervals $[st, ed]$ such that $A_L(j) > 0, \forall j \in [st, ed]$. Each time an interval $[st, ed]$ is determined, we subtract one off $A_L(j)$ for all indices j in the interval $[st, ed]$. This process terminates when A_L becomes all zero.

Figure 4(a) displays three different types of regions that are to be removed in order to carve out the required shape. In this figure, a rectangular image is to be reshaped according to the given mask marked in white. The colored areas are the regions that need to be removed. After examining the figure, we can classify the regions into three types based on the boundary each region borders. For example, by shifting vertically or horizontally the pixels in a *type one* region, we can only reach one boundary, while the pixels in a *type two* region can reach multiple boundaries (horizontal and vertical). This implies that the *type one* regions can be removed by carving out only one kind of seam segments (either *L(eft), R(ight), T(op) or B(ottom)*, while multiple types of seam segments can be used to remove *type two* regions. In contrast, *type three* regions are in the image interior and do not border any boundary. In particular, pixels in these regions cannot reach any boundary by simple shifting and therefore, *type three* regions cannot be removed by carving out seam segments.

As illustrated by the example in Figure 4(b), using horizontal seam segments is better for two reasons. First, pixels of a seam segment are searched only within the corresponding rows/columns. Since the total number of pixels to be removed is the same, longer seam segments allow us to search for low-energy pixels in a larger area, thus lower the amount of distortion and loss of saliency. Second, since the seam segment carving algorithm shifts the current boundary inward

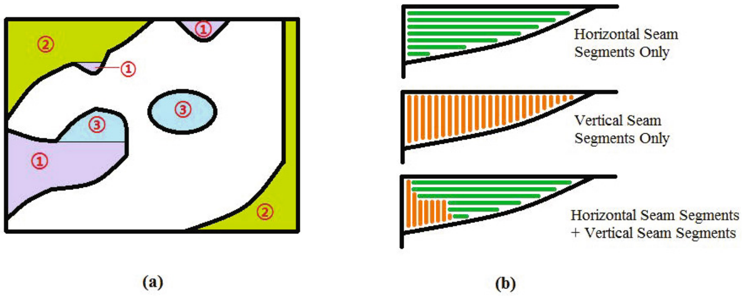


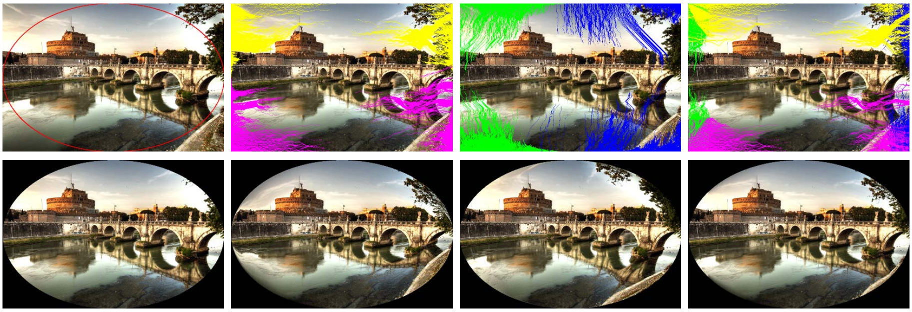
Fig. 4. (a) Three types of region defined by the boundaries they bordered. Type one region borders one boundary (either the horizontal or vertical boundary) and Type two region borders two boundaries (both horizontal and vertical). Type three region is in the interior and does not border any boundary. Removal of Type one region can be accomplished using one type of seam segments (either horizontal or vertical) while Type two region **(b)** can be removal by carving out random combination of vertical (orange) and horizontal (green) seam segments. Note that Type three region cannot be removed by removing seam segments.

to gradually match the target boundary, due to the large difference in slope between the left vertical boundary and the new boundary in this example, it is difficult to preserve the structure of an object inside the cropped area, even if the object can be correctly retained by the algorithm.

