Seam Carving for Content-Aware Image Resizing

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The Operator

- approach to
  - content-aware resizing is to remove pixels in a judicious manner.
- how to chose the pixels to be removed?
- goal is to
  - remove unnoticeable pixels that blend with their surroundings.

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

Figure 2: Results of 5 different strategies for reducing the width of an image. (a) the original image and its e_1 energy function, (b) best cropping, (c) removing columns with minimal energy, (d) seam removal, (e) removal of the pixel with the least amount of energy in each row, and finally, (f) global removal of pixels with the lowest energy, regardless of their position. Figure 3 shows the energy preservation of each strategy.

The Operator

- Given an energy function, let **I** be an n × m image

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

- define a vertical seam

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

- where ***x*** is a mapping ***x*** : [1, . . . ,n] $\longrightarrow$ [1, . . . ,m].
- a vertical seam
  - is an 8-connected path of pixels in the image from top to bottom,
  - containing one, and only one, pixel in each row of the image
- The pixels of the path of seam s (e.g. vertical seam {si}) will therefore be

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

The Operator

- define a horizontal seam

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

- y is a mapping
  - y : [1, . . . ,m] → [1, . . . ,n]

- Removing
  - the pixels of a seam from an image has only a local effect:
  - all the pixels of the image are shifted left (or up) to compensate for the missing path.

- one can replace
  - the constraint |x(i)−x(i−1)| ≦ 1 with |x(i)−x(i−1)| ≦ k,
  - and get either a simple column (or row) for k = 0, a piecewise connected
  - Or even completely disconnected set of pixels for any value 1 ≦ k ≦ m.

The Operator

- Given an energy function e, we can define the cost of a seam as
$$E(\mathbf{s}) = E(\mathbf{I_s}) = \sum_{i=1}^{n} e(\mathbf{I}(s_i))$$
- look for the optimal seam s* that minimizes this seam cost :
$$s^* = \min_{\mathbf{s}} E(\mathbf{s}) = \min_{\mathbf{s}} \sum_{i=1}^{n} e(\mathbf{I}(s_i))$$
- The optimal seam can be found using dynamic programming.

The Operator

- The first step is
  - to traverse the image from the second row to the last row
  - and compute the cumulative minimum energy M for all possible connected seams for each entry (i, j):

$$
\begin{aligned}
M(i,j) \quad = \quad & e(i,j)+ \\
& \min(M(i-1,j-1), M(i-1,j), M(i-1,j+1))
\end{aligned}
$$

- At the end of this process,
  - the minimum value of the last row in M will indicate the end of the minimal connected vertical seam.
- in the second step
  - backtrack from this minimum entry on M to find the path of the optimal seam .

Content from:

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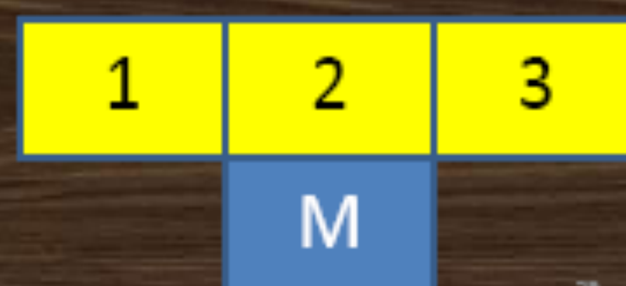
FIND THE BEST SEAM

