Triangle-Mesh Models, Their Generation, and Their Application in Image Scaling

(PhD Oral Exam)

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University of Victoria

Outline

1. Mesh generation with minimal squared error for image representation
   - Triangle-mesh models of images
   - ERD mesh model
   - Proposed SEMMG method and its development
   - Evaluation results

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2. Image scaling with minimal edge blurring using mesh models
   - Problem statement
   - Proposed MIS method and its development
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   - Problem statement
   - Proposed MIS method and its development
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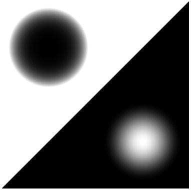
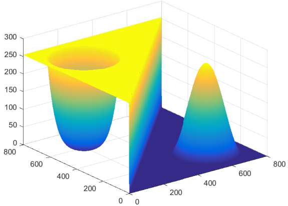
3. Conclusions
4. Future research

Triangle Mesh Models of Images



original image ϕ

$\longleftrightarrow$



surface model

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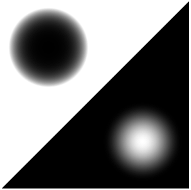

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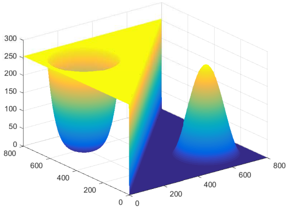

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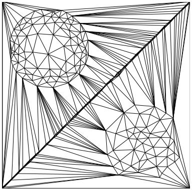

triangulation

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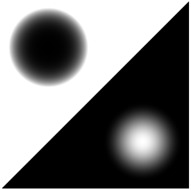

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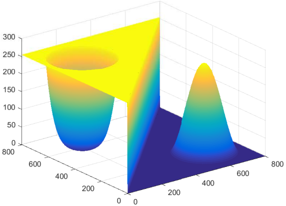

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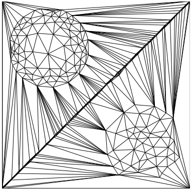

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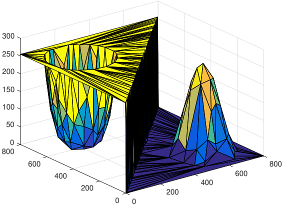

triangle-mesh model

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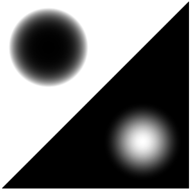

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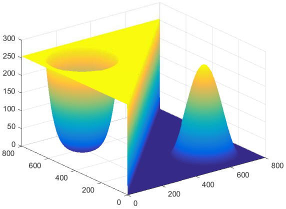

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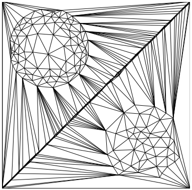

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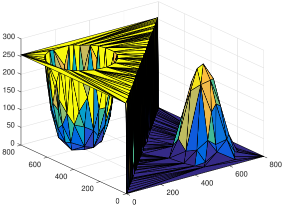

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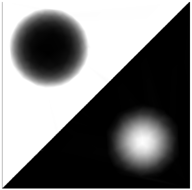

reconst. image ϕ'

ERD Mesh Model

- Explicit representation of discontinuities (ERD)
- Piecewise-linear interpolating function
- Based on constrained Delaunay triangulation (CDT)
- Using wedges and wedge values

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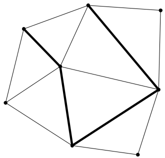

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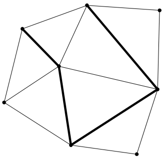

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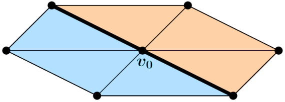

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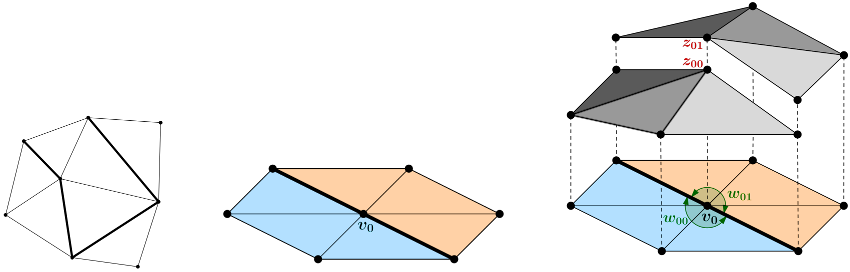


