A Novel Edge-Preserving Mesh-Based Method for Image Scaling

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Outline

- Image scaling problem
- Introduction to triangle-mesh models of images
- Proposed image scaling method
- Results
- Conclusions
Image Scaling Problem

- Image $I_{W \times H} \rightarrow$ scale with factor $\alpha > 1$ $\rightarrow$ scaled image $I_{\alpha W \times \alpha H}$
- Different image scaling methods:
  1. Raster-based: using pixels $\Rightarrow$ bilinear, bicubic, ...
  2. Vector-based: using geometric primitives $\Rightarrow$ triangle-mesh models

Raster-based methods often suffer from severe edge blurring.
Image Scaling Problem

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- Goal: produce scaled image with better subjective quality
Triangle Mesh Models of Images

original image $\phi$  surface model
Triangle Mesh Models of Images

original image $\phi$

surface model

triangulation
Triangle Mesh Models of Images

original image $\phi$  
surface model

triangulation  
triangle-mesh model
Triangle Mesh Models of Images

original image $\phi$

surface model

triangulation

triangle-mesh model

reconst. image $\phi'$
ERD Mesh Model

- Originally proposed by Tu and Adams in 2013
- Explicit representation of discontinuities (ERD)
- Discontinuous and piecewise-linear approximating function
- Based on constrained Delaunay triangulation (CDT)
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![CDT](image1)

three wedges

one wedge

Seyedali Mostafavian and Michael D. Adams (UVic)
How is image discontinuity (edges) modeled?

- Each wedge is associated with a *wedge value*
- Wedge values are used to create approximating function
ERD Mesh Model Cont’d

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ERD mesh model parameters:

1. Set of sample points, $P = \{v_i\}$
2. Set of edge constraints, $E$
3. Set of wedge values, $Z$
Mesh-Generation Method

- ERD mesh model parameters:
  1. Set of sample points, $P = \{v_i\}$
  2. Set of edge constraints, $E$
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- The process to select model parameters is called **mesh generation**

- Image $\phi \rightarrow \text{mesh generation} \rightarrow P, E, \text{and } Z$

- Image resolution of $W \times H$

- Sampling density of mesh, $d = \frac{|P|}{W \times H} \times 100$
Proposed Image Scaling Method

Two steps:

1. **Input image** → **mesh generation** → ERD mesh model

2. ERD mesh model → **image reconstruction** → scaled image
Proposed Image Scaling Method Cont’d

Step 1: Mesh Generation

Select model parameters (i.e., $P, E, Z$) with $N$ samples:

1. Initial triangulation:
   - Detect image edges (Canny edge detector)
   - Edges approximated with polylines: $P_0$ and $E$
   - Constrained Delaunay triangulation with $P_0$ and $E$
Proposed Image Scaling Method Cont’d

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2. **Calculate initial wedge values**
Proposed Image Scaling Method Cont’d

Step 1: Mesh Generation

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   - Detect image edges (Canny edge detector)
   - Edges approximated with polylines: $P_0$ and $E$
   - Constrained Delaunay triangulation with $P_0$ and $E$

2. Calculate initial wedge values

3. Select new point $q$ to add to mesh

4. Insert $q$ into mesh

5. Recalculate wedge values

6. Repeat steps 3 to 5 until $|P| = N$
Image reconstruction contains two steps:

1. **Mesh Refinement:** to produce smoother edge curves and image function
   - Mesh is refined iteratively through a subdivision process
   - A variation of the Loop subdivision (proposed by Liao et. al. in 2012)
   - Three steps of subdivision is used

2. **Mesh Rasterization:**
   Rasterize the (subdivied) mesh to a finer grid \(ightarrow\) scaled image
Assume image $I$ and scale factor $\alpha > 1$:

1. $I \rightarrow \text{reduce resolution by factor } \frac{1}{\alpha} \rightarrow I_{low}$

