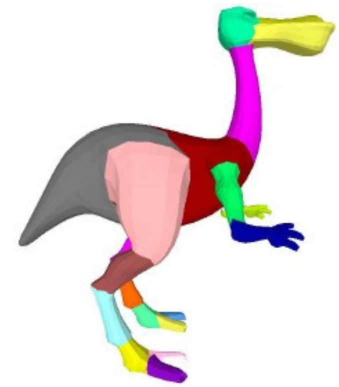
Mesh Segmentation Driven by Gaussian Curvature

[1]Hitoshi Yamauchi, [2]Stefan Gumhold,
[1]Rhaleb Zayer, and [1]Hans-Peter Seidel

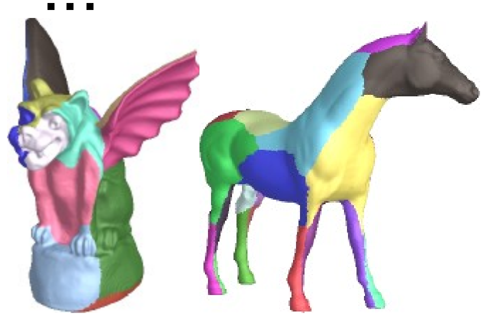
[1]MPI Informatik, Saarbrücken, Germany
[2]Technical University of Dresden, Germany

Why segmentation?

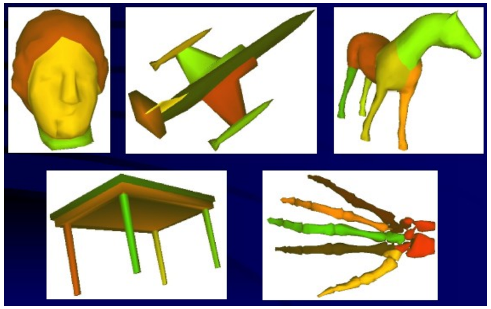
- A basic geometry processing tool for:
  - Shape understanding
  - Mesh simplification
  - Mesh matching, retrieval
  - Animation, morphing (parts extraction)
  - Texture mapping
  - ...



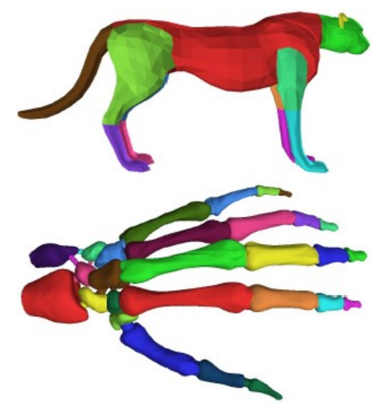
[Katz & Tal, 03]



[Sander et al. 03]



[Liu et al. 04]



[Funkhouser et al. 04]

Segmentation Zoo

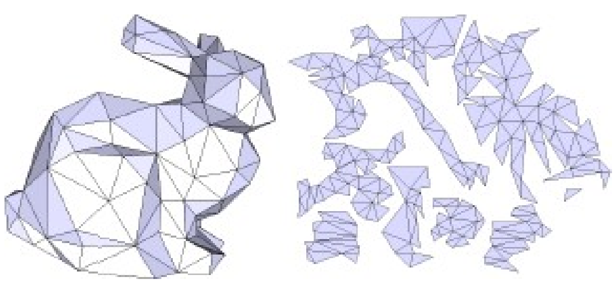
- Many criteria for segmentation
  - Application dependent
  - Need a definition of criteria/application
- Our main application
  - Texture mapping (parameterization)
    - Achieve low distortion parameterization
  - Goal of segmentation
    - Generate patches as developable as possible

Outline

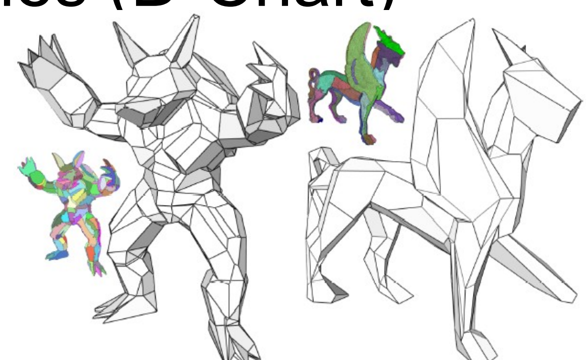
- <u>Related work</u>
- Our approach
- Gauss area for surface segmentation
- *t*-flooding algorithm
- Demo
- Results
- Conclusion

Related work

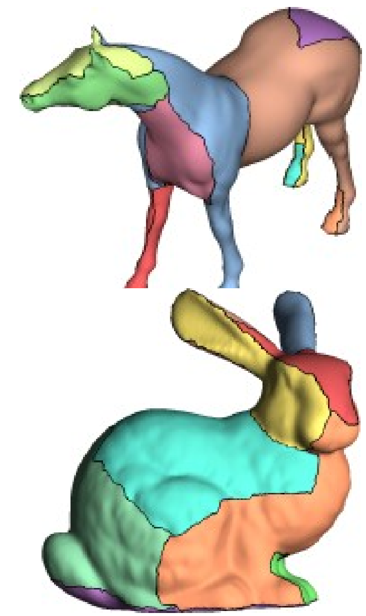
- Segmentation based on fitting primitives
  - Developable charts ... e.g., triangle strip
    - No consideration on boundary condition of each chart
    - Trade off between the # of charts and developability
  - Normal (plane)
    - Can not account for cylinders, cones
  - Uni-axial union of cones (D-Chart)



[Mitani et al. 04]



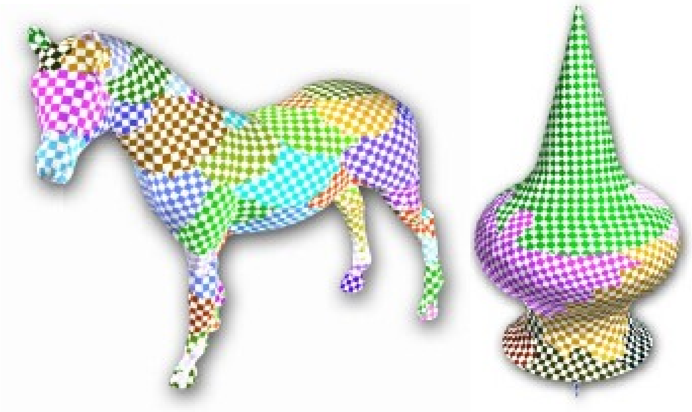
[Cohen-Steiner et al. 04]



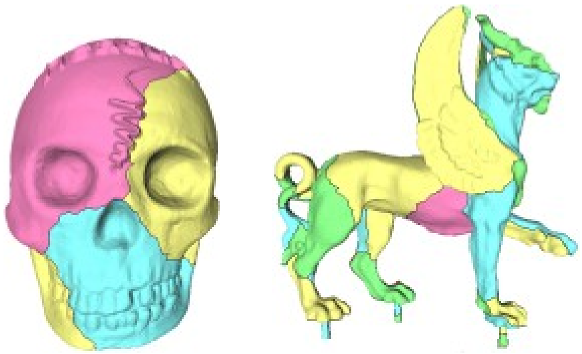
[Julius et al. 05]

Related work

- Parameterization driven segmentation
  - Account for the parameterization distortion during the segmentation process
  - Parameterization and segmentation are carried on simultaneously
  - To get segmentation, segmentation is needed



[Sorkine et al. 2002]



[Zhou et al. 2004]

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Our approach

- Introduce a new measure for developability
- Gauss area (area on Gauss map)
  - Captures Gaussian curvature properties
  - Avoids the numerical difficulties of using Gaussian curvature directly for segmentation
- Distribute Gauss area over the charts
  - *t*-flooding growing (time parameterized flooding)
    - High Gauss area is added to chart later
    - $\Rightarrow$ High Gauss area parts tend to be cut

Contributions

- Segmentation driven by a variant of Gaussian curvature
- Gauss area: Normal distribution on Gauss map
  - Robust and simple computation
- *t*-flooding algorithm
  - Control over the relative growing process of the charts
  - Reduce boundary artifacts

Outline

- Related work
- Our approach
- <u>Gauss area for surface segmentation</u>
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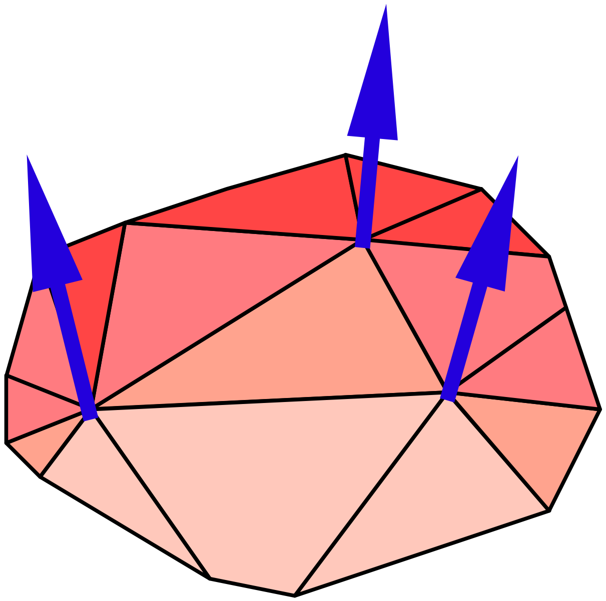
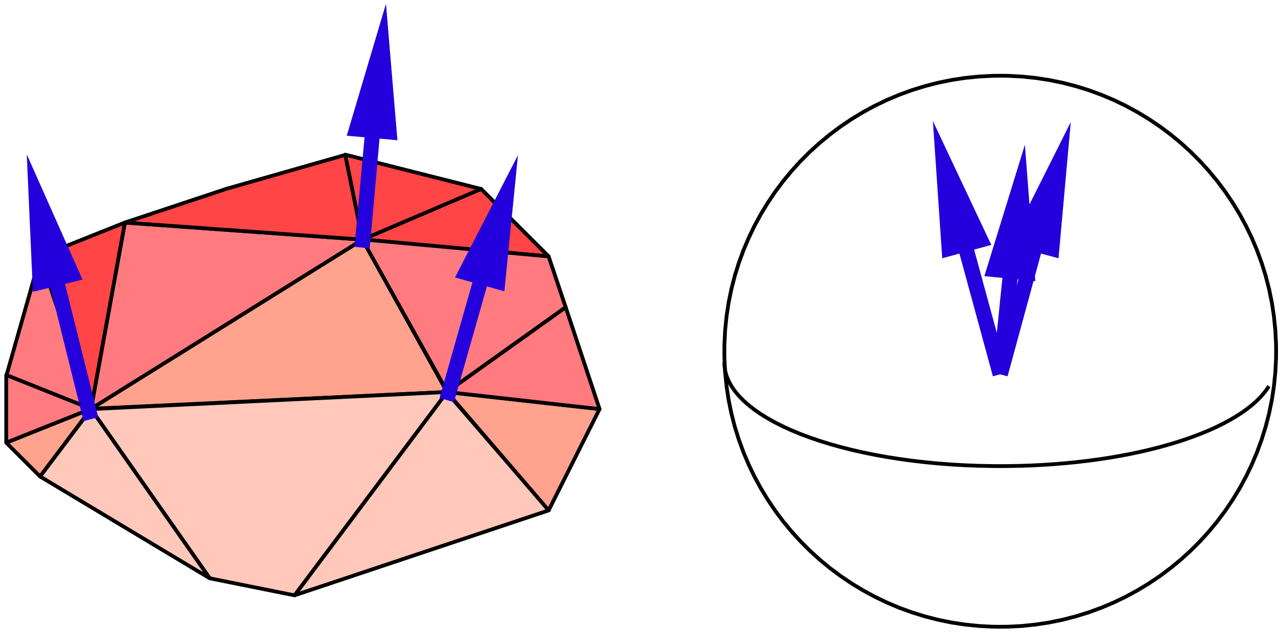
Gauss area: area on Gauss map