CDT　　two wedges　　discontinuity modeling

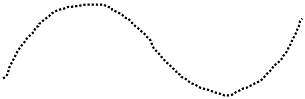
Mesh-Generation Method

- Process to select model parameters is called **mesh generation**
- Inputs to mesh generation:
  - Image ϕ known on discrete domain Λ of size $W \times H$
  - N desired number of sample points
- Outputs are ERD mesh model parameters:
  1. Set of sample points, $P = \{v_i\}$ (where $|P| = N$)
  2. Set of edge constraints, E
  3. Set of integer wedge values, Z
- Sampling density of mesh, $d = \dfrac{N}{W \times H} \times 100$

General Steps of ERD Mesh Generation

For selecting model parameters (P, E, Z) with N samples

1. Initial triangulation:
   - Edge detection
   - Polyline generation + simplification
   - Constrained Delaunay triangulation



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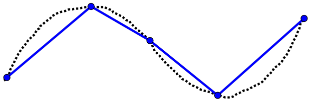

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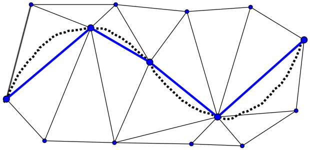

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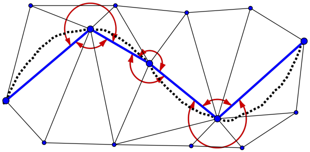

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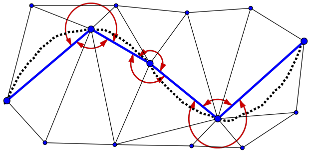

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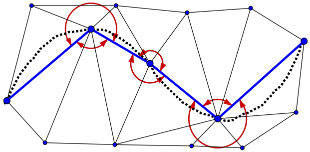

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4. Repeat step 3 until $|P| = N$

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- Combined all modifications ⇒ proposed SEMMG method

Evaluation of SEMMG Method

1. Compared to ED, MGH, ERDED, ERDGPI methods:
   - Test data of 35 images
   - 10 sampling densities from 0.0078125% to 3%
   - Total of 350 test cases

	ED	MGH	ERDED	ERDGPI
SEMMG outperforms (% of cases)	100%	89%	99%	85%
Average PSNR increase	8.86 dB	2.25 dB	5.43 dB	2.22 dB

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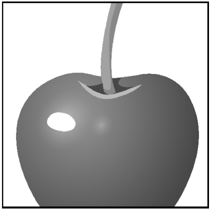
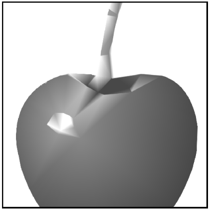
2. Compared to GVS, HWT, BSP, ATM methods:
    - Average PSNR increase from 1.10 dB to 3.85 dB
    - 65-80% fewer vertices compared to GVS method
    - 10-60% fewer triangles compared to BSP method

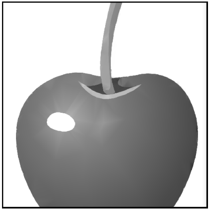
Visual Examples



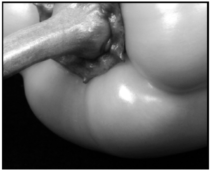
original



MGH 28.10 dB
d=0.03125%



SEMMG 38.78 dB
d=0.03125%



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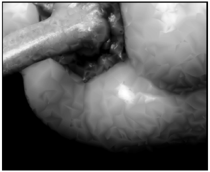
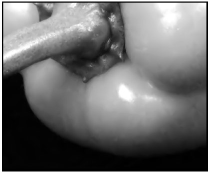


ERDGPI 37.57 dB
d=0.25%



SEMMG 40.70 dB
d=0.25%

- Common distortions: edge blurring/ringing $\rightarrow$ poor subjective quality