An interesting fact for *type two* regions is that they can be removed by carving out a random combination of vertical and horizontal seam segments, as shown in Figure 4(b). However, it is straightforward to see that removing seam segments in different orders produces different final results. Figure 5(b,c) shows two failed examples that remove only vertical or horizontal seam segments. In these two examples, although both of them are able to retain the contents lying outside the new boundary, visible distortions such as the shadows of the bridge and tree branches do occur in both examples.

However, finding the optimal carving order is difficult and often untenable. Instead, based on the discussion above, we developed a greedy approach to efficiently select the next seam segment to remove. At the beginning of each iteration, we scan four boundaries and extract all the possible seam segments to be removed. Among these seam segments, the longest seam[1] is selected. This approach has been shown in practice to produce smoother and less distorted results without the need to pay special attention to the boundary shape. As shown in Figure 5(d), this approach is able to correctly retain the objects lying outside the new boundary, e.g. branch and bank, as well as to preserve the overall structural integrity.

[1] Here, the 'longest' seam segment is the one with the largest $(ed - st)$ value.



Original Image & Direct Cropping	All Horizontal Seam Segments	All Vertical Seam Segments	Shape-aware Seam Segment Selection
(a)	**(b)**	**(c)**	**(d)**

Fig. 5. Effectiveness of the proposed seam segment selection *(First row):* Original image with new boundary highlighted, only horizontal seam segments are removed, only vertical seam segments are removed, seam segments selected by our method (green, blue, yellow, violet seam segments denote the four type of seam segments, L, R, T, B, respectively) *(Second row):* Result from direct cropping, result from carving out only horizontal and vertical seam segments, result produced by the proposed method. Note that only in the retargeted image produced by our method, the tree branches and reflection of the bridge are less distorted.

3.3 Energy Function for Seam Segment Carving

Similar to other seam carving-based methods, the criterion for selecting the seam segment is formulated as an energy function of the seam segment, and the seam segment with the lowest energy is selected for removal. The energy function (1) used in the proposed algorithm for the seam segment $S_{L,n}$ is composed of two parts, E_{seam} and E_{pos}. $E_{seam}(S_{L,n})$ is the well-known energy term proposed in [7], which consists of the forward energy terms E_v and E_h. The possible image distortion caused by the two endpoints of a seam segment is measured by E_{pos} with α the balance factor between the two terms (set to 0.6 in our experiments). In the following, we will use $S_{L,n}$ instead of $S_{L,n}(st, ed)$ to keep the notation simple.

$$E_{total}(S_{L,n}) = E_{seam}(S_{L,n}) + \alpha E_{pos}(S_{L,n}) \tag{1}$$

E_{seam} is computed according to the formula:

$$E_{seam}(S_{L,n}) = \sum_{(i,j)\in S_{L,n}} E_h(i,j) + \sum_{(i,j),(i^+,j+1)\in S_{L,n}} E_v(i,i^+,j). \tag{2}$$

The horizontal energy E_h of removing a pixel (i, j) is:

$$E_h(i,j) = |I(i+1,j) - I(i-1,j)|. \tag{3}$$

In the vertical direction, the energy is related not only to the pixel (i, j) but also the selected pixel in row $j + 1$. Suppose the pixel $(i^+, j + 1)$ is to be removed, since we require the seam segments to be continuous, the vertical forward energy can be computed by:

$$E_v(i, i^+, j) = \begin{cases} |I(i-1, j) - I(i, j+1)| & i^+ = i-1 \\ 0 & i^+ = i \\ |I(i+1, j) - I(i, j+1)| & i^+ = i+1 \end{cases} \quad (4)$$