- Compute normals



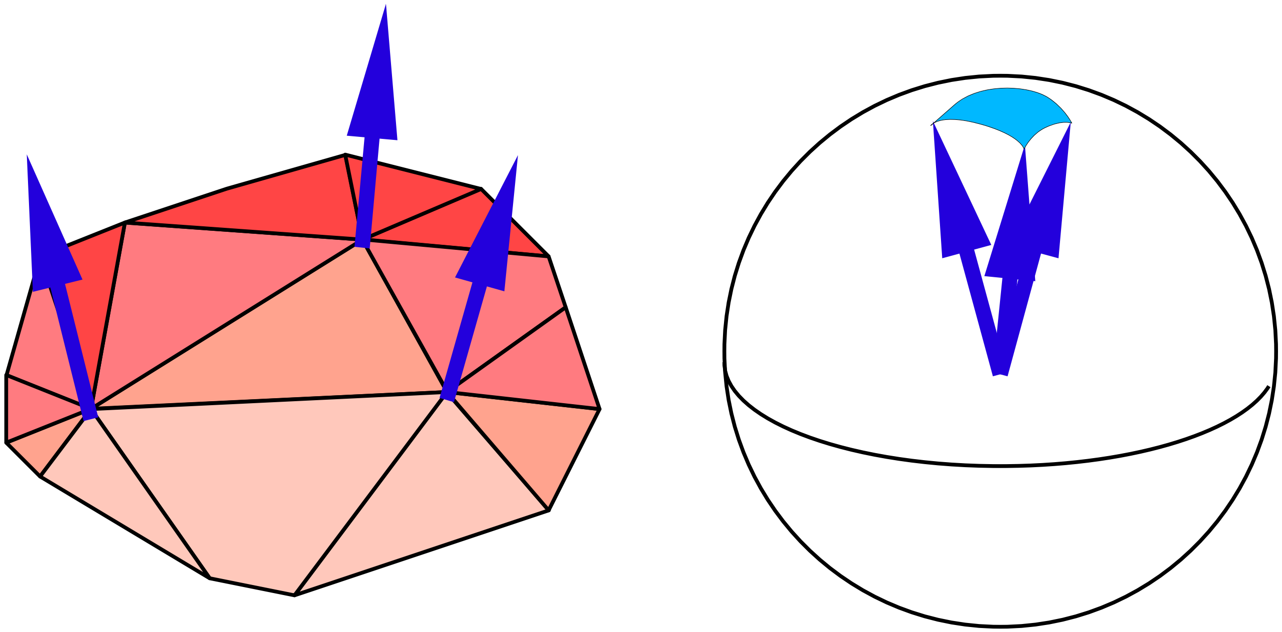
Gauss area: area on Gauss map

- Compute normals
- Project the normals on a unit sphere



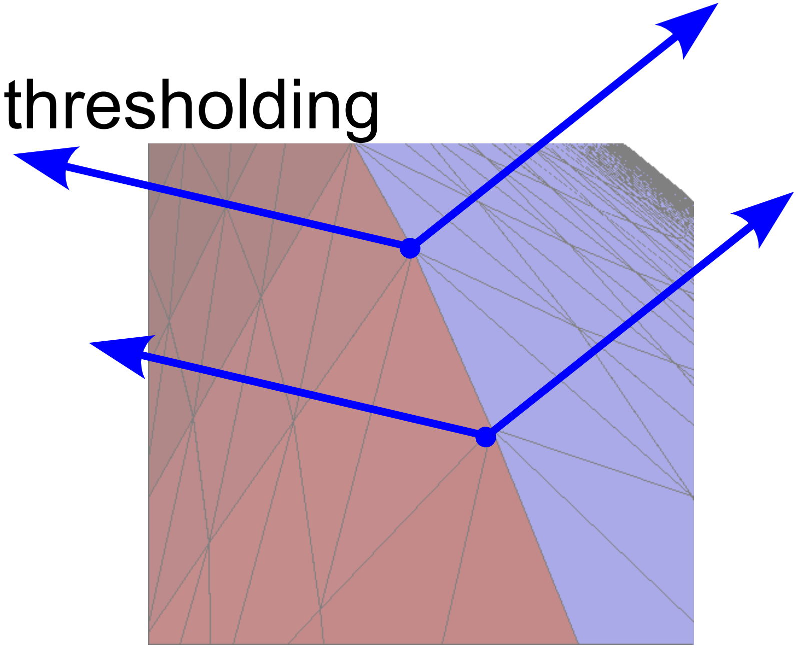
Gauss area: area on Gauss map

- Compute normals
- Project the normals on a unit sphere
- Compute area on Gauss map



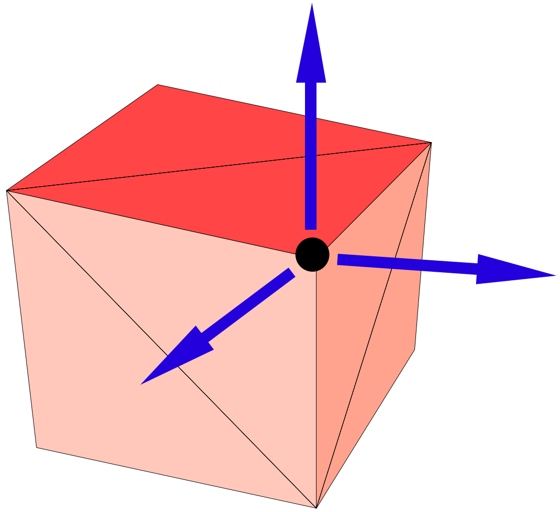
Multiple normals

- Triangle mesh: a piecewise linear approximation of a shape
  - Not assume everything is smooth
    - At sharp creases and corners, consider the multiple normals
  - Multiple normals by thresholding



Gauss area computation

– At the corner, multiple normals are generated by thresholding



Gauss area computation

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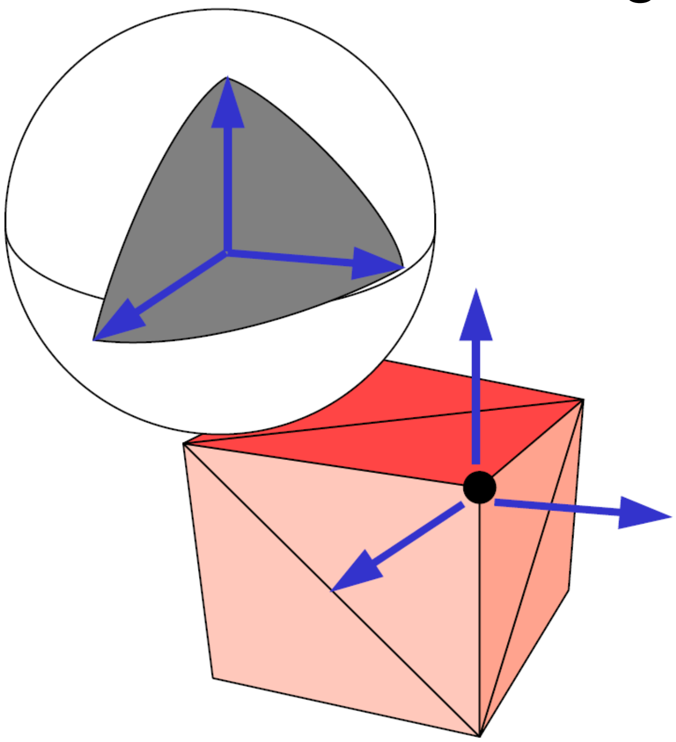
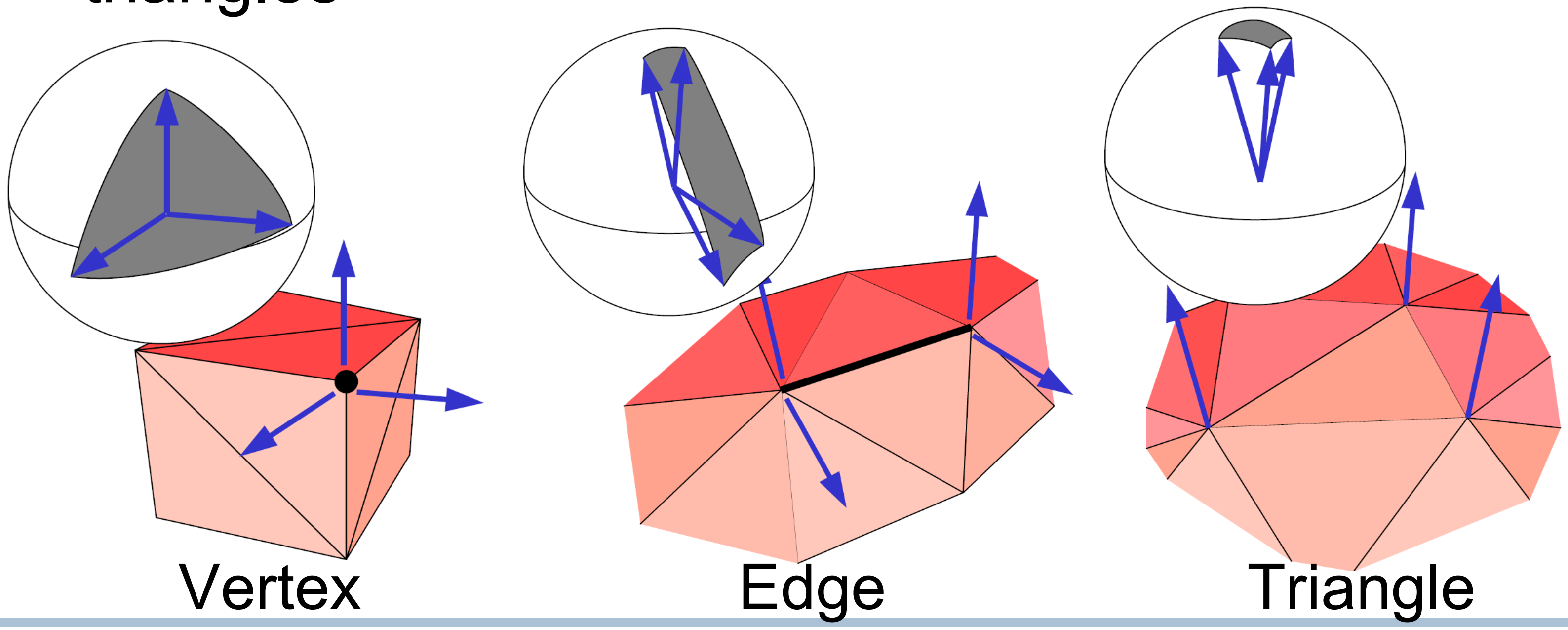
- At the corner, multiple normals are generated by thresholding
- Gauss area is assigned to the vertex



