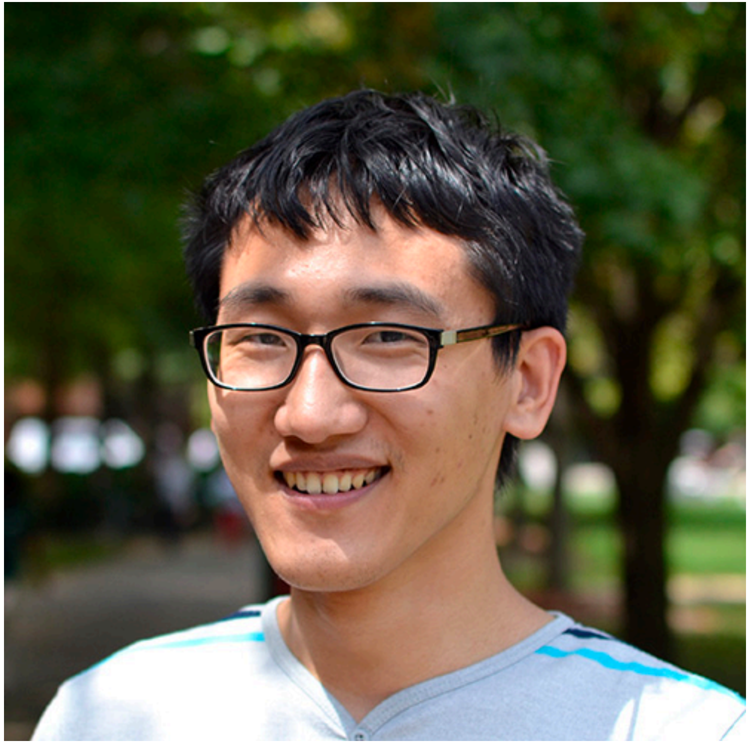
Seamless: Seam erasure and seam-aware decoupling of shape from mesh resolution

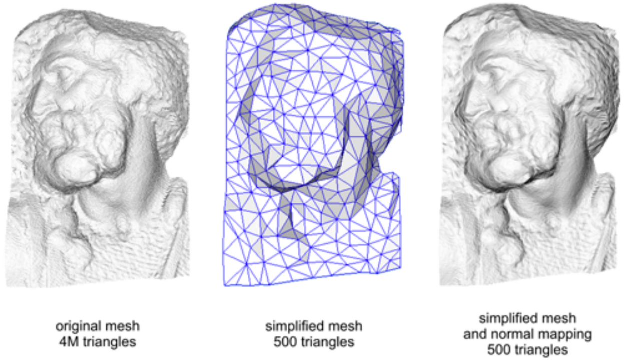
Songrun Liu*, George Mason University
Zachary Ferguson*, George Mason University
Alec Jacobson, University of Toronto
Yotam Gingold, George Mason University
(*Joint first authors)



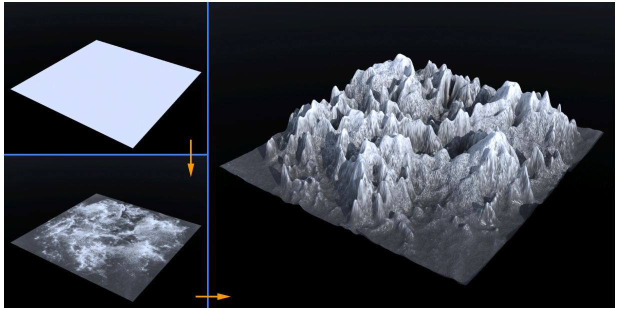
Songrun Liu

TEXTURES

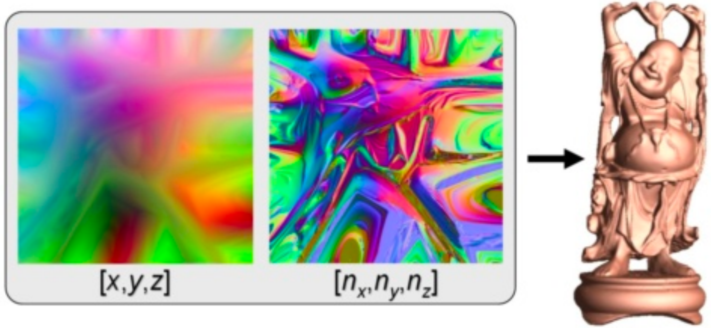
Color Map



Normal Map



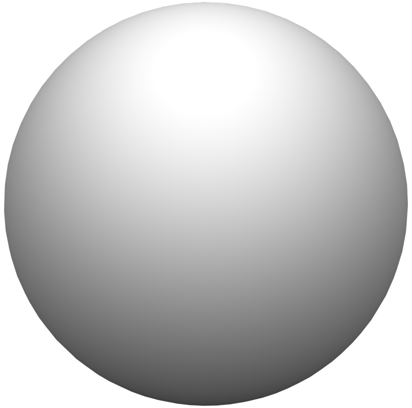
Displacement Map



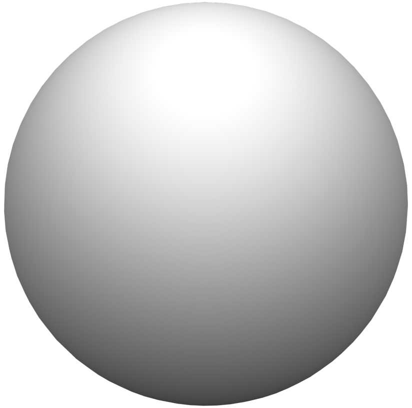
Geometry Images [Gu et al. 2002]

