Seam-Carving for Content-Aware Image Resizing

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Background

Previous techniques to achieve image resizing:

- Detecting salient regions around the image & cropping around them
- Warping images avoiding the region of interest(s)
- Scaling & recompositing segmented image components or foreground/background objects [Wang and Cohen 2006]
- Using seams for stitching together images: Digital Photomontage [Agarwala *et al*. 2004], Drag-and-Drop Pasting [Jia *et al*.]
- Generating large textures from small ones: [Efros *et al. 2001*], video synthesis [Kwatra *et al*. 2003]
- Object removal via inpainting

Approaching the Problem

(a) Original (b) Crop (c) Column (d) Seam (e) Pixel (f) Optimal

Seam Carving Operator

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

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

Seam path pixels: $$\mathbf{I_s} = \{\mathbf{I}(s_i)\}_{i=1}^n = \{\mathbf{I}(x(i), i)\}_{i=1}^n$$

Energy Preservation Optimization

Seam energy cost:

$$E(\mathbf{s}) = E(\mathbf{I_s}) = \sum_{i=1}^{n} e(\mathbf{I}(s_i))$$

Optimal seam s^*:

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

Optimal seam search:

(dynamic programming)

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

Comparing Approaches

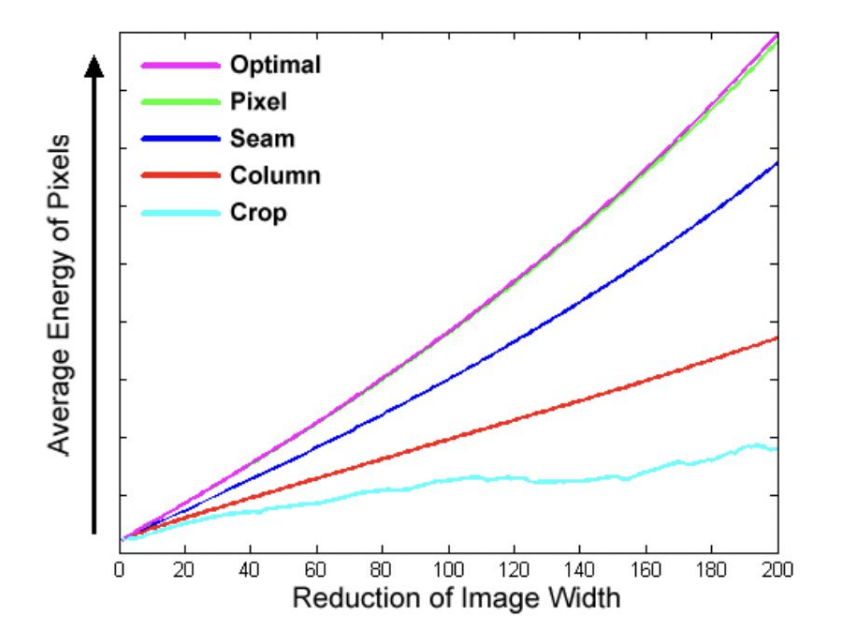
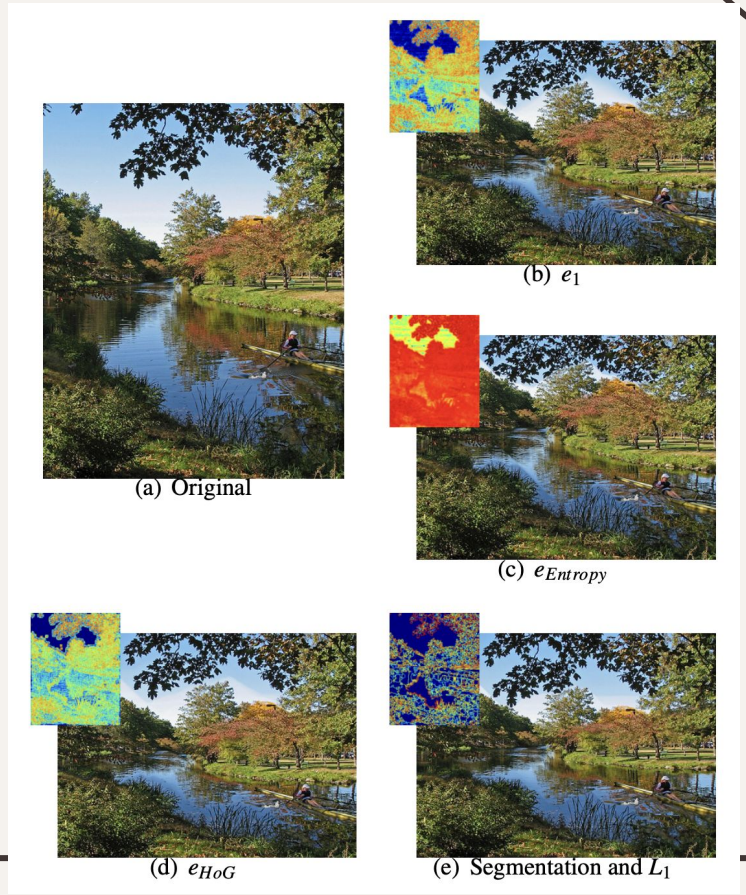