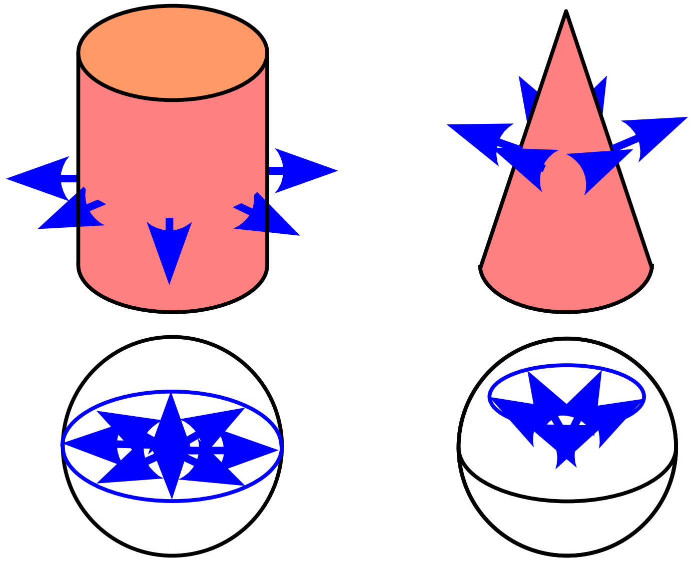
Gauss area computation

- At the corner, multiple normals are generated by thresholding
- Gauss area is assigned to the vertex
- Similarly, a Gauss area is assigned to edges and triangles

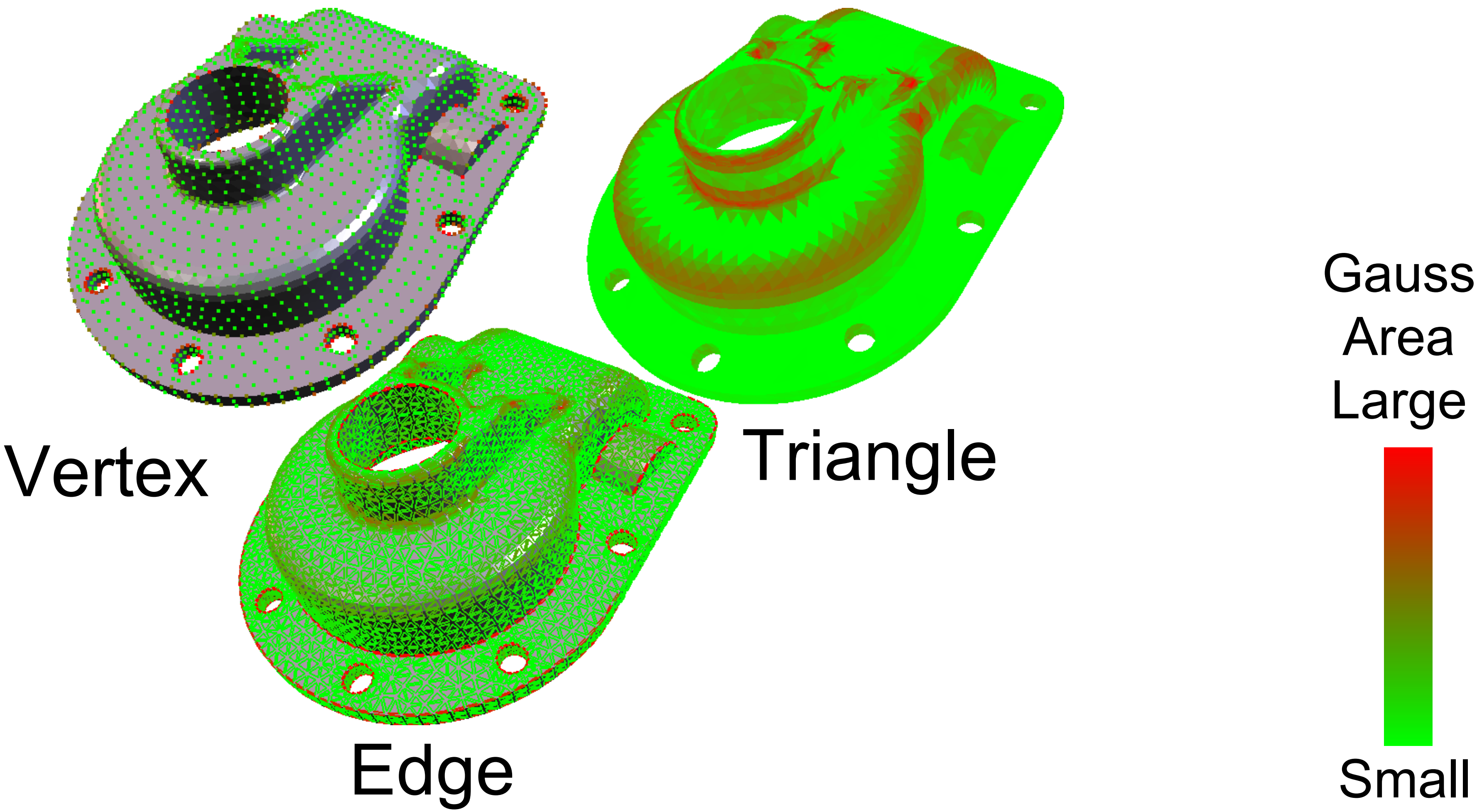


Gauss area properties

- Captures Gaussian curvature properties
- Robust and simple computation, always in [0, 4π]
- Developable surfaces have no Gauss area



Gauss area visualization



Gauss area visualization

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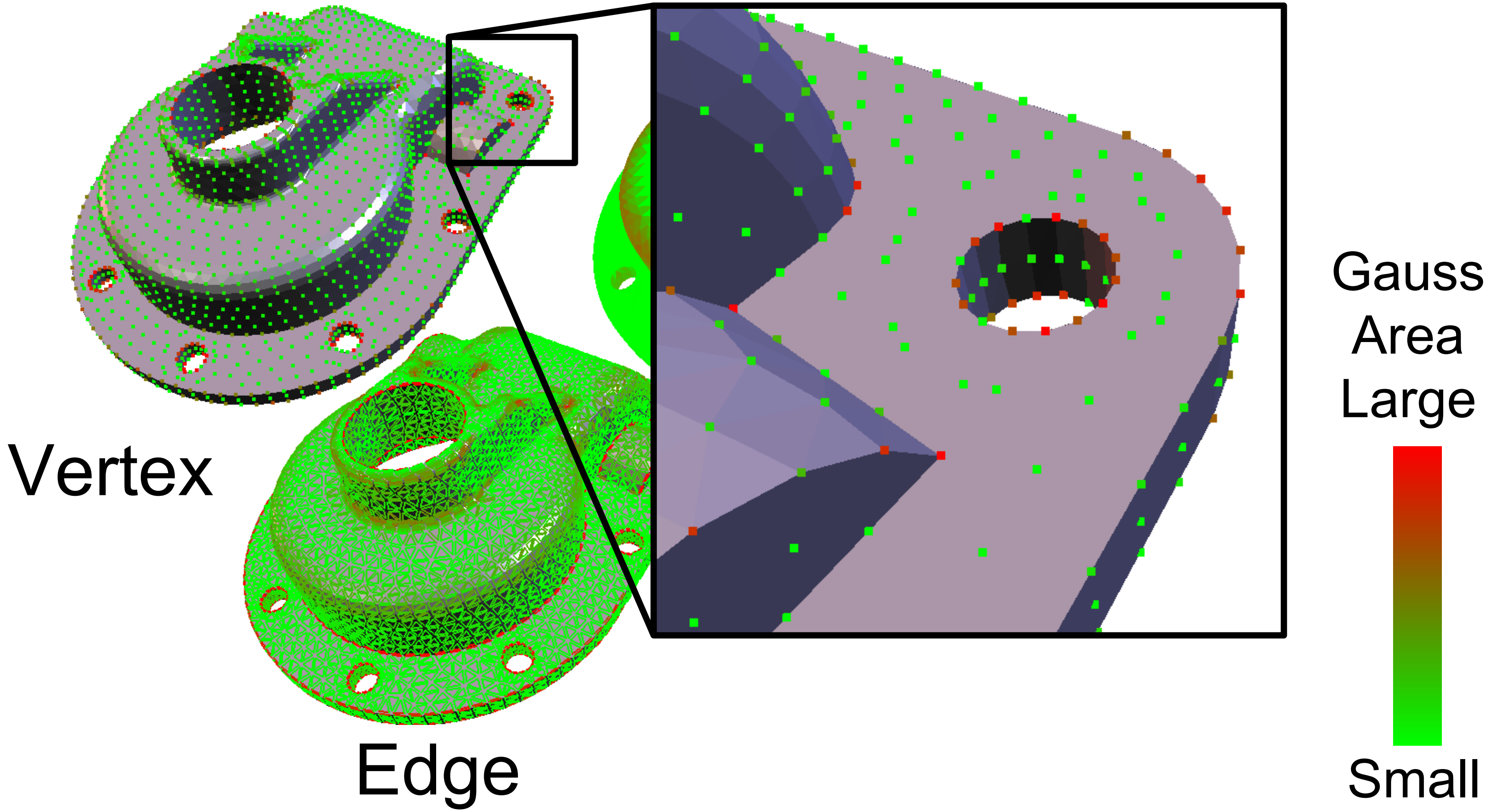

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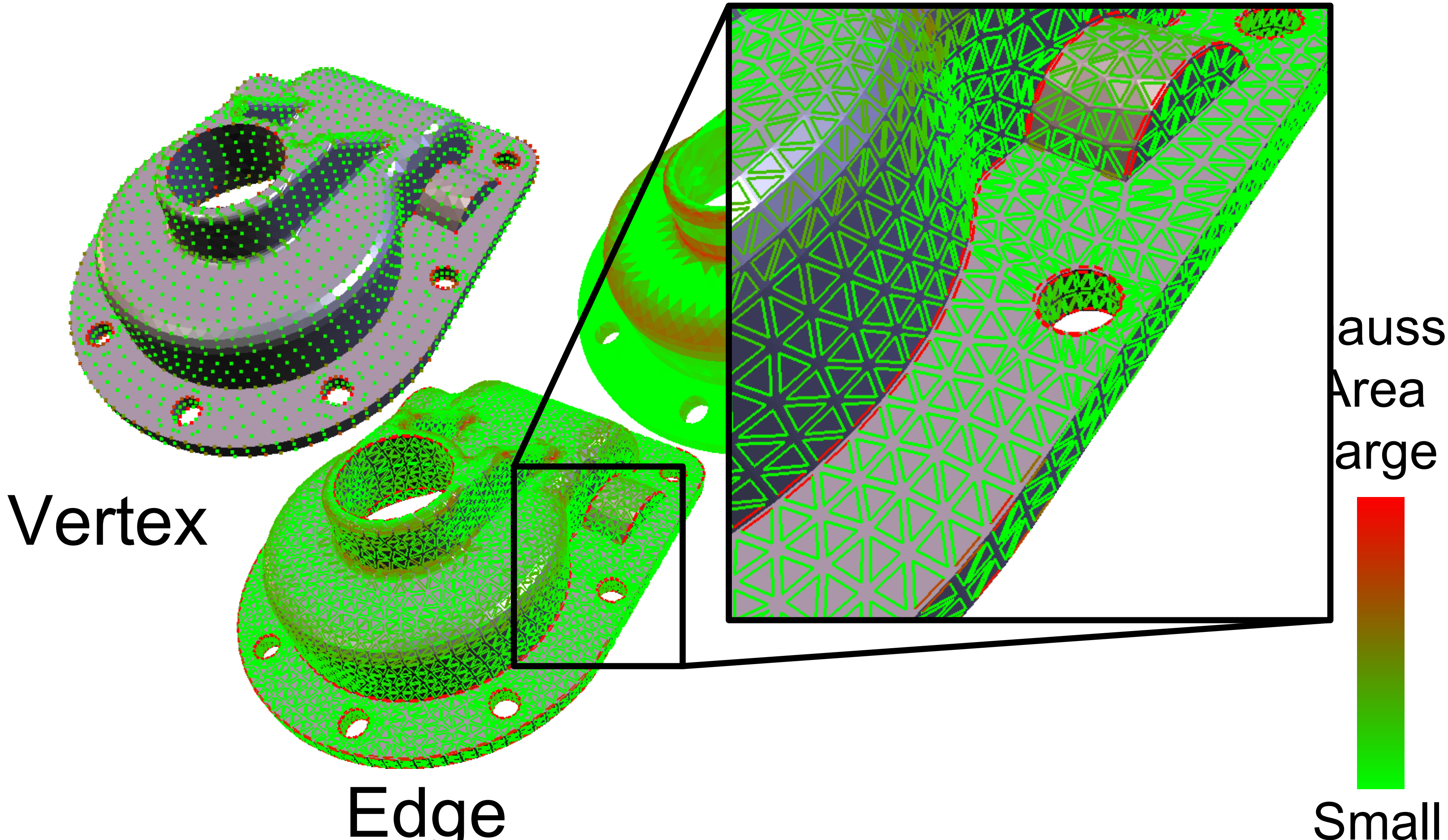