Find M values: values prepared to find a seam

- Start with Second row
- Follow M equation for the individual

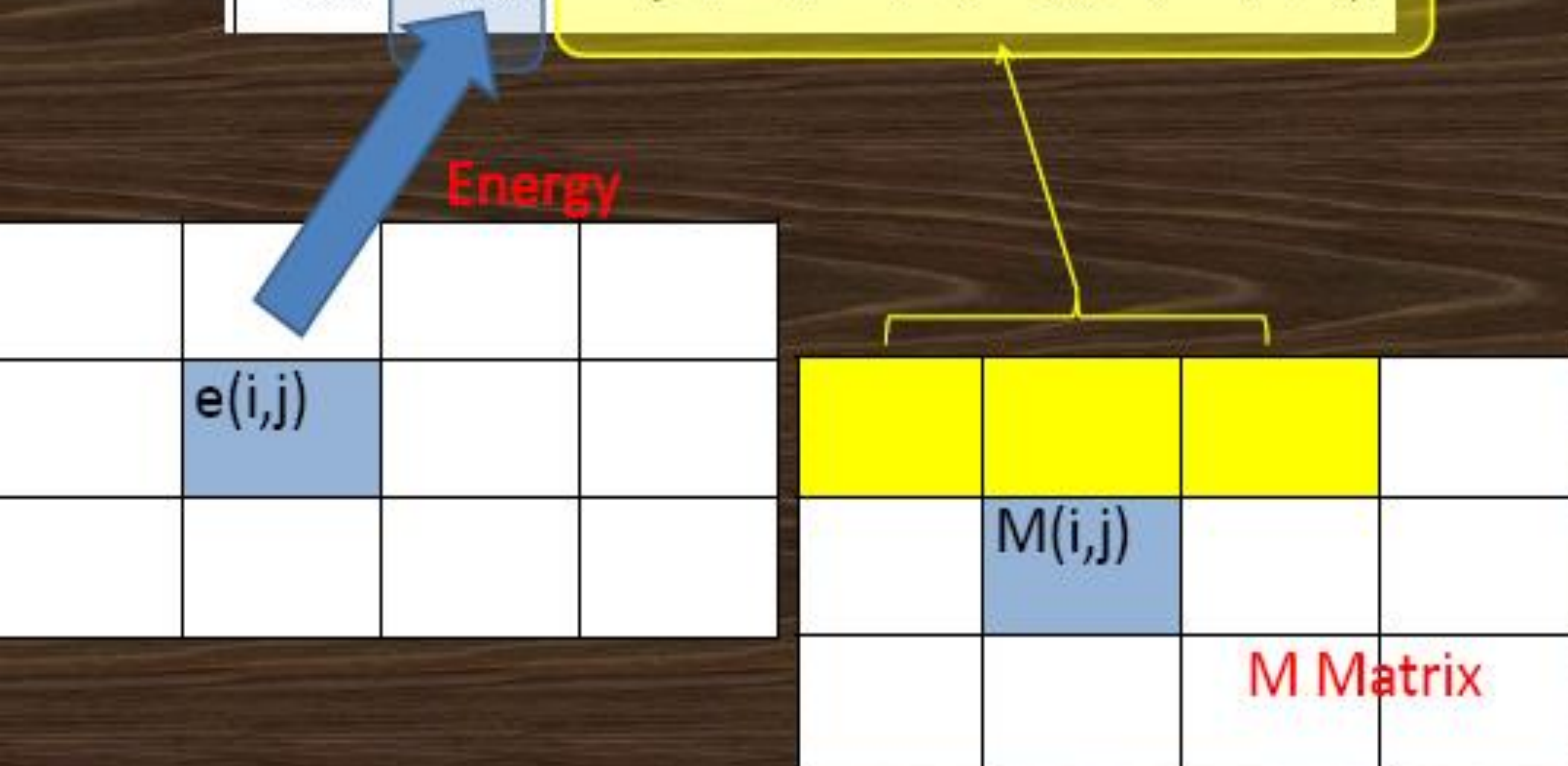
$$M(i,j) = e(i,j) + \min\big(M(i-1,j-1), M(i-1,j), M(i-1,j+1)\big)$$

- Keep track the minimal M values



COMPUTING M VALUES

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



FIND THE BEST SEAM

- Example: energy matrix

5.5	16	22.5	13	16
6.5	8	11.5	20	6.5
2.5	9.5	7	7.5	4
5.5	3.5	5.5	10	4.5
6.5	3.5	9.5	9	0.5

FIND THE BEST SEAM

To find M, Start with the second row. In the first row we can use energy

5.5	16	22.5	13	16
6.5	8	11.5	20	6.5
2.5	9.5	7	7.5	4
5.5	3.5	5.5	10	4.5
6.5	3.5	9.5	9	0.5

FIND THE BEST SEAM

Find M value of this pixel

5.5	16	22.5	13	16
6.5	8	11.5	20	6.5
2.5	9.5	7	7.5	4
5.5	3.5	5.5	10	4.5
6.5	3.5	9.5	9	0.5