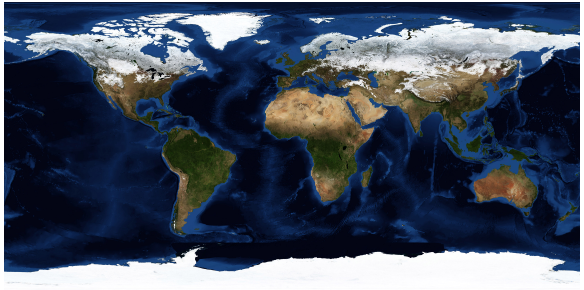
TEXTURE MAPPING

TEXTURE MAPPING

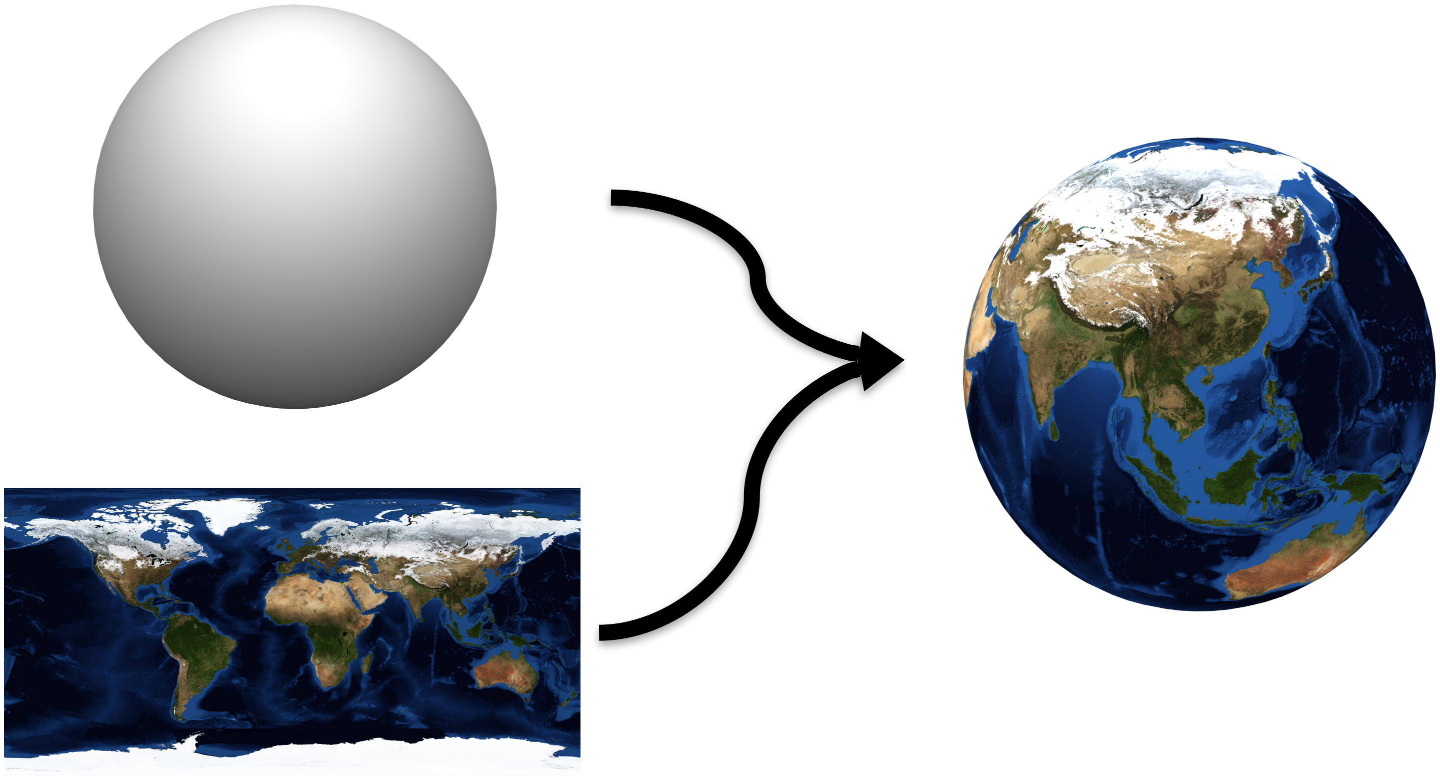


TEXTURE MAPPING