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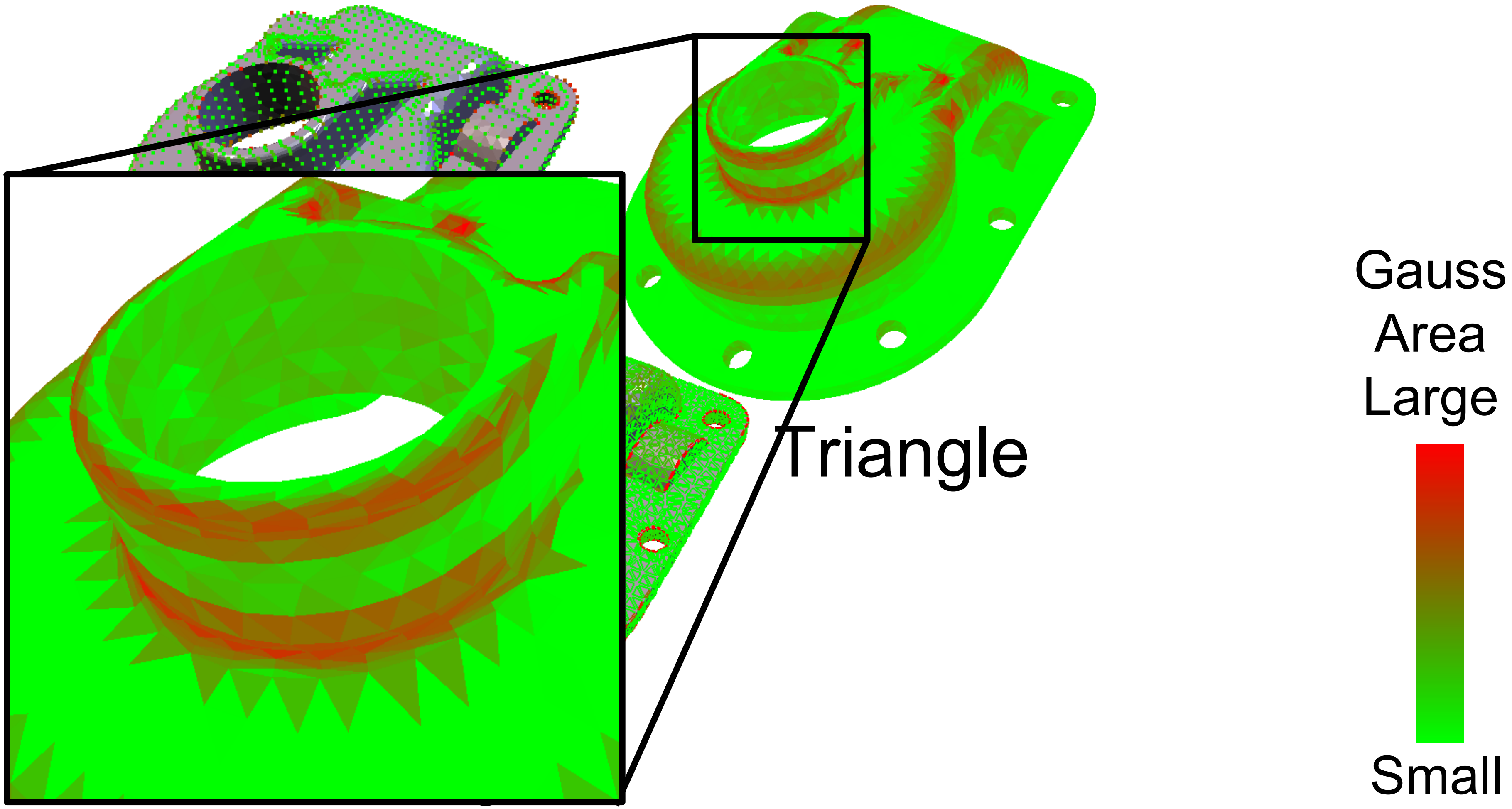
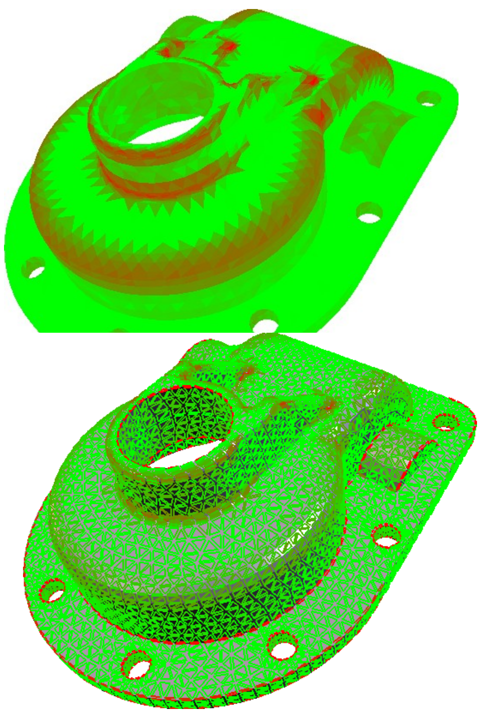
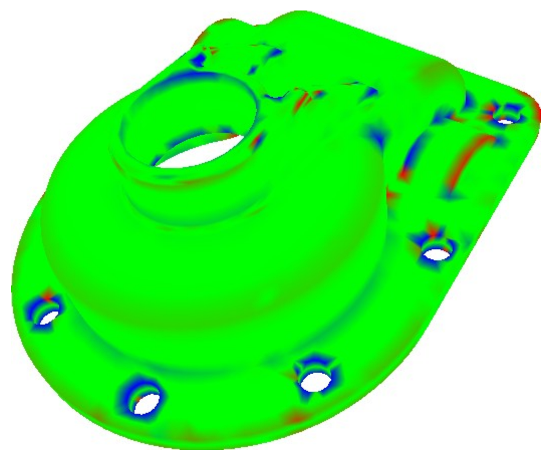


Gauss area & Gaussian Curvature

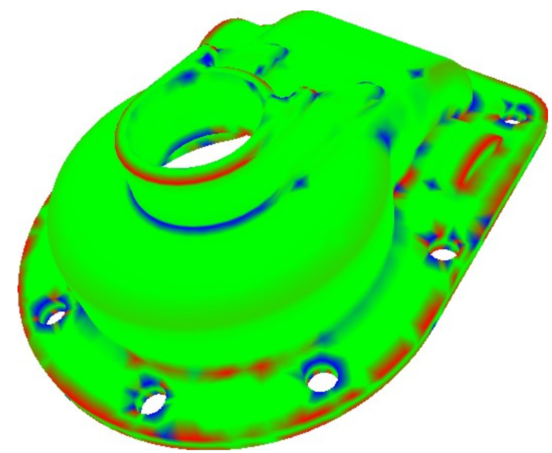
- Gauss area can capture the Gaussian curvature properties



Gauss area (Tri., Edge)



Welch et al. 94

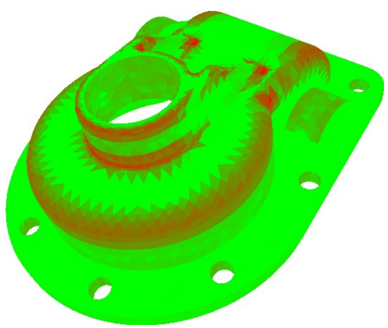


Goldfeather et al. 04 (Quadric)

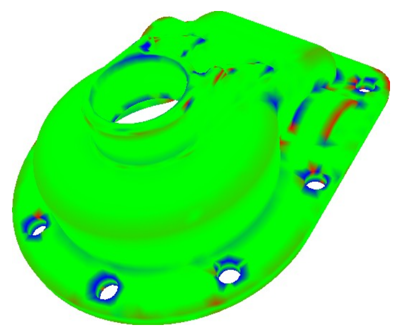
Gauss area & Gaussian Curvature

– The distribution of the Gauss area values is compact and yields a stable integration for our segmentation purpose.

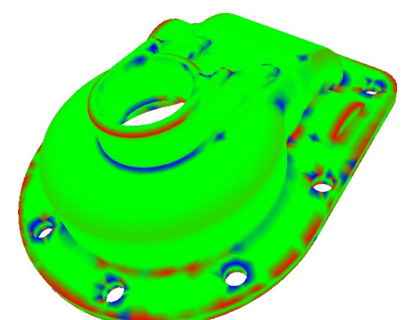
	Range	σ
Garea vtx, edge, triangle	[0, 1.42], [0, 0.46], [0, 0.11]	0.064, 0.052, 0.0094
Welch 94	[-6.7x10^3, 5.7x10^3]	5.67x10^2
Goldfeather 04	[-2.9x10^6, 6.6x10^3]	4.1x10^4



Gauss area (Tri.)