LR image


bilinear with $k = 4$


bicubic with $k = 4$

Application of Mesh Models in Image Scaling
Problem Statement

- Common distortions: edge blurring/ringing → poor subjective quality

LR image

bilinear with $k = 4$

bicubic with $k = 4$

- Goal: Mesh-based method for producing scaled images with better subjective quality and minimal edge blurring
- Outcome: MIS method is proposed for scaling grayscale images that are approximately piecewise smooth

Development of Proposed MIS Method

- General steps of MIS method to scale an image:
  1. raster image → mesh generation → mesh model of image
  2. mesh model → mesh transformation → scaled model
  3. scaled model → model rasterization → scaled image

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- SEMMG method not designed for image scaling

- SEMMG was used in step 1 to detect distortions/shortcomings in image scaling

- Specific modifications applied to reduce/eliminate distortions

Development of Proposed MIS Method Cont'd

- Applied modifications to 4 main areas:
  1. Wedge-value selection: backfilling-based technique ⇒ more effective parameter Z
  2. Mesh refinement: modified centroid-based approach ⇒ more effective parameter P
  3. Model rasterization: subdivision-based approach ⇒ smoother edge contours
  4. Polyline simplification: adaptive polyline simplification (APS) technique ⇒ more effective parameter E
- Combined all modifications ⇒ proposed MIS method

Evaluation of MIS Method

- Experimental Comparisons:
  - Methods with available implementation
  - MIS method is compared to bilinear, bicubic, DCCI, NEDI, and SRCNN methods
  - Subjective Evaluation
  - Objective Evaluations: PSNR, SSIM, PEE metrics
- Conceptual Comparisons:
  - Mesh-based methods with unavailable implementation
  - Differences/similarities using theoretical analysis

- Between bilinear, bicubic, DCCI, NEDI, SRCNN, and MIS methods
- 20 LR images and $k = 4 \rightarrow$ 20 HR images with 19 human subjects $\Rightarrow$ 380 rankings
- 300 pairwise comparisons per subject
- Methods ranked from 1st (best) to 6th (worst)

Evaluation of MIS Method Cont'd

Subjective Evaluation

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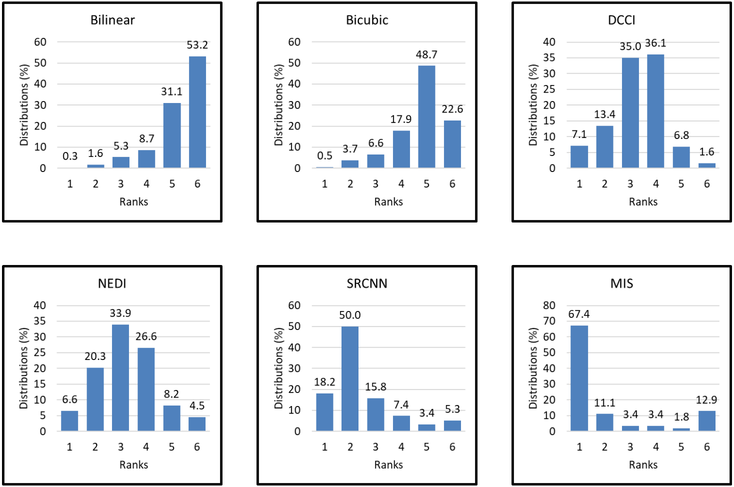
- Methods ranked from 1st (best) to 6th (worst)
- Statistical properties of the 380 ranks:

	Bilinear	Bicubic	DCCI	NEDI	SRCNN	MIS
Mean Rank	5.28	4.78	3.27	3.23	2.44	2.00
Median Rank	6	5	3	3	2	1
Standard Deviation	0.97	1.02	1.06	1.19	1.26	1.75