E_{pos} in (1) is the novel 'position energy' for the seam segments. The reason for adding this term is that unlike the cut-through seams which remove exactly one pixel per row, our seam segments $S_{L,i}(st, ed)$ only delete pixels between the st_{th} and ed_{th} rows. In this case, additional distortions will occur between rows $(st-1)$ and st, and likewise between the rows ed and $(ed+1)$. This is because the pixels left to the seam segment in st_{th} and ed_{th} row will move leftwards for one pixel, but there is no pixel movements in rows $(st-1)$ and $(ed+1)$. It is the inconsistency in pixel movement that brings about additional distortions, which we called 'position distortion' in this paper. Moreover, the farther a seam segment is from the boundary, the more significant position distortion can potentially occur since more pixels would be affected by inconsistent pixel movement. With this understanding in mind, we define the position energy as follows: (assuming the starting/ending point of the seam segment is (i_{st}, st) and (i_{ed}, ed))

$$E_{pos}(S_{L,n}(st, ed)) = E_{head}(i_{st}, st) + E_{tail}(i_{ed}, ed), \quad (5)$$

where E_{head} and E_{tail} are defined below: if the first carved point is not lying on the left boundary $(i_{st} = 1)$, or the starting row is not the top row, $st \neq 1$, then

$$E_{head}(i_{st}, st) = \sum_{i=1}^{i_{st}-1} |I(i, st) - I(i+1, st-1)|. \quad (6)$$

Otherwise, E_{head} is 0. Similarly, if a seam segment does not terminate at the left boundary or the bottom row, the energy E_{tail} is:

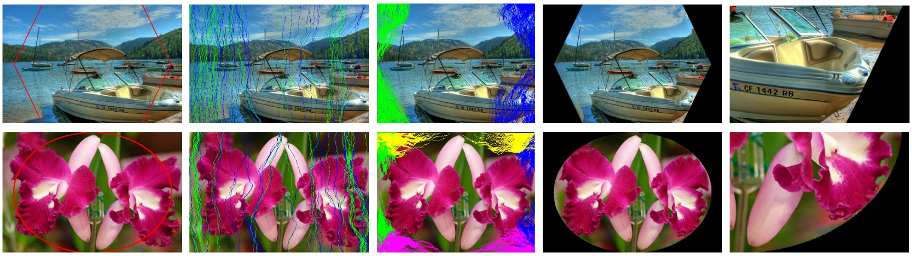
$$E_{tail}(i_{ed}, ed) = \sum_{i=1}^{i_{ed}-1} |I(i, ed) - I(i+1, ed+1)|. \quad (7)$$

E_{tail} is set to 0 if $i_{ed} = 1$ or $ed = H$.

It is clear that if a seam starts from the top and ends in the bottom of the image, E_{pos} is zero, and our method reduces to the former seam carving method. Similarly, if the seam segment contains only one pixel, E_v is zero. With the energy function (1) mentioned above the seam segment can be determined efficiently using dynamic programming as in other seam carving-based methods.

4 Experimental Results and Applications

We have evaluated the proposed algorithm on a collection of images taken from the *RetargetMe* dataset [14], the *MSRA Salient Object Database* [15] as well



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

Fig. 6. Two successful examples showing the preservation of important image details. *(From left to right)* **(a)** Original image with new boundary highlighted, **(b)** Cutting-through seams, **(c)** Seam segments, **(d)** Retargeted images, **(e)** Detailed close-up views.

as some available online images. In the experiments, we retarget the images to several different types of shapes, and in most cases, our algorithm is able to retain salient regions with minimal distortion. Figure 6 displays two such examples. In this figure, the bow section of the foreground boat is completely retained and several neighboring boats are partially retained as well, all of which would have been lost if a direct cropping is applied instead. In the orchid example, the entire right petal is kept almost intact with some details of its exquisite boundary shape correctly preserved, which again would have been lost using a direct cropping.

Two Applications. In this subsection, we present two novel applications that often require retargeting images to non-rectangular domains, for which the proposed algorithm is designed.

Aesthetic Image Editing. In many applications such as icon design, commercial advertisement and poster and magazine production, images are often intentionally reshaped for generating more pronounced and impressive visual effects. In the creation of E-cards and the production of digital photo albums, it is also common to reshape images to fit a given non-rectangular image frame. In Figure 7, images are retargeted into different shapes, and for comparison, we also show results from two other methods, direct cropping and 'retarget & crop', with the latter given by carving out only the cut-through seams followed by a direct cropping according to the specified boundary. As shown in the examples, both 'retarget & crop' and our method can retain more salient image contents than direct cropping. However, our method outperforms the 'retarget & crop' method in that more salient image regions are retained with less distortion, like the flower and butterfly wings in top row, and small pebbles on the beach in the bottom row.