Welch et al. 94



Goldfeather et al.04 Quadric

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t-flooding algorithm

- Time parameterized flooding
  - Estimate Gauss area of each chart at time *t*
- Distributes Gauss area on patches
  - Equalize Σ (Gauss area of chart i) among charts
  - Based on Lloyd Max iterative growing algorithm
  - Control over the patch growing speed
  - Multiple priority queue implementation
  - Offset computation

Control over the patch growing speed

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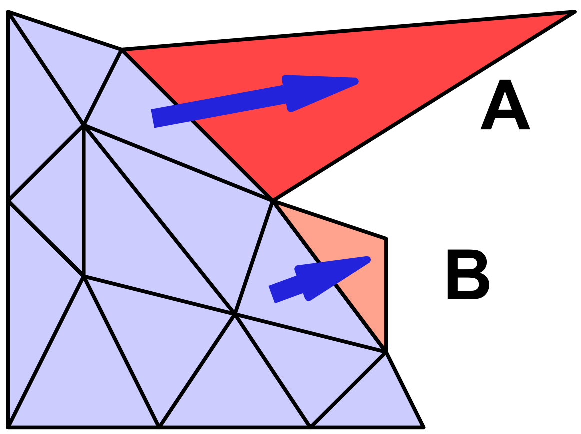
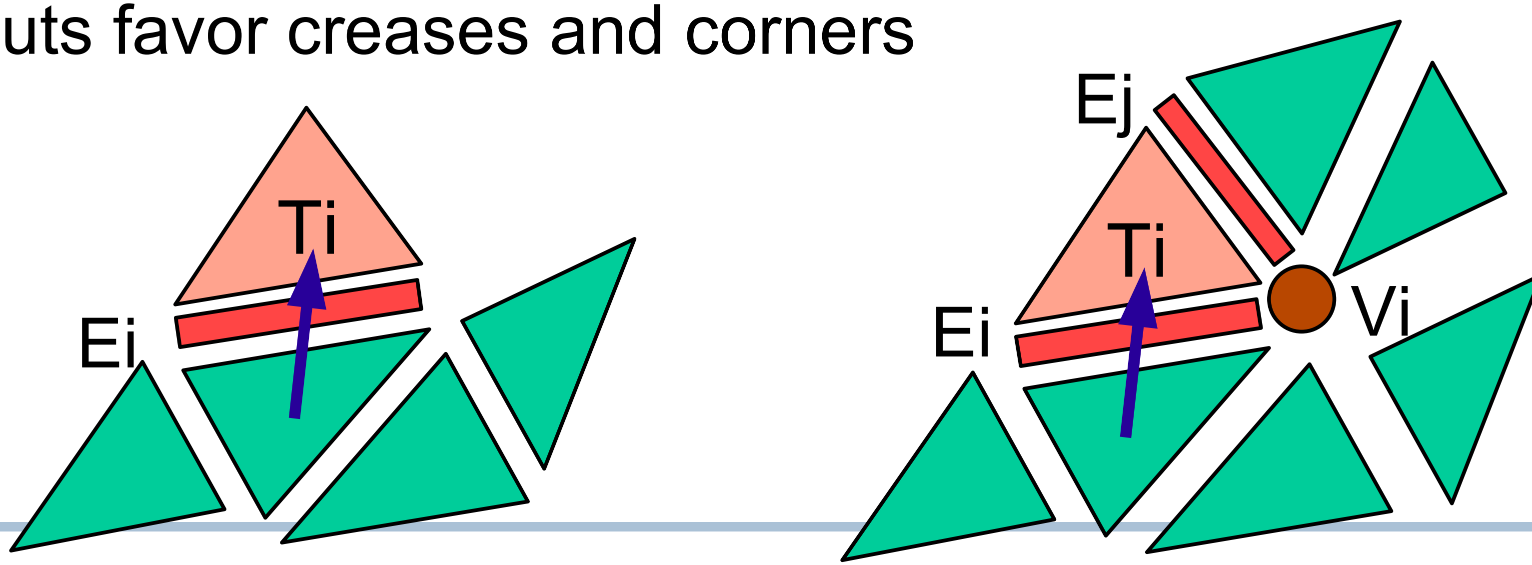
- Gauss area doesn't consider the 3D triangle shape
- At time *t*, all patch should have
  - similar 3D areas
  - similar Gauss areas



- Candidate triangles (A & B) have the same Gauss areas but different shapes
- ⇒ Consider their 3D areas

Grow a triangle

- No edge/vertex closing
  - Garea(Ti) + Garea(Ei)
- With edge/vertex closing
  - Garea(Ti) + Garea(Ei) + Garea(Ej) + Garea(Vi)
- Vi has Gauss area, closing tends to be avoided
  - Cuts favor creases and corners



Grow a triangle

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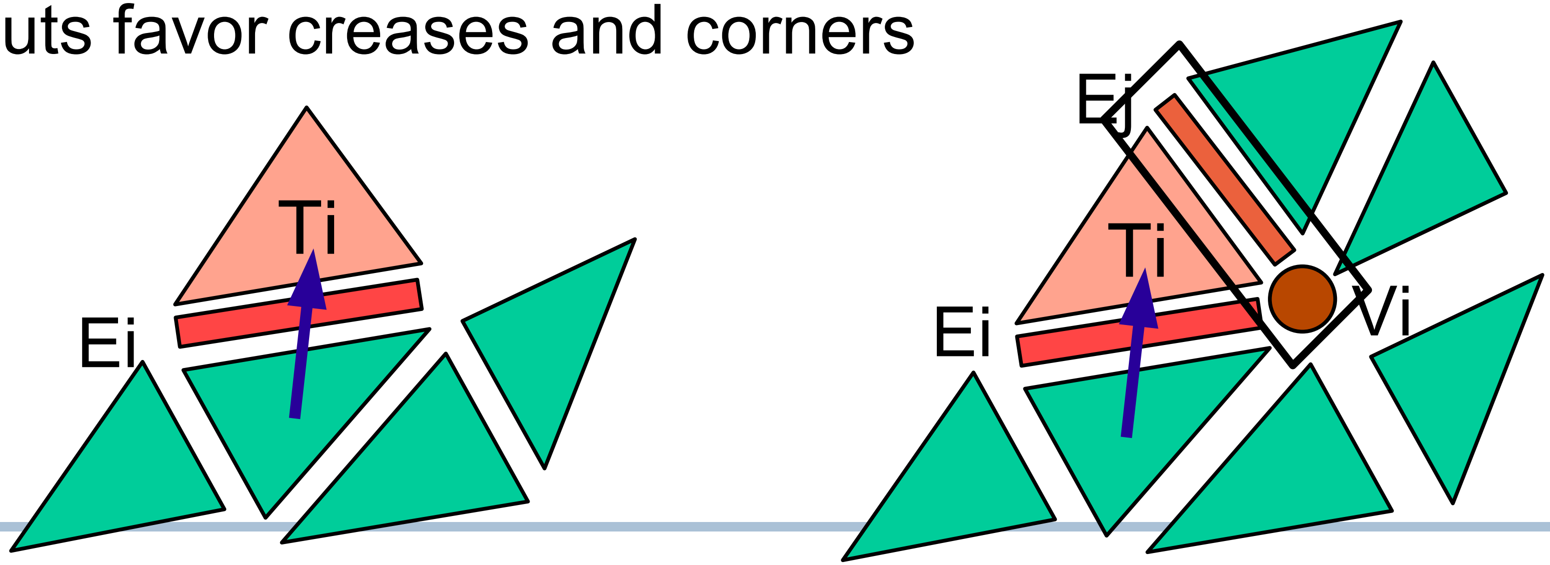
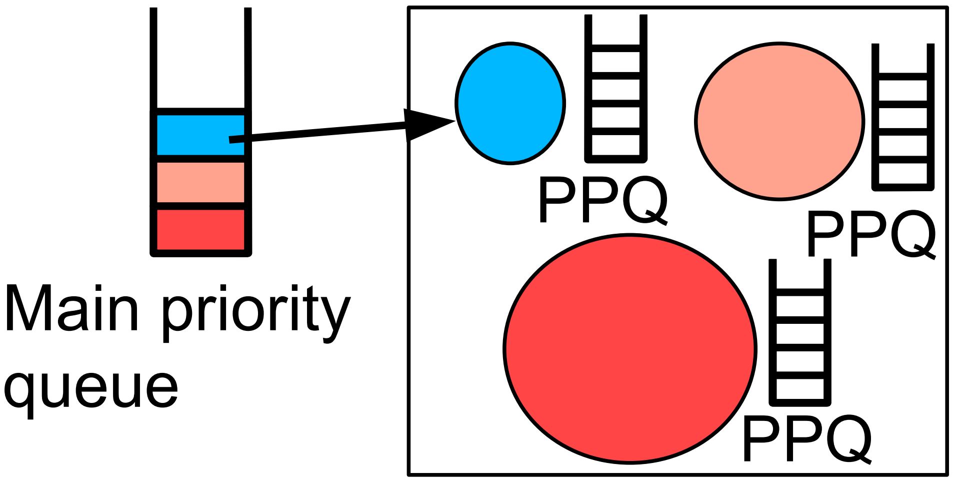


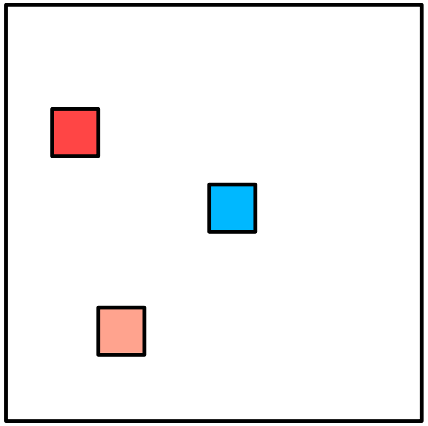
Multiple priority queue implementation

- Use a Main priority queue and Patch priority queues
  - Main priority queue determines which chart grows next according to Σ (Gauss area in chart i)
  - Patch priority queue (PPQ) determines which triangle will be added to the chart



Offset computation

- Early blocking problem
  - Computation of patch center has difficulty in a low Gauss area part
  - $\Rightarrow$ Misleads Lloyd Max algorithm



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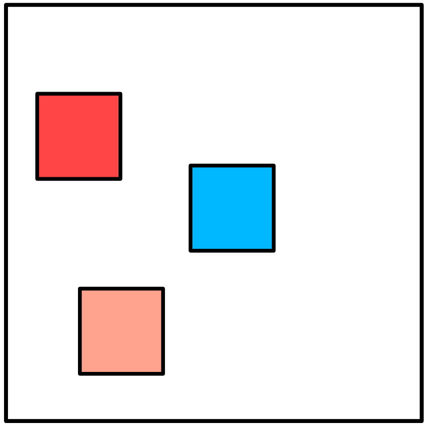

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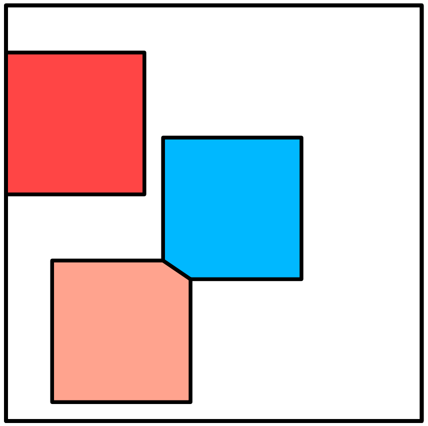

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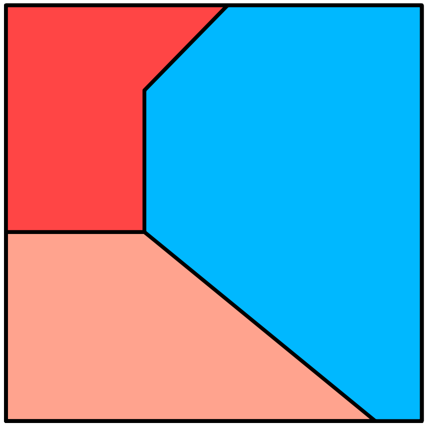
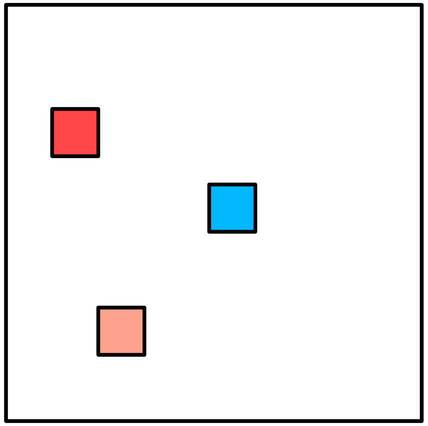
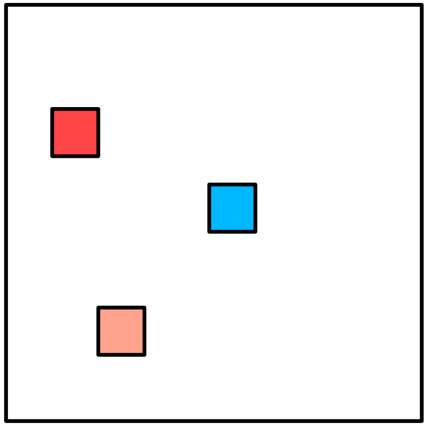