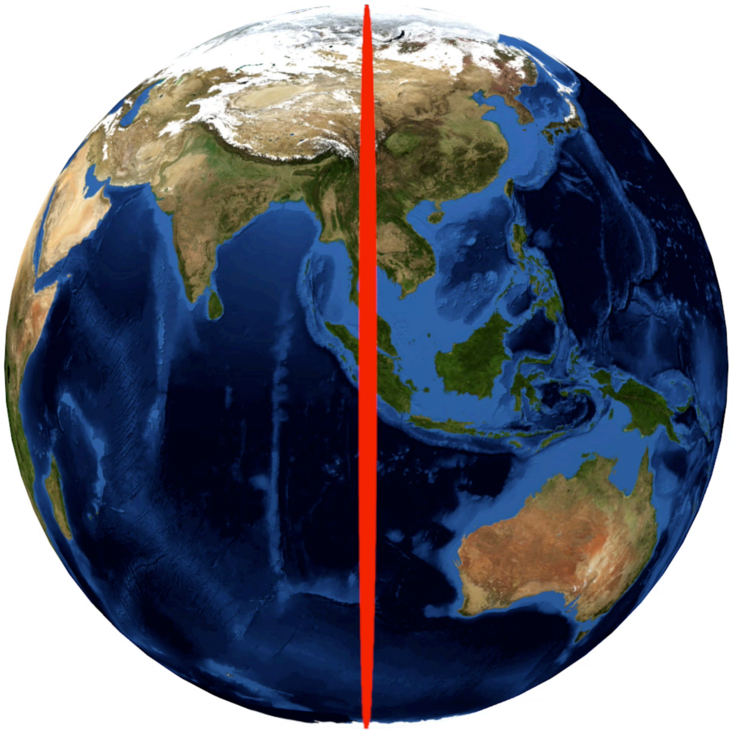




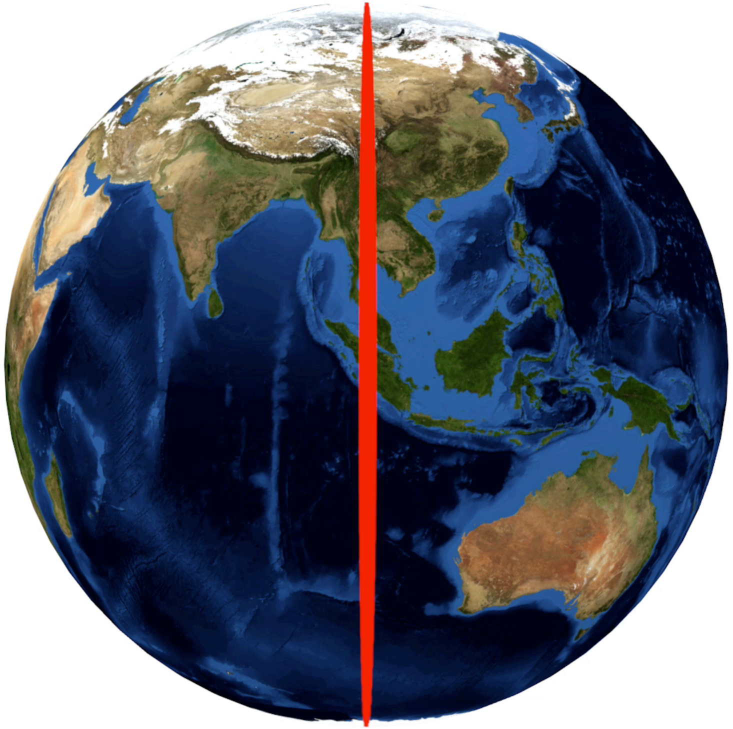
TEXTURE MAPPING



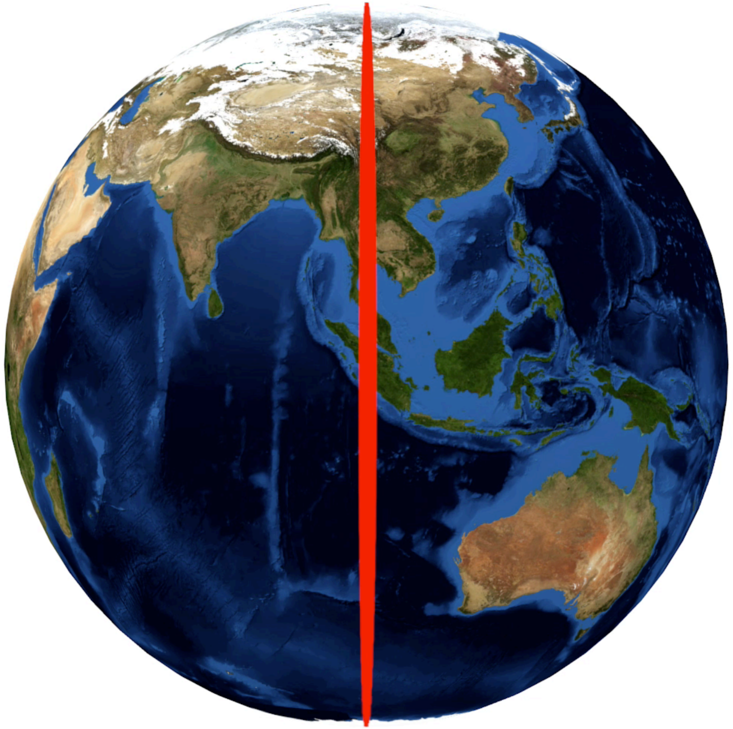
2D PARAMETERIZATION