- MIS method achieved best mean rank of 2 and median rank of 1

Evaluation of MIS Method Cont'd

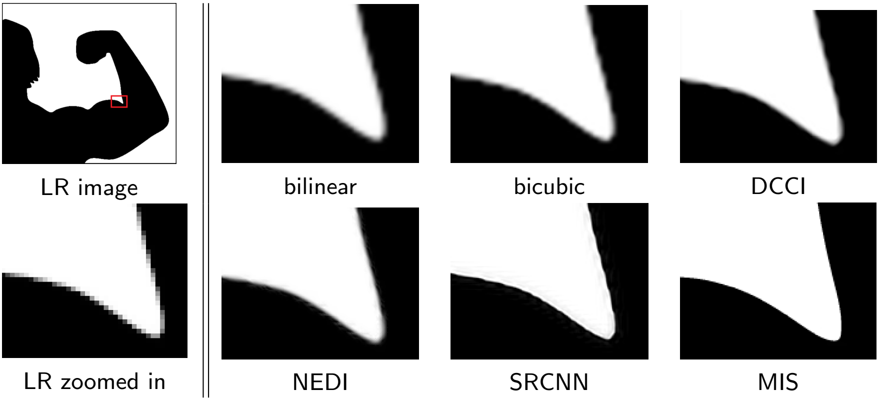
Subjective Evaluation Cont'd



- MIS method ranked 1st in approximately 67% of cases

Evaluation of MIS Method Cont'd

Visual Examples



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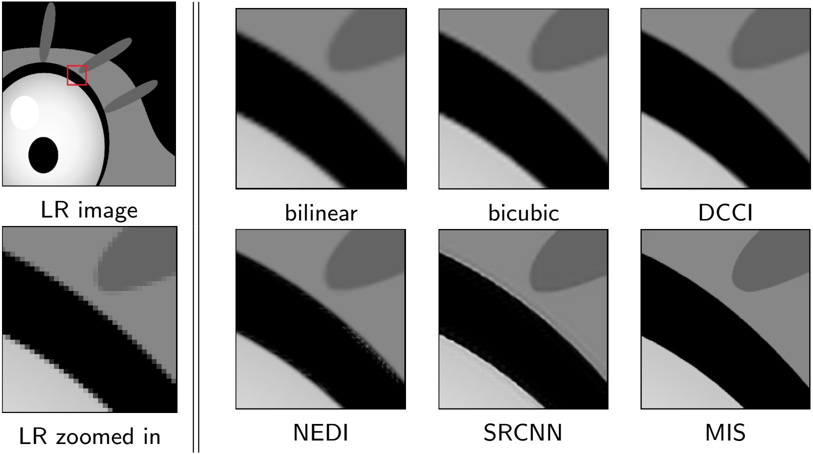

Conclusions

2 problems were addressed:

1. Mesh generation with minimal squared errors
   - The SEMMG method was proposed
   - Improved meshes in terms of both PSNR and subjective quality
   - Compared to ED, MGH, ERDED, and ERDGPI methods using 350 test cases:
     - Outperformed ED in 100% with average PSNR margin of 8.86 dB
     - Outperformed MGH in 89% with average PSNR margin of 2.25 dB
     - Outperformed ERDED in 99% with average PSNR margin of 5.43 dB
     - Outperformed ERDGPI in 85% with average PSNR margin of 2.22 dB

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   - Outperformed GVS, HWT, BSP, and ATM methods with average PSNR of 3.85, 0.75, 2, and 1.10 dB
   - 65-80% fewer vertices compared to GVS method
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Conclusions Cont'd

2. Scaling grayscale images with minimal edge blurring using mesh models
   - MIS method was proposed for approximately piecewise-smooth images
   - Improved subjective quality:
     - Sharper and more accurate edges with minimal blurring/ringing
     - Compared to bilinear, bicubic, DCCI, NEDI, and SRCNN
     - Ranked best overall in 67% out of 380 subjective rankings
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    - Flexible functionalities:
        - Image models that are portable, reusable, and editable
        - Combination of any affine transformations: translation, rotation, shearing
        - Almost independent from scale factor

Future Research

- Edge detection:
  - more advanced edge detector
  - edges with sub-pixel accuracy
  - better detection of junction points
  - better performance with too small images

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- Color images
  - image model with the same triangulation: scalar z value $\rightarrow$ 3-tuples (r, g, b), OR
  - image model with different triangulations: separate triangulation per color channel

THANK YOU