Offset computation

- Early blocking problem
- Patches growing too fast are punished during the iterative process with a time offset
- The use of damping factor leads convergence



Without time offset



With time Offset

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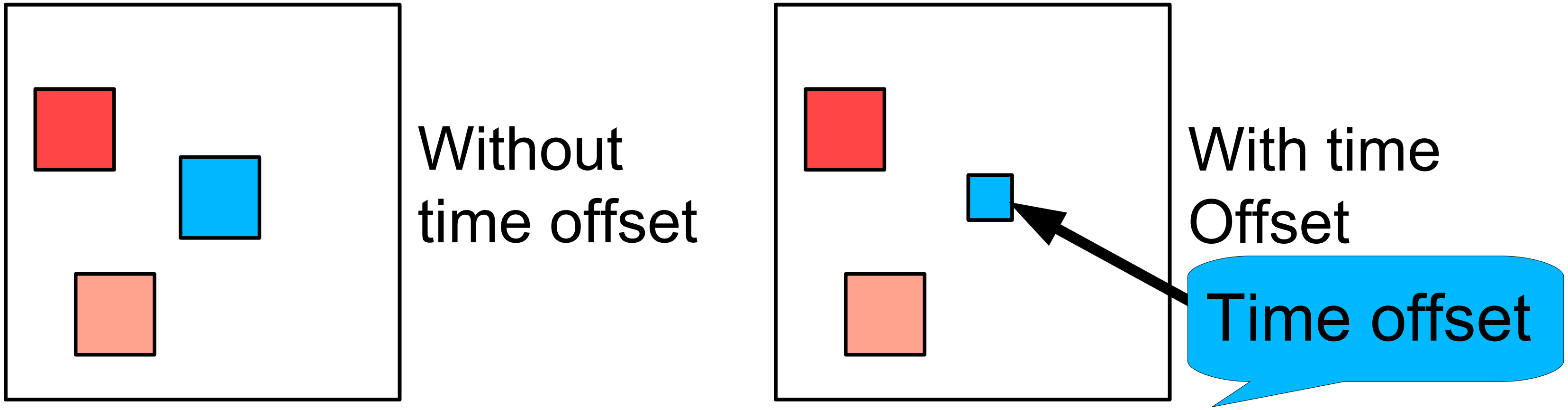

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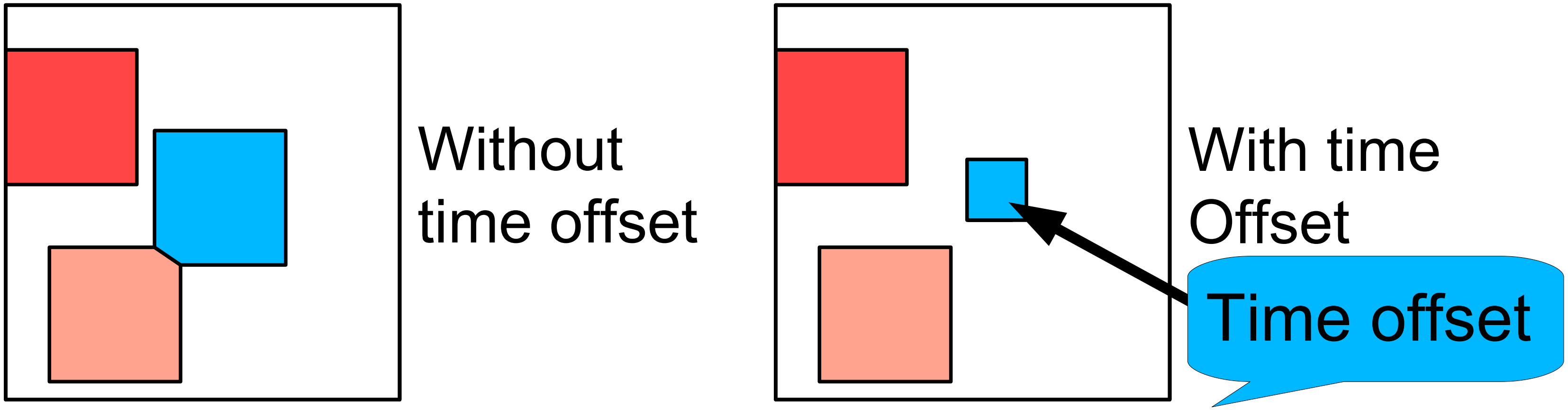

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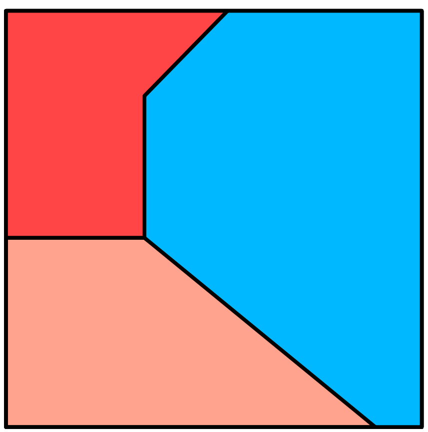

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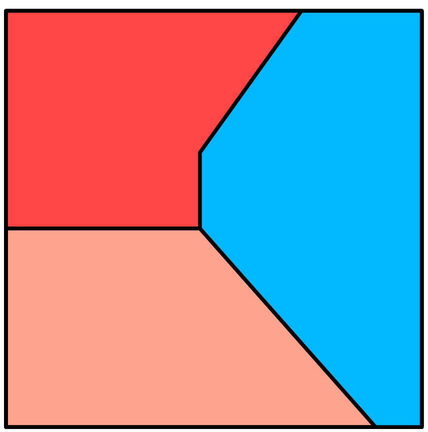

With time Offset
Better balance

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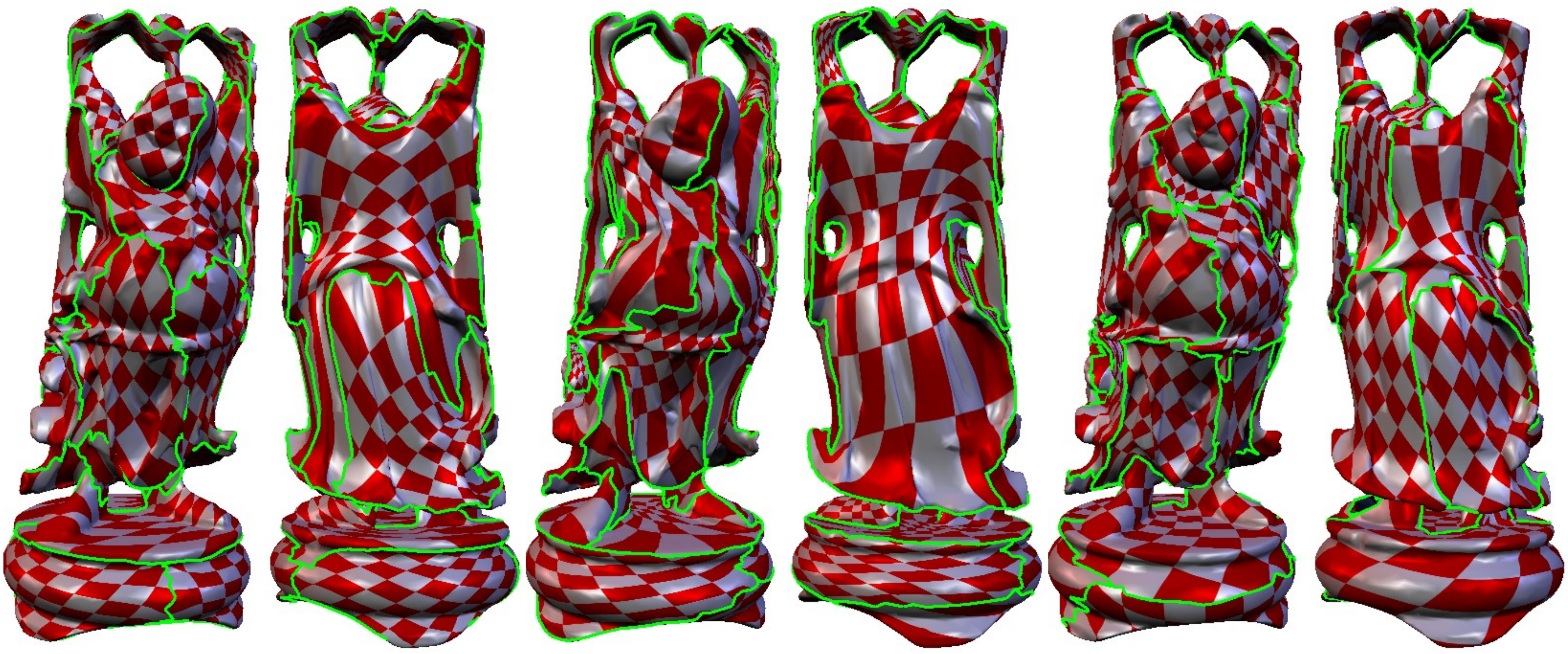
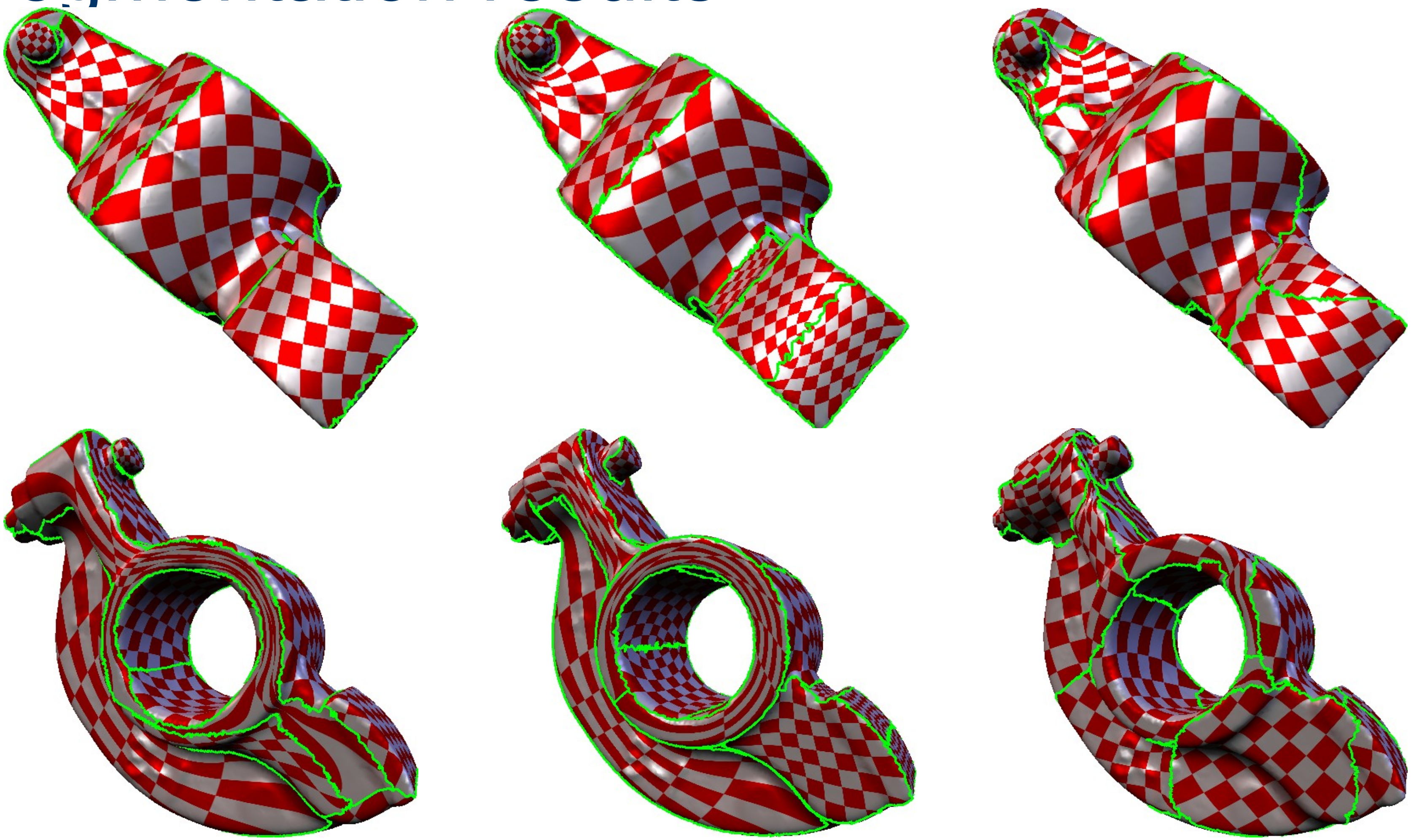
Segmentation results