FIND THE BEST SEAM

Use 2 values to compare
the minimum one

Keep track

5.5	16	22.5	13	16
12				

6.5+5.5 =
12

0	0	0
2		

1	2	3
	M	

FIND THE BEST SEAM

Find M value of this pixel

5.5	16	22.5	13	16
6.5	8	11.5	20	6.5
2.5	9.5	7	7.5	4
5.5	3.5	5.5	10	4.5
6.5	3.5	9.5	9	0.5

FIND THE BEST SEAM

Use 3 values to compare the minimum one

5.5	16	22.5	13	16
12	8			

Keep track

8+5.5 = 13.5

0	0	0	
2	1		

1	2	3
	M	

FIND THE BEST SEAM

5.5	16	22.5	13	16
12	13.5	11.5		

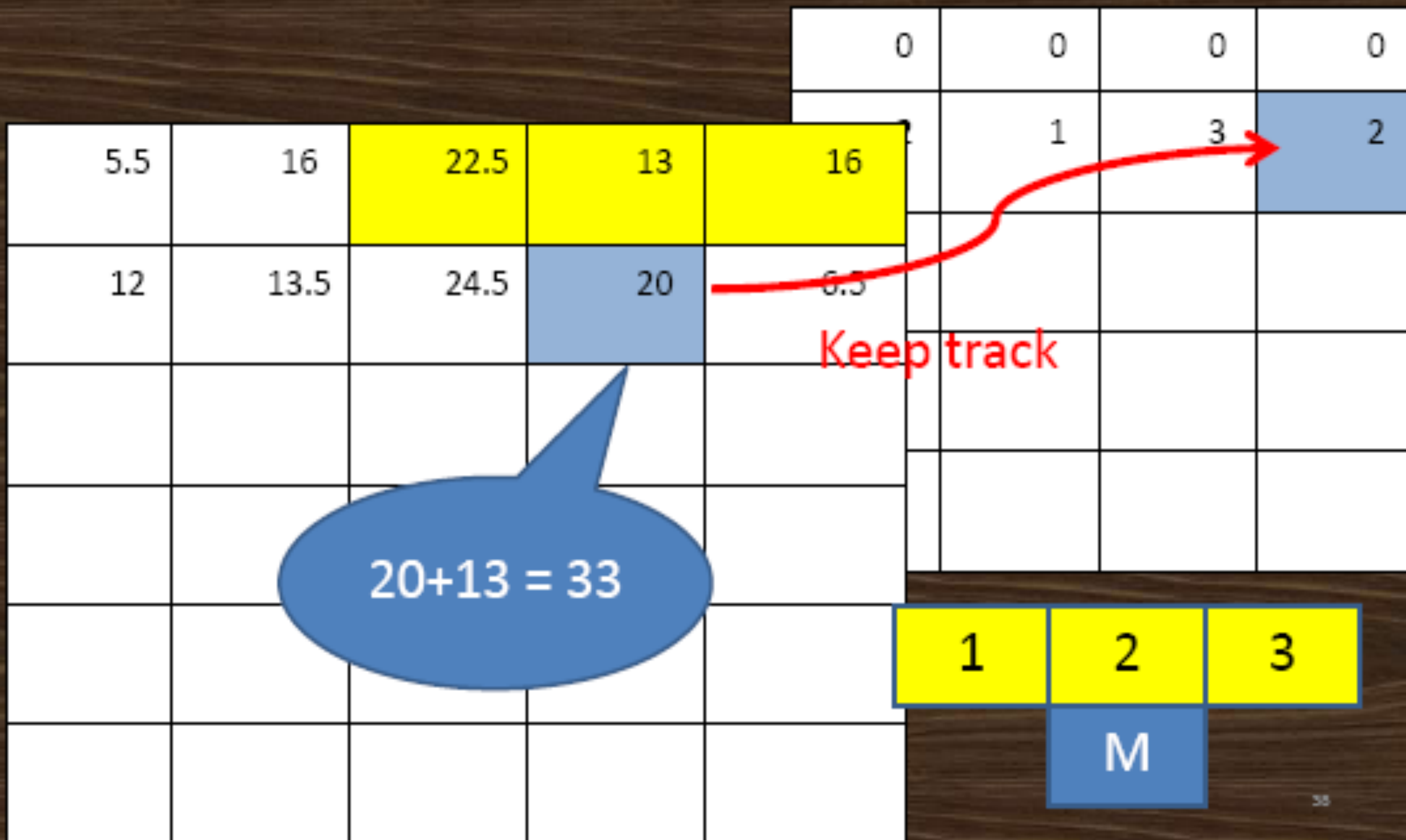
11.5+13 =
24.5

Keep track

0	0	0
2	1	3

1	2	3
	M	

FIND THE BEST SEAM



FIND THE BEST SEAM

0	0	0	0	0
		3	2	1

5.5	16	22.5	13	16
12	13.5	11.5	33	6.5

6.5+13 = 19.5

Keep track

1	2	3
	M	

FIND THE BEST SEAM

- Matrix of M

5.5	16	22.5	13	16
12	13.5	24.5	33	19.5
14.5	21.5	20.5	27	23.5
20	18	26	30.5	28
24.5	21.5	27.5	35	28.5

FIND THE BEST SEAM

- Matrix of Keeping track

0	0	0	0	0
2	1	3	2	1
2	1	1	3	2
2	1	2	1	2
3	2	1	1	2

BACKTRACK

– This process will produce the seam

  - Find the least M value of the last row

  - Follow the track that we keep from the previous process

BACKTRACK

- Example

0	0	0	0	0
2	1	3	2	1
2	1	1	3	2
2	1	2	1	2
	2	1	1	2

Backtrack

5.5	16	22.5	13	16
12	13.5	24.5	33	19.5
14.5	21.5	20.5	27	23.5
20	18	26	30.5	28
24.5	21.5	27.5	35	28.5

1	2	3
	M	

BACKTRACK

0	0	0	0	0
2	1	3	2	1
2	1	1	3	
2	1	2	1	
3	2	1	1	

Least M at the last row

5.5	16	22.5	13	16
12	13.5	24.5	33	19.5
14.5	21.5	20.5	27	23.5
20	18	26	30.5	28
24.5	21.5	27.5	35	28.5

1	2	3
	M	

BACKTRACK

0	0	0	0	0
2	1	3	2	1
2	1	1	3	
2	1	2	1	
3	2	1	1	

1	2	3
	M	

5.5	16	22.5	13	16