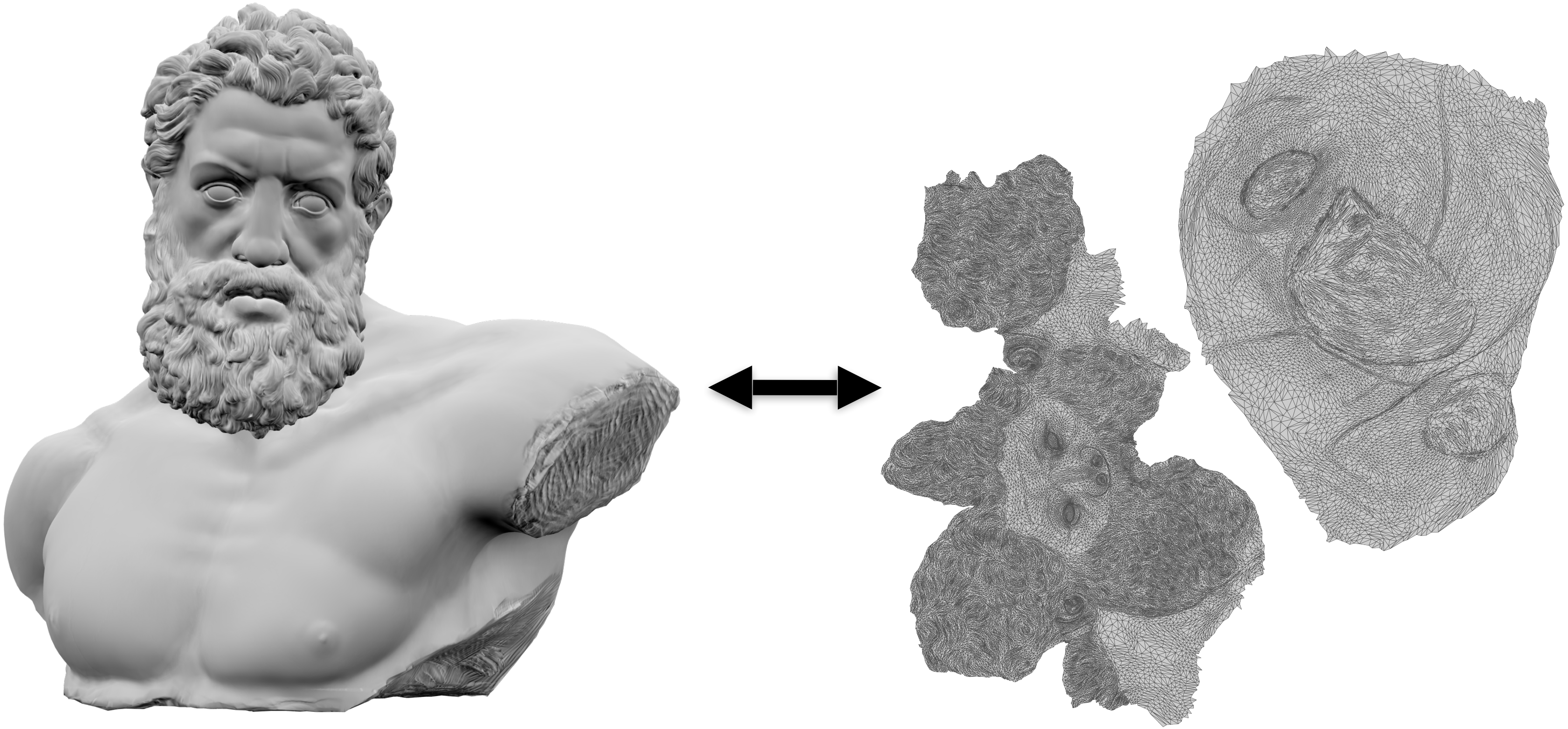
2D PARAMETERIZATION



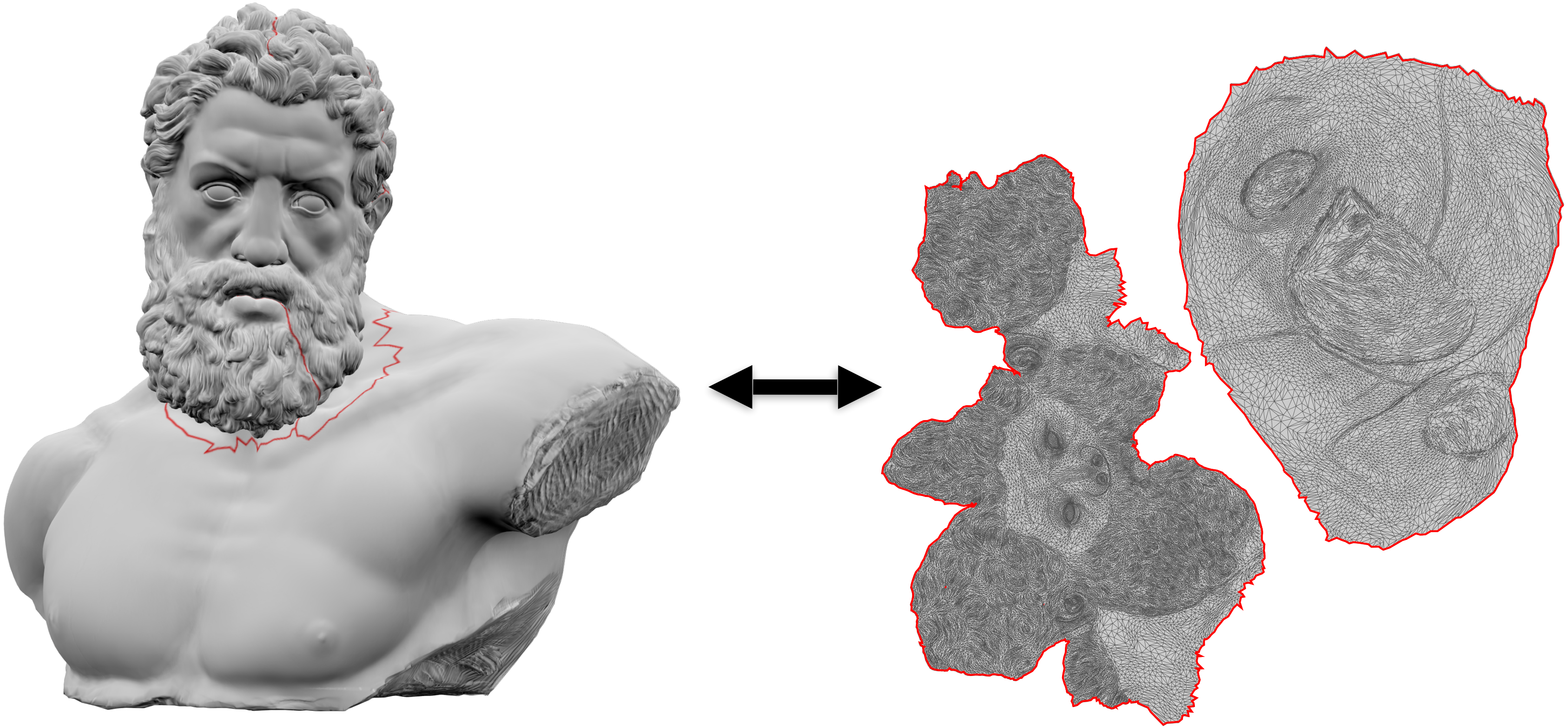
2D PARAMETERIZATION