[MCGIM] [VSA] [t-flooding]

Segmentation results



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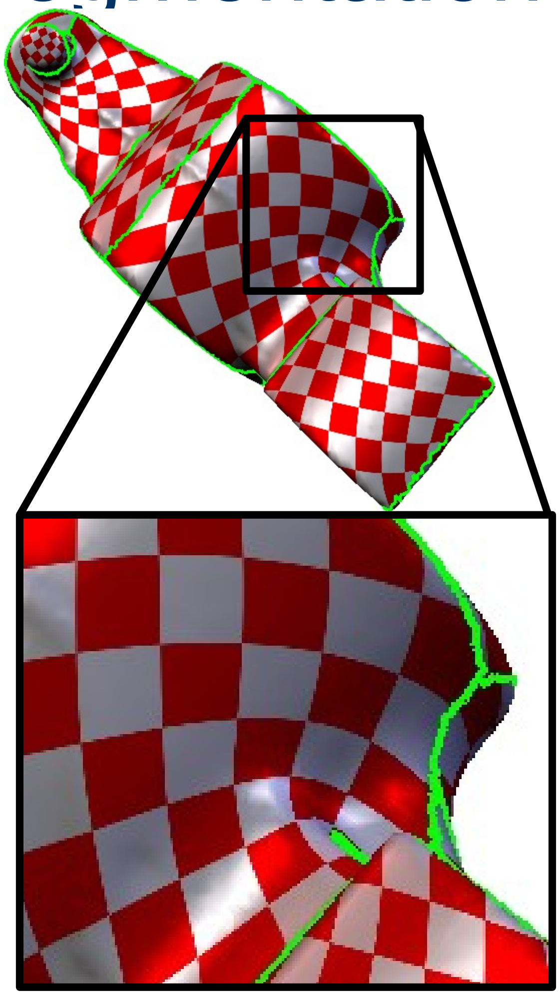
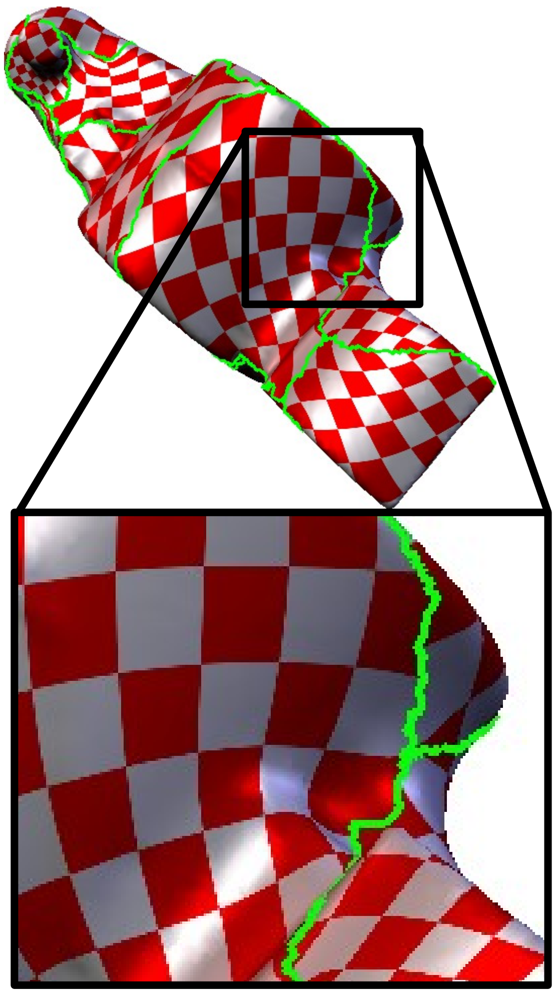


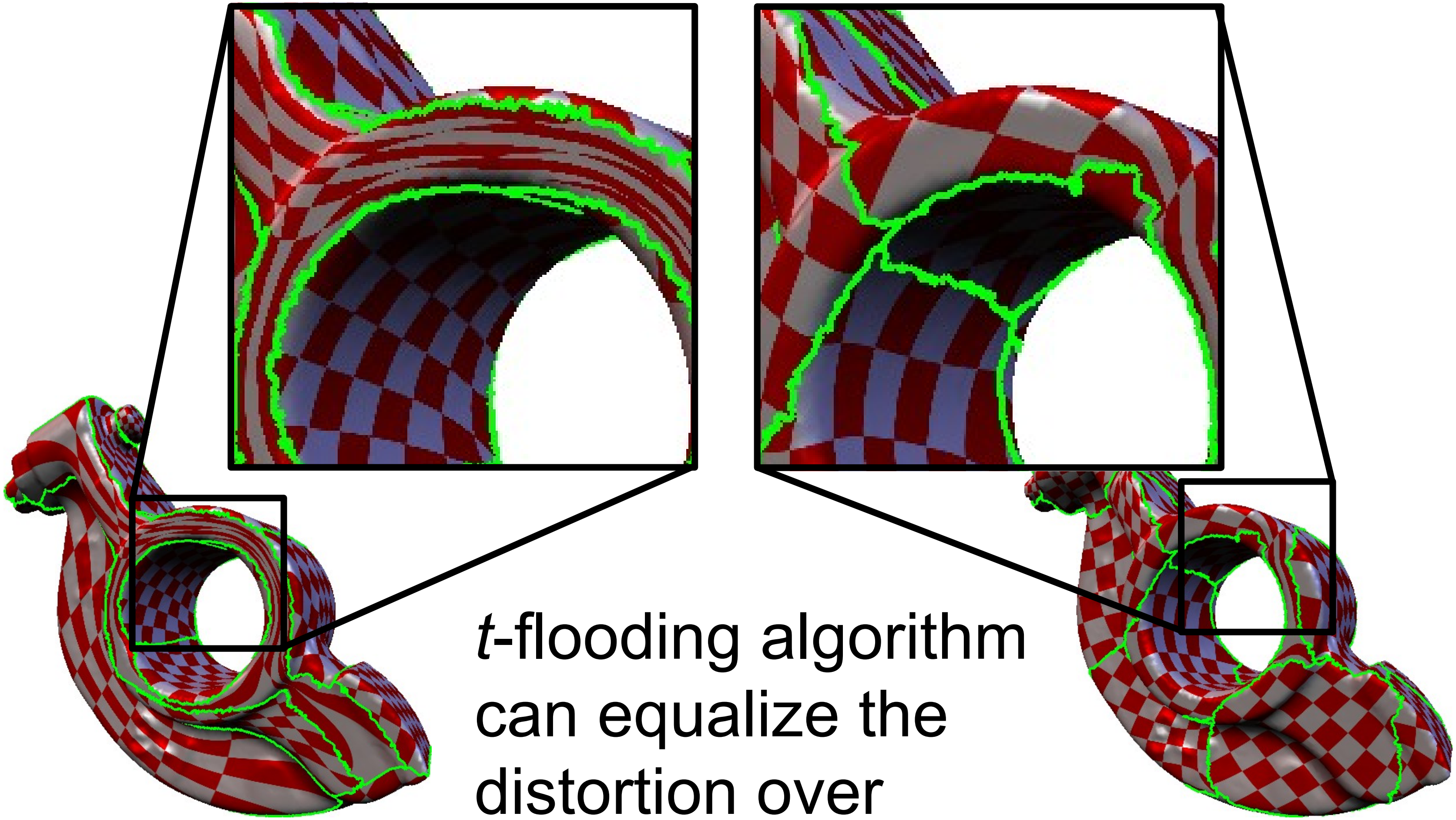
[MCGIM]

Both methods have similar low distortion in these parts



[t-flooding]

Segmentation results

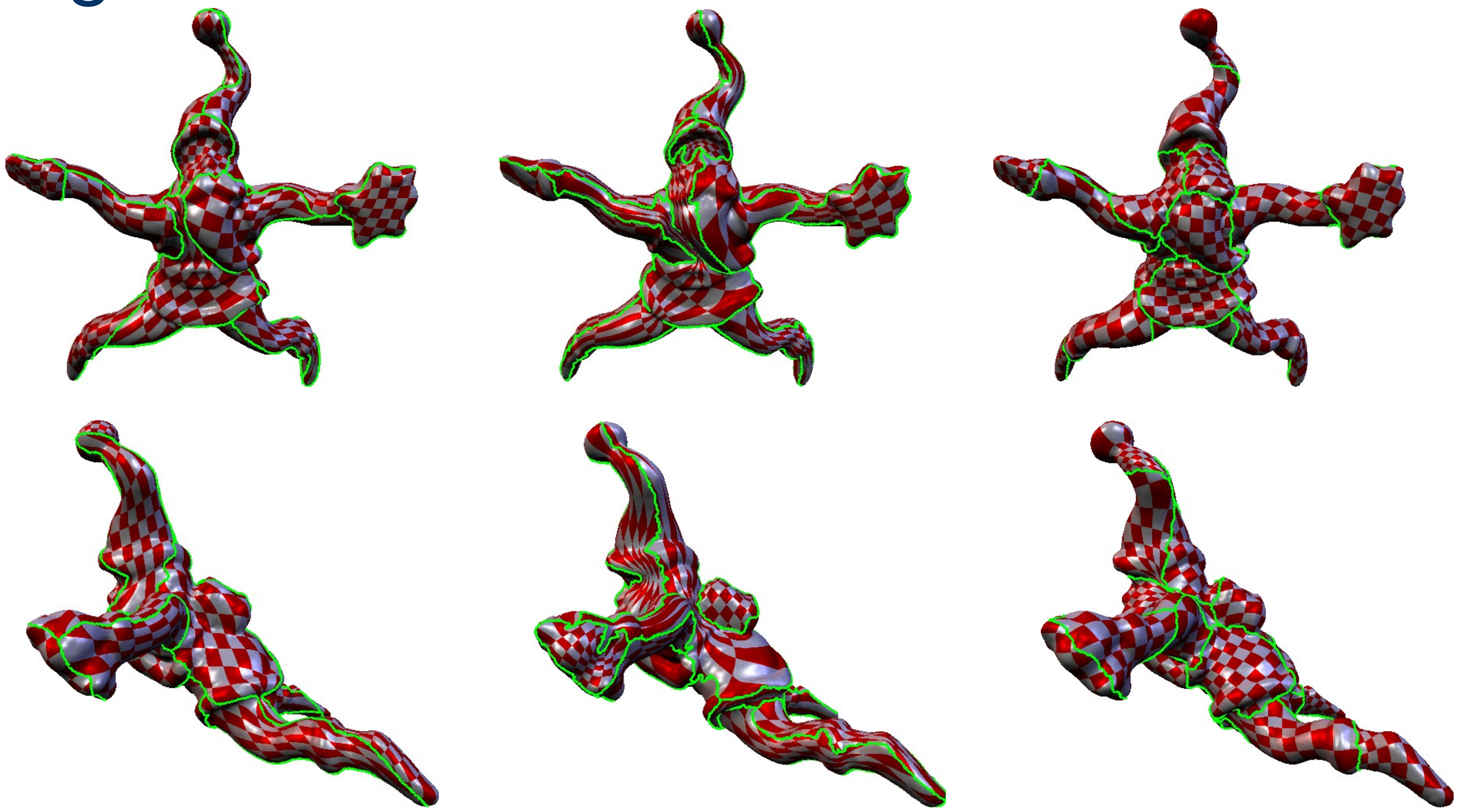


[MCGIM]

t-flooding algorithm can equalize the distortion over patches

[t-flooding]