12	13.5	24.5	33	19.5
14.5	21.5	20.5	27	23.5
20	18	26	30.5	28
24.5	21.5	27.5	35	28.5

BACKTRACK

0	0	0	0	0
2	1	3	2	1
2	1	1	3	2
2	1	2	1	
3	2	1	1	

1	2	3
	M	

5.5	16	22.5	13	16
12	13.5	24.5	33	19.5
14.5	21.5	20.5	27	23.5
20	18	26	30.5	28
24.5	21.5	27.5	35	28.5

BACKTRACK

0	0	0	0	0
2	1	3	2	1
2	1	1	3	
2	1	2	1	
3	2	1	1	

1	2	3
	M	

5.5	16	22.5	13	16
12	13.5	24.5	33	19.5
14.5	21.5	20.5	27	23.5
20	18	26	30.5	28
24.5	21.5	27.5	35	28.5

BACKTRACK

0	0	0	0	0
2	1	3	2	1
2	1	1	3	2
2	1	2	1	
3	2	1	1	

1 2 3

M

5.5	16	22.5	13	16
12	13.5	24.5	33	19.5
14.5	21.5	20.5	27	23.5
20	18	26	30.5	28
24.5	21.5	27.5	35	28.5

DELETE SEAM

In order to reduce the image size, we can do by delete Seam:

- remove that seam directly
- shift the rest to fill the blanks

DELETE SEAM

- Example

5.5	16	22.5	13	16
12	13.5	24.5	33	
14.5	21.5	20.5	27	
20	18	26	30.5	
24.5	21.5	27.5	35	

16	22.5	13	16
13.5	24.5	33	19.5
21.5	20.5	27	23.5
20	26	30.5	28
24.5	27.5	35	28.5

Image Energy Functions

- The entropy energy
  - Computes the entropy over a 9×9 window and adds it to e1.
- The segmentation method
  - first segments the image [Christoudias et al. 2002]
  - and then applies the e1 error norm on the results,
  - effectively leaving only the edges between segments.
- eHoG is defined as follows:

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

- where HoG(I(x,y))
  - is taken to be a **histogram of oriented gradients** at every pixel [Dalal and Triggs 2005].
  - use an 8-bin histogram computed over a 11×11 window around the pixel.
- found either e1 or eHoG to work quite well.