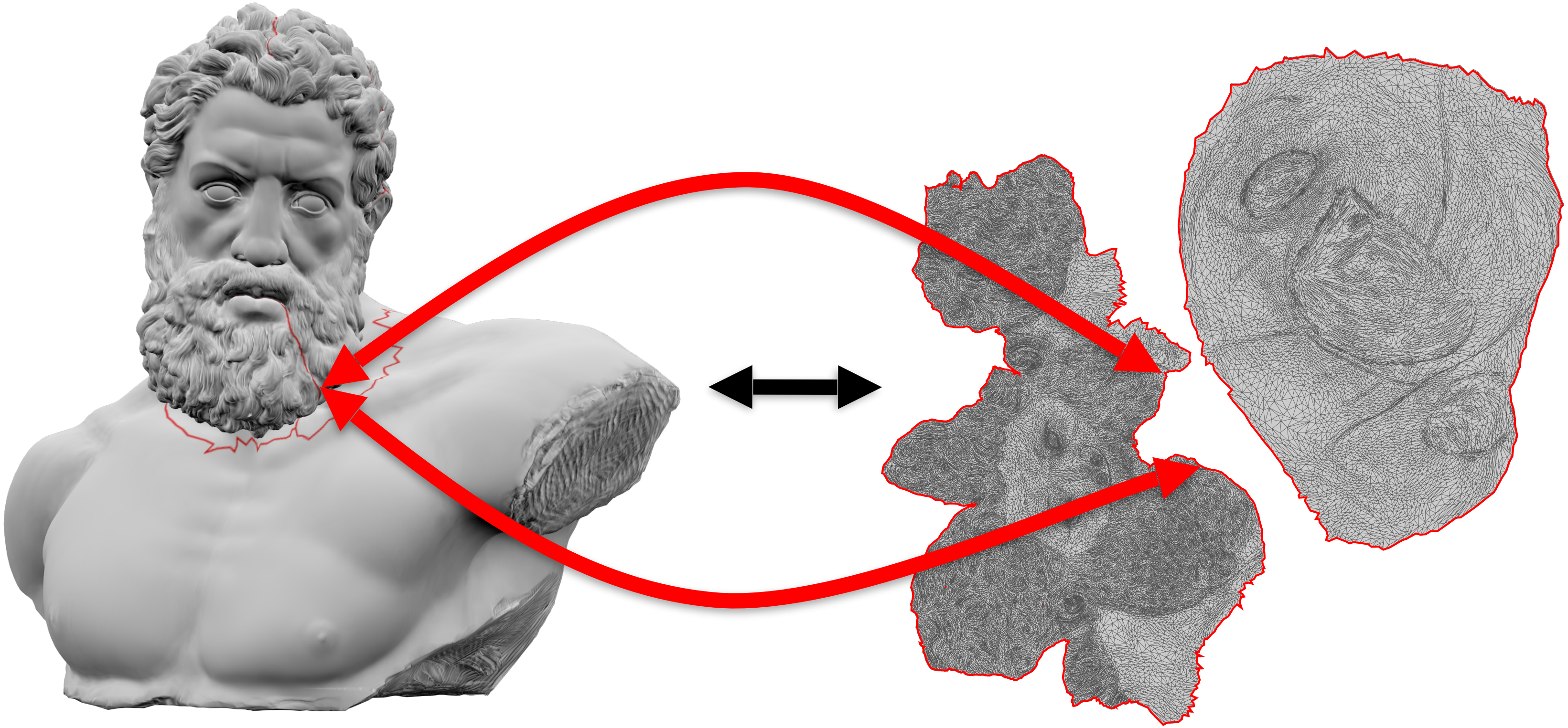
SEAMS



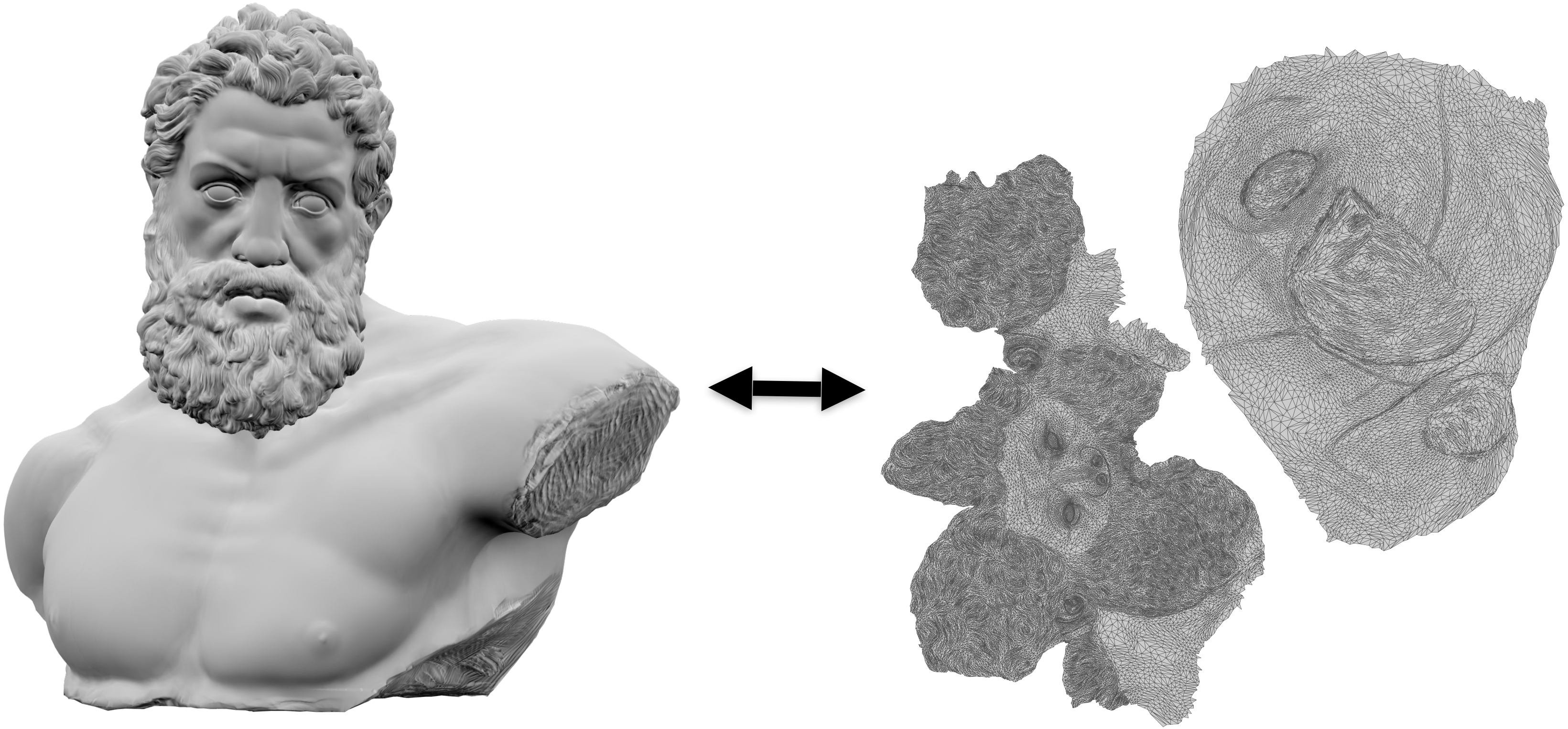
SEAMS



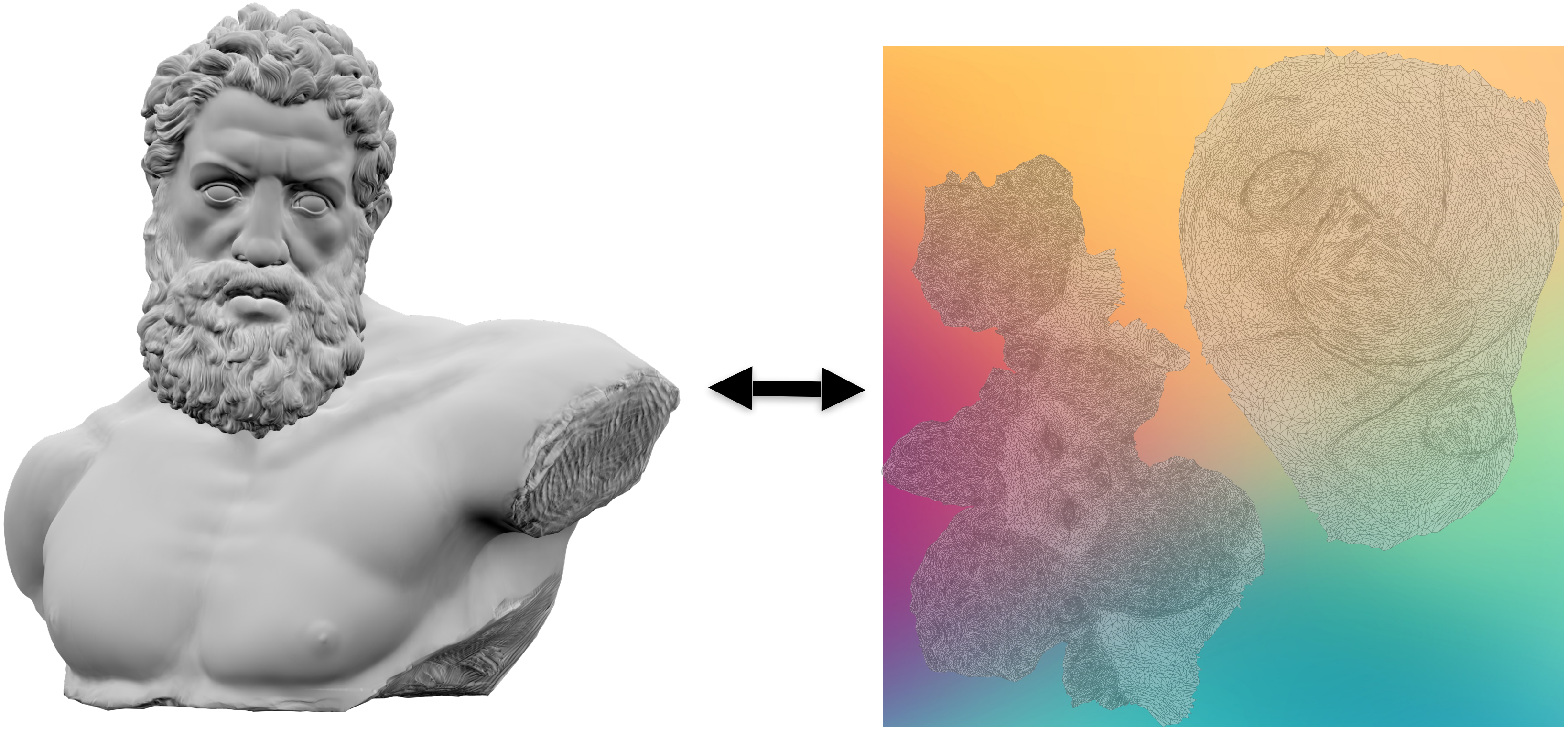
SEAMS



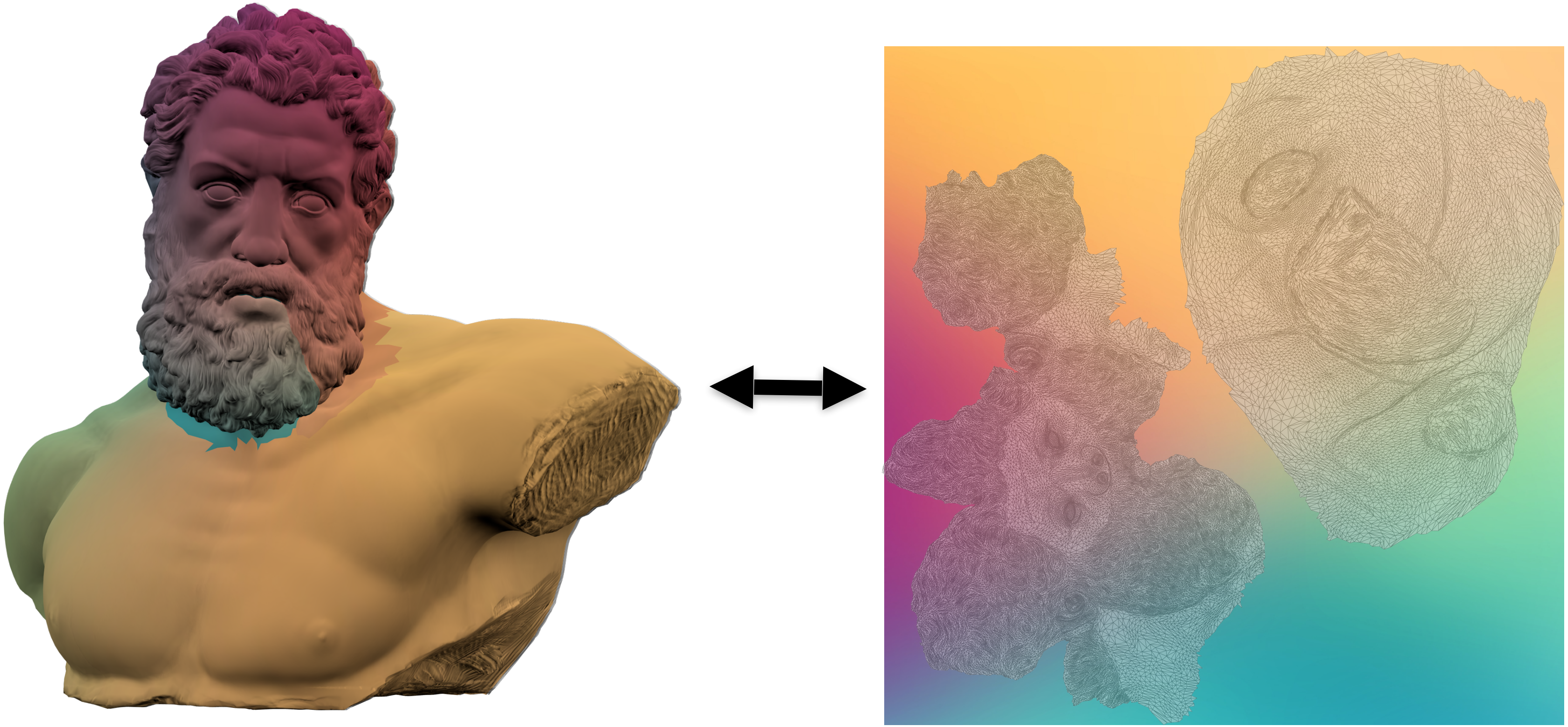
SEAM DISCONTINUITIES



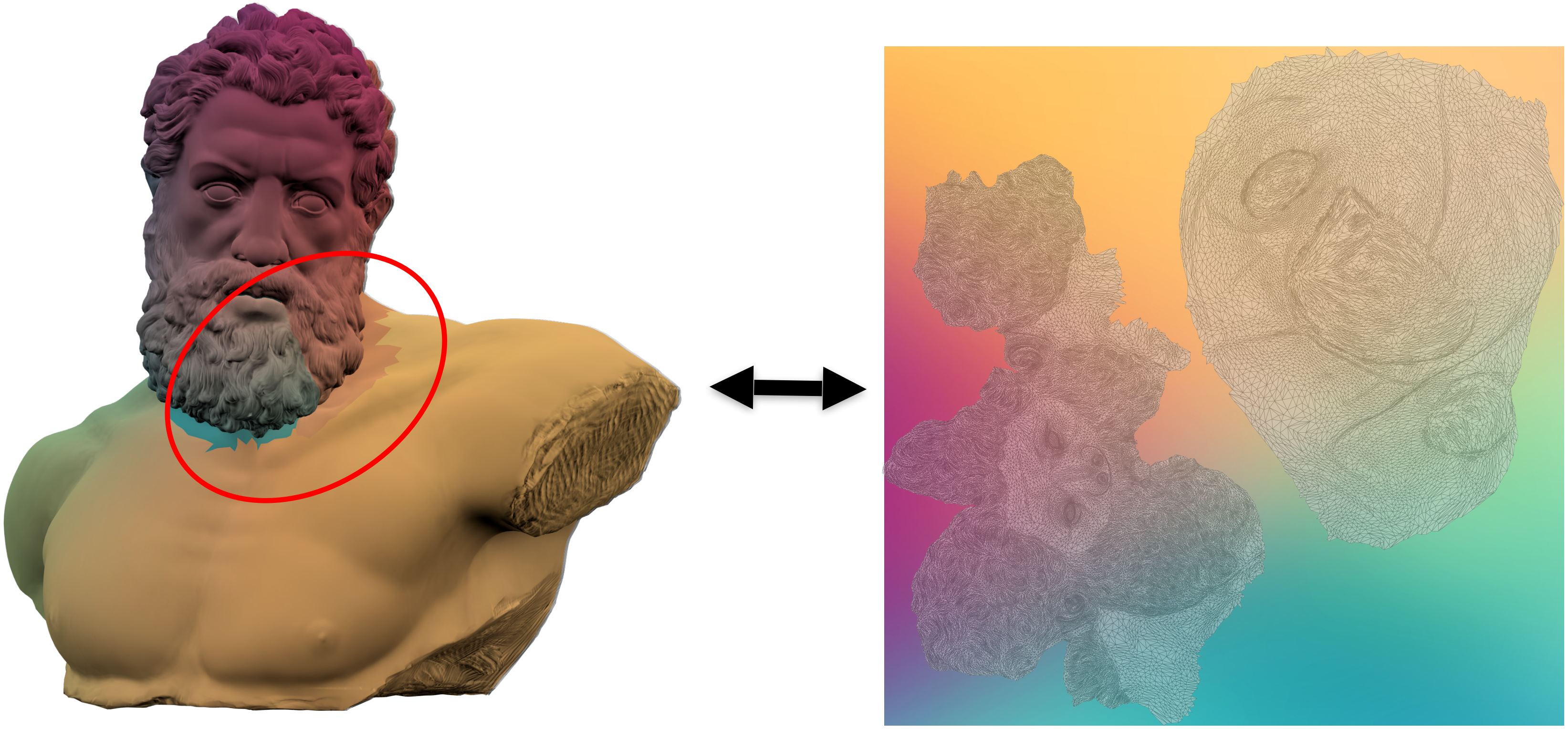
SEAM DISCONTINUITIES



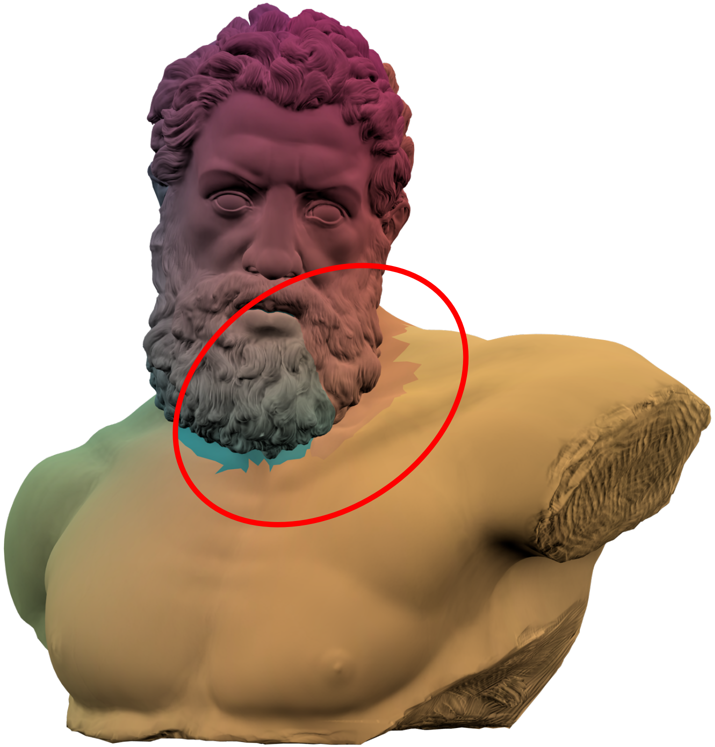
SEAM DISCONTINUITIES



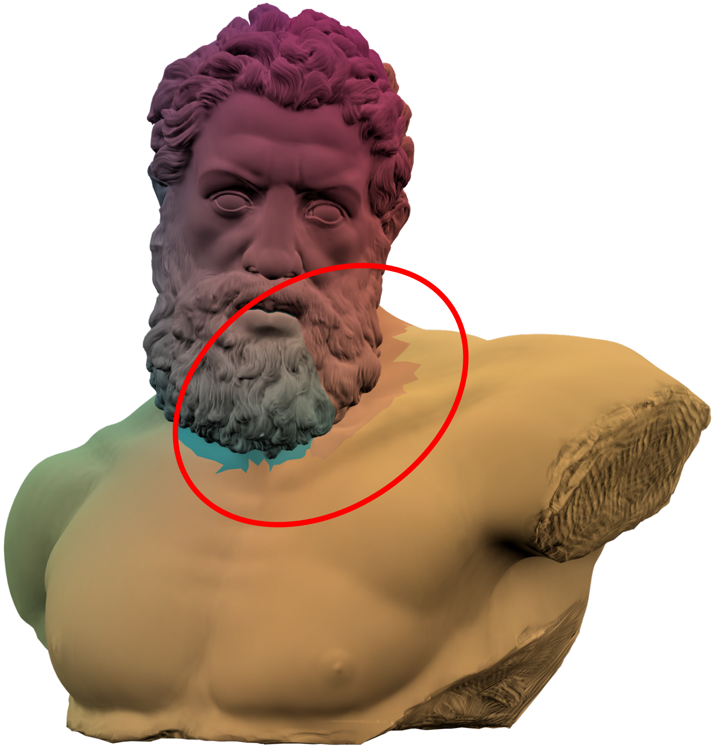
SEAM DISCONTINUITIES



SEAM DISCONTINUITIES



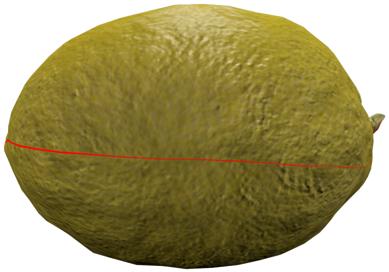
SEAM DISCONTINUITIES



DISCONTINUITIES IN GEOMETRY IMAGES

Before

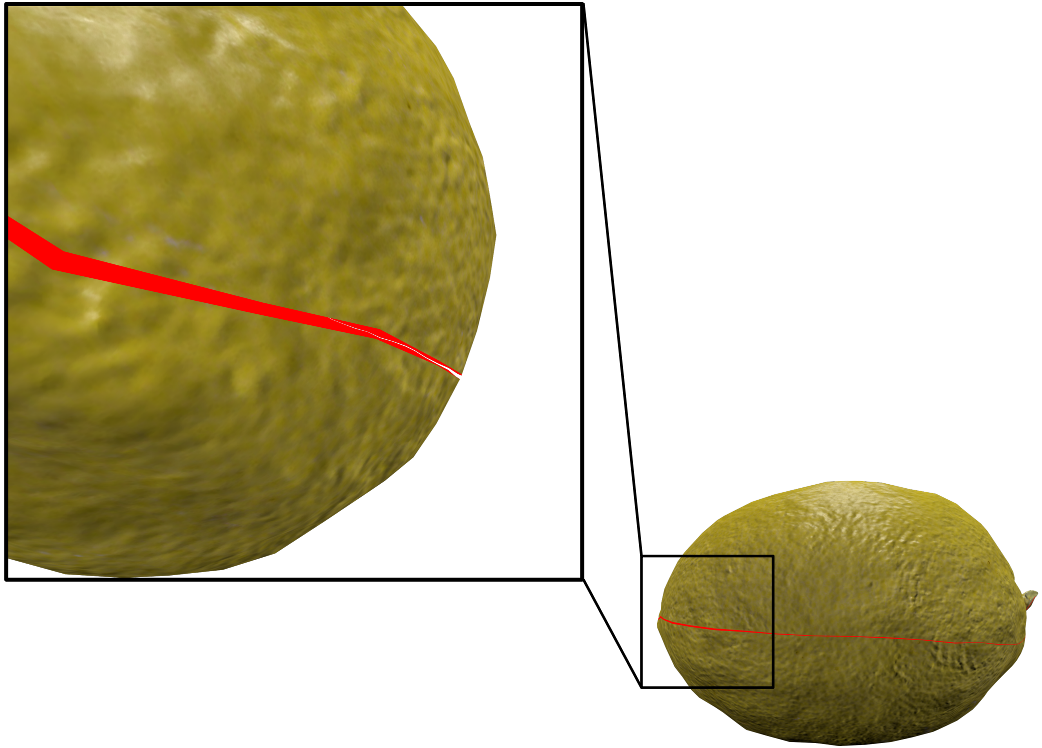
After