Segmentation results

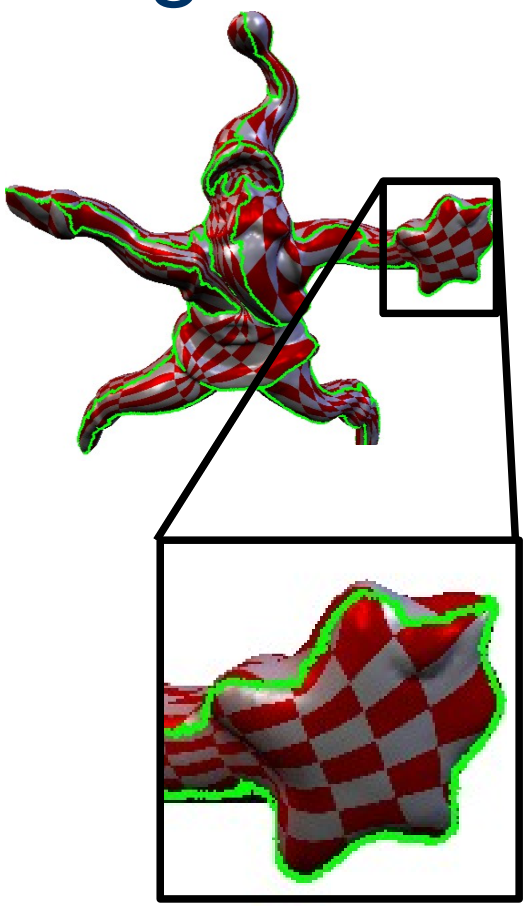


[MCGIM] [VSA] [t-flooding]

Segmentation results

[VSA] [t-flooding]

Segmentation results



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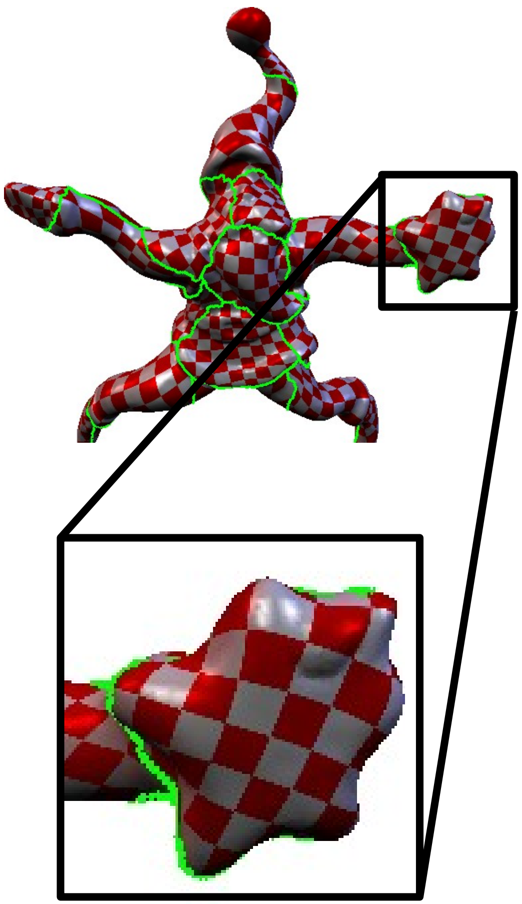
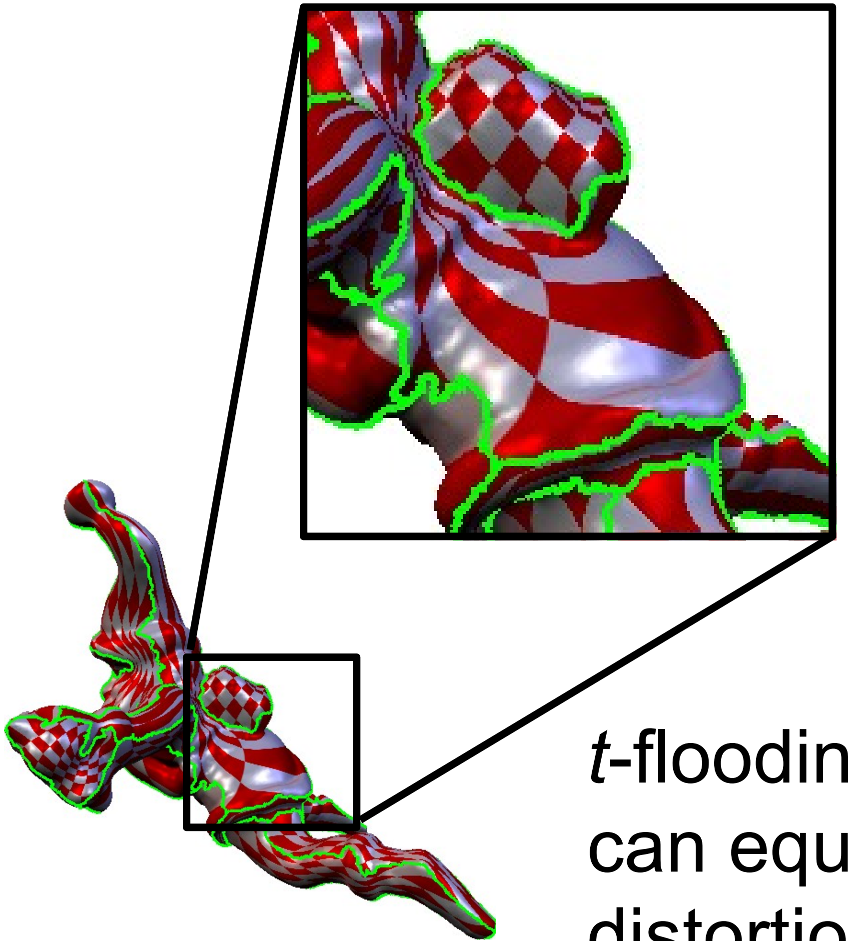
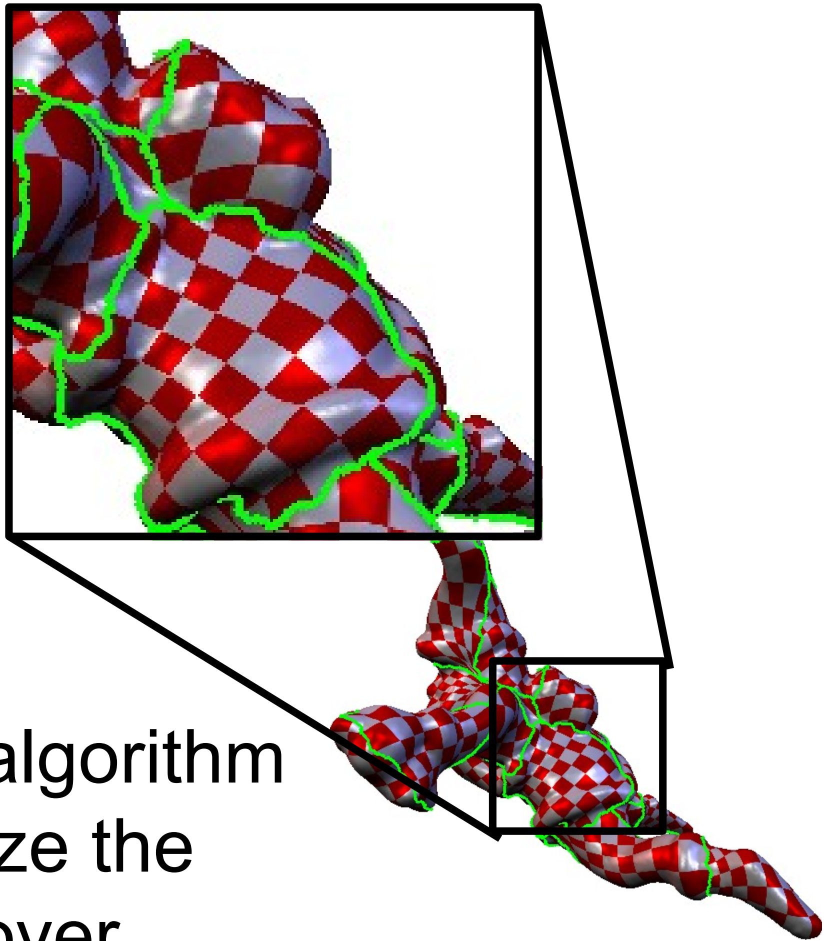


[t-flooding]

Segmentation results





t-flooding algorithm can equalize the distortion over patches

[VSA]

[t-flooding]

Conclusion & Future work

- Conclusion
  - Segmentation driven by a variant of Gaussian curvature
  - Balanced Gauss area distribution among charts
  - Control of patch grow speed thanks to the new t-flooding algorithm
- Future work
  - Improve thresholding for multiple normals
  - Apply *t*-flooding algorithm to other segmentation methods

Thank you.

Questions?

Result

- Parameterization distortion

model	Happy	Rocket	Santa
MCGIM	8.1(7.8)	29.1(39.3)	22.9(11.6)
VSA	12.4(12.6)	28.2(21.5)	60.1(47.1)
t-flooding	7.3(4.7)	17.9(7.3)	17.2(8.6)
# of triangles	19976	80354	151558
Elapsed time	20.6	91.5	363

  - Average (standard deviation) of L^2 geometric distortion
  - Geometric stretch(on a Pentium IV 1.7GHz Linux machine)

Result

- Standard deviation of Gauss area distribution

model	Happy	Rocket	Santa
MCGIM	64.3	11.0	14.3
VSA	69.0	17.3	18.9
t-flooding	25.6	4.55	2.48

Topology constraints

- Too keep disk like topology
  - *t*-flooding doesn't guarantee to keep each patch topology
- Two auxiliary tools
  - HandleCutter
    - Cut a high genus part to cylinders
  - LoopMargeCutter
    - Connect interior boundary loop with outside boundary