Adaptive Camera-Projector System. A potentially important application domain for image retargeting is the notion of ubiquitous display provided by a camera-projector system. See Figure 8. In this setup, a camera (typically a webcam) and a projector are connected to a computer such that the projector provides the

Fig. 7. Comparisons of the results from the proposed method and two other methods (see text) *(Left to right)* **(a)** original image with new boundary highlighted, **(b)** results from direct cropping, **(c)** results from 'retarget & crop', **(d)** results from our method.

display and the camera captures the projected image as a feedback for adjusting the image for improving display. In addition, the camera also provides the image needed for determining the display area on which the image will be projected. To allow greater flexibility and versatility, the camera-projector system does not assume the display area is rectangular and since most of the images to be displayed are rectangular, this requires the image to be retargeted online prior to be displayed by the projector online given the display area determined by the image capture by the camera, a task for which our image retargeting method is designed.

We have developed and implemented an adaptive camera-projector system shown in Figure 8 that can automatically detect the display area with its boundary and retarget the image to conform with the detected display area. In this camera-projector system, the display boundary is detected by projecting and capturing simple patterns on the display area. In this experiment, the display areas are made by cutting a white board into two different shapes and pasting them onto a glass window. Three examples in the figure (rows 2-4) show that the transparency of the glass window makes it a poor display area and to provide better displays, images should be projected onto the opaque shaped area on the window. The targeted non-rectangular display area can be detected by the camera-projector system and the proposed image retargeting algorithm can be applied to retarget the image to yield more pleasing and satisfying displays. As the examples shown in Figure 8, the originally excluded areas, like the surrounding branches (row 2), the mouth of the fish (row 3), and the buildings and clouds (row 4), are successfully retrieved by our retargeting algorithm.

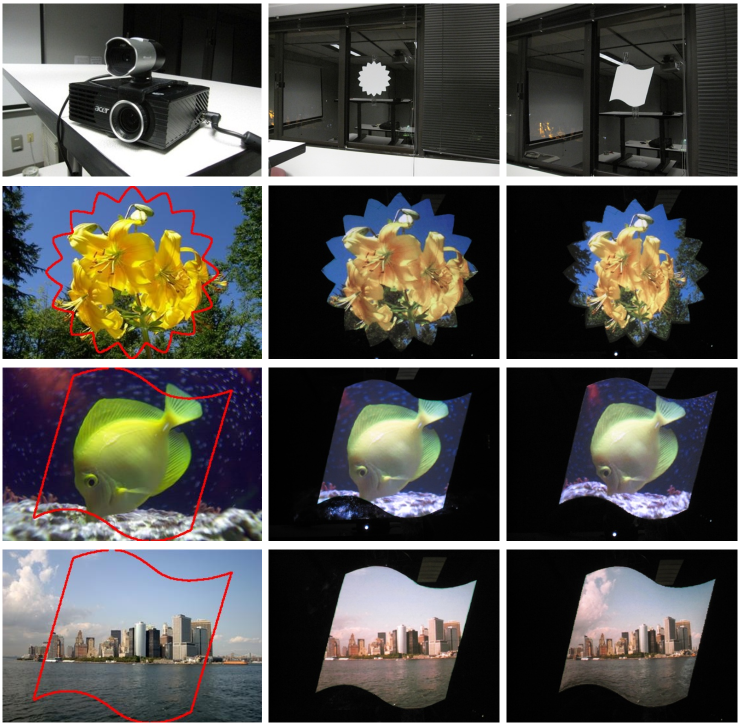


Fig. 8. Example of an adaptive camera-projector system. *(Top Row)* The camera-projector system and two shaped display areas. *(Second to fourth row)* Experimental results: (left) original image and detected new boundary superimposed on the image, (center) projected image (projection of the cropped image) as seen by webcam, (right) adaptively projected image (projection of the retargeted image).

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