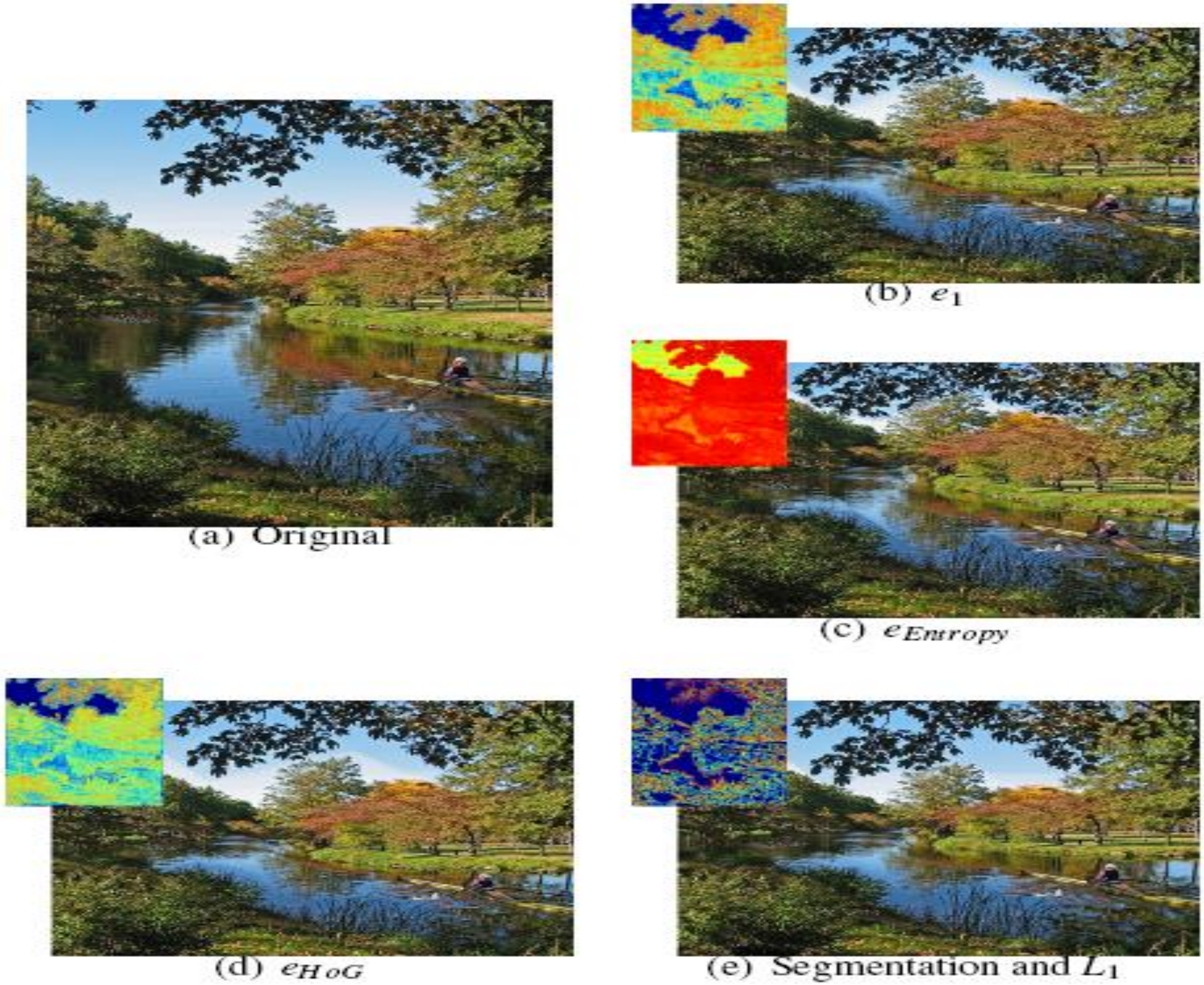


Figure 4: Comparing different energy functions for content aware resizing.