Image Energy Functions

$$e_1(\mathbf{I}) = |\frac{\partial}{\partial x}\mathbf{I}| + |\frac{\partial}{\partial y}\mathbf{I}|$$

$$e_{HoG}(\mathbf{I}) = \frac{|\frac{\partial}{\partial x}\mathbf{I}| + |\frac{\partial}{\partial y}\mathbf{I}|}{\max\left(HoG(\mathbf{I}(x,y))\right)},$$

HoG(I(x,y)): 8-bin histogram of oriented gradients



Seam Carving Image Resizing

- Modify aspect ratio (nxm ⇒ nxm’)
- Decrease image size
- Increase image size
- Amply image content
  (fixed image size)
- Remove objects

Optimal Seam Selection Order

To reduce an nxm image to n'xm'

⇒ Perform a search for seam removal order by optimizing the objective function

$$\min_{\mathbf{s}^{\mathbf{x}},\mathbf{s}^{\mathbf{y}},\alpha} \sum_{i=1}^{k} E(\alpha_i \mathbf{s}_{\mathbf{i}}^{\mathbf{x}} + (1-\alpha_i)\mathbf{s}_{\mathbf{i}}^{\mathbf{y}})$$

where

$$k = r + c,\ r = (m - m'),\ c = (n - n')$$

$$\alpha_i \in \{0,1\}\ , \sum_{i=1}^{k} \alpha_i = r\ , \sum_{i=1}^{k} (1-\alpha_i) = c$$

Optimal Order Search with Transport Maps

Transport map **T**: cost of optimal sequence of horizontal/vertical seam removal operations for target image n'xm'

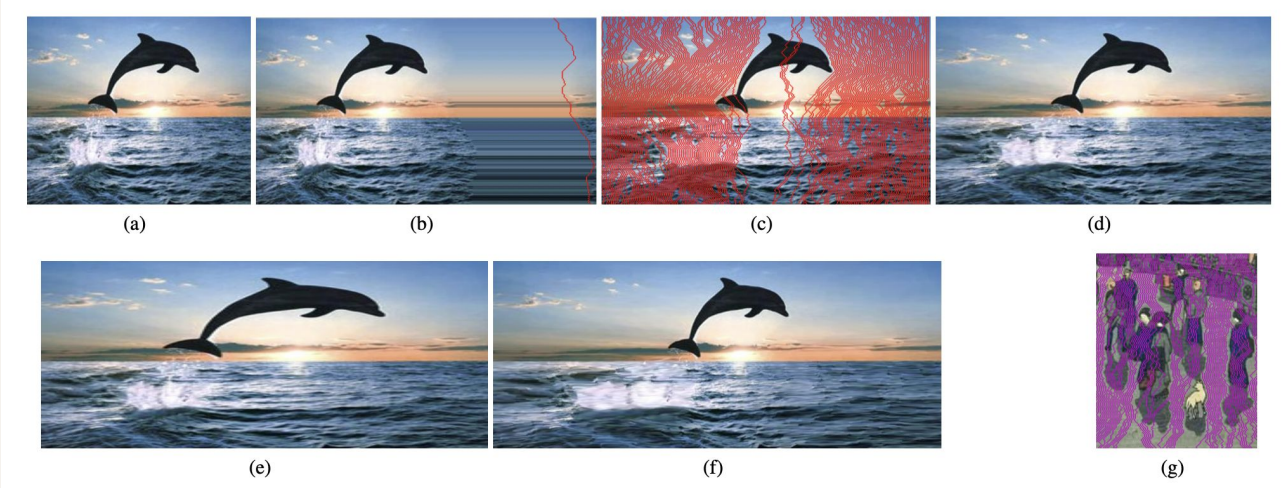
Solved by dynamic programming:

$$\begin{aligned}\mathbf{T}(r,c) \quad = \quad & min(\mathbf{T}(r-1,c)+E(\mathbf{s^x}(\mathbf{I_{n-r-1\times m-c}})),\\ & \mathbf{T}(r,c-1)+E(\mathbf{s^y}(\mathbf{I_{n-r\times m-c-1}})))\end{aligned}$$

Increasing Image Dimensions

Enlarging procedure: To enlarge a dimension by factor k:

1. Find first *k* seams as for removal
2. Duplicate pixels of each seam by avg. with left+right/top+bottom neighbors



Content Amplification

Object Removal

Multi-size Images

Provide a representation of the image for the range of 1x1 to nxm and beyond to N'xM' (for M' > m, N' > n) using a ***time-evolution representation*** with

nxm Index map V: $\mathbf{V}(i,j) = t$ (*t*-th seam where pixel (i,j) was removed)

To query image of width *m'* <= m ⇒ For each row, gather all pixels with V >= m-m'

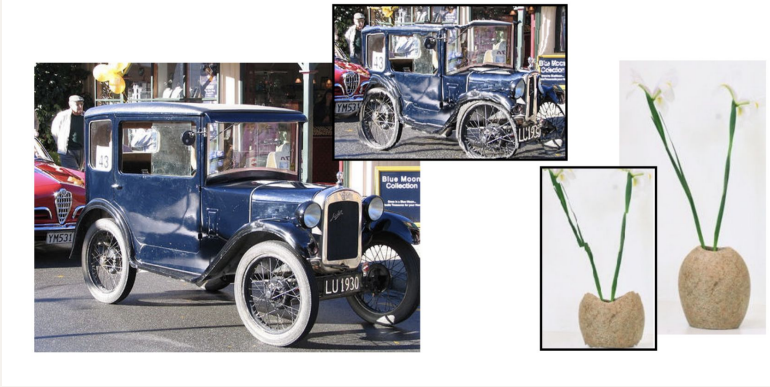
To query image of width *m+k (m < k <= M')* ⇒ V > (m - (m+k)) = -k

* For image enlarging: use average of k-th seam and left/right (or up/down) neighbors for pixel insertion

More Results

Limitations

- Fine-tuning final images- seam carving may look better in conjunction with other methods (i.e. poisson reconstruction)
- High content density - too many important areas
- Image content layout - unavoidably removing important regions



Impact

- Used in Photoshop CS4 (“Content Aware Scaling”), GIMP, ImageMagick
- Original authors subsequently published papers:
  - Video (2D seams over time), new energy function (graph cut for 2D seams & new energy function that minimizes energy introduction) [2008]
  - Combining seam carving with cropping and scaling [2009]
  - 2015 comparative study of image retargeting algorithms:
    Seam carving standalone not so good, but combined with cropping/scaling, placed in top 10

Credits

Paper:

Shai Avidan and Ariel Shamir. 2007. Seam carving for content-aware image resizing. In ACM SIGGRAPH 2007 papers (SIGGRAPH '07). Association for Computing Machinery, New York, NY, USA, 10–es.
DOI:https://doi.org/10.1145/1275808.1276390

Paper and images were obtained from:
https://faculty.idc.ac.il/arik/SCWeb/imret/index.html

GIFs were generated from the presentation video in the above website using the free GIF creation tool, GIPHY.

Impact/later work referenced from the seam carving Wikipedia article.