2. $I_{low} \rightarrow \text{scaling method to increase resolution by factor } \alpha \rightarrow I'$

3. Compare $I'$ with $I$ with:
   - Subjective: visual inspection
   - Objective: percentage edge error (PEE) metric

4. Compared with \textbf{bilinear} and \textbf{bicubic} methods
Evaluation Results: Scale Factor $\alpha = 8$

- hi-res image $I$
- $I$ (zoomed)

Methods:
- bilinear, $\text{PEE}=55.17$
- bicubic, $\text{PEE}=47.58$
- propos., $\text{PEE}=0.95$, $d=2\%$
Evaluation Results: Scale Factor $\alpha = 4$

- **hi-res image $I$**
- **$I$ (zoomed)**
- **bilinear, PEE=19.25**
- **bicubic, PEE=11.22**
- **proposed, PEE=-0.42, d=4%**
Conclusions

- A novel mesh-based method proposed for image scaling
- Proposed method uses a mesh model which explicitly represents discontinuities
- Proposed method can:
  - effectively preserve the sharpness at edges
  - create scaled images of higher quality to human eyes
- Proposed method outperforms the commonly-used bilinear and bicubic methods
- Our method can benefit many applications in digital photography, computer graphics, and medical imaging
THANK YOU
\[ \alpha_n = \frac{1}{n} \left[ \frac{5}{8} - \left( \frac{3}{8} + \frac{1}{4} \cos \frac{2\pi}{n} \right)^2 \right], \text{ when } n \text{ is the valence of the vertex} \]
Two types of vertices:

1. Zero or one constrained edge: $z = \phi(v)$
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1. Zero or one constrained edge: \( z = \phi(v) \)

2. More than one constrained edges: backfilling-based approach
1-Mesh Generation: Wedge-Value Calculation Cont’d

Backfilling-based method:

- Wedge value $z$ for wedge $w$ associated with vertex $v$
- $S$: vertices connected to $v$ in $w$, not incident on constrained edges
- Values at points near edges are not reliable (blurred zone)

$$S = \{b, c\}$$

$$z = \frac{1}{|S|} \sum_{p \in S} \phi(p)$$
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- Wedge value $z$ for wedge $w$ associated with vertex $v$
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\[
S = \{b, c\} \\
z = \frac{1}{|S|} \sum_{p \in S} \phi(p)
\]
Proposed Image Scaling Method Cont’d
1-Mesh Generation: Point Selection

Point $q$ to be inserted in mesh is selected in 2 steps:

1. Select face $f^*$ with highest squared error as

$$f^* = \arg\max_{f \in F} \sum_{p \in \Omega_f} \left( \hat{\phi}(p) - \phi(p) \right)^2$$

$\Omega_f$: all valid points in face $f$

Valid point: NOT 8-connected pixels of any image edges

$F$: all faces for which $\Omega \neq \{\emptyset\}$
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Valid point: NOT 8-connected pixels of any image edges
$F$: all faces for which $\Omega \neq \{\emptyset\}$

2. Select $q$ as the point with the highest absolute error in $f^*$ as

$$q = \arg\max_{p \in \Omega_{f^*}} \left| \hat{\phi}(p) - \phi(p) \right|$$
Evaluation Results Cont’d
Test Image 2 with $\alpha = 4$

Original

Orig. Magnified

Bilin., PEE = 27.51

Bicub., PEE = 18.44

Prop., PEE = 0.18

Mesh @ 2%
Evaluation Results Cont’d
Test Image 1 with $\alpha = 8$

Original

Original Magnified

Bilinear, PEE = 55.17

Bicubic, PEE = 47.58

Propose, PEE = 0.95

Mesh @ 2%
Evaluation Results Cont’d

Test Image 3 with $\alpha = 4$

Original

Original Magnified

Bilinear, $\text{PEE}=19.25$

Bicubic, $\text{PEE}=11.22$

Proposed, $\text{PEE}=-0.42$

Mesh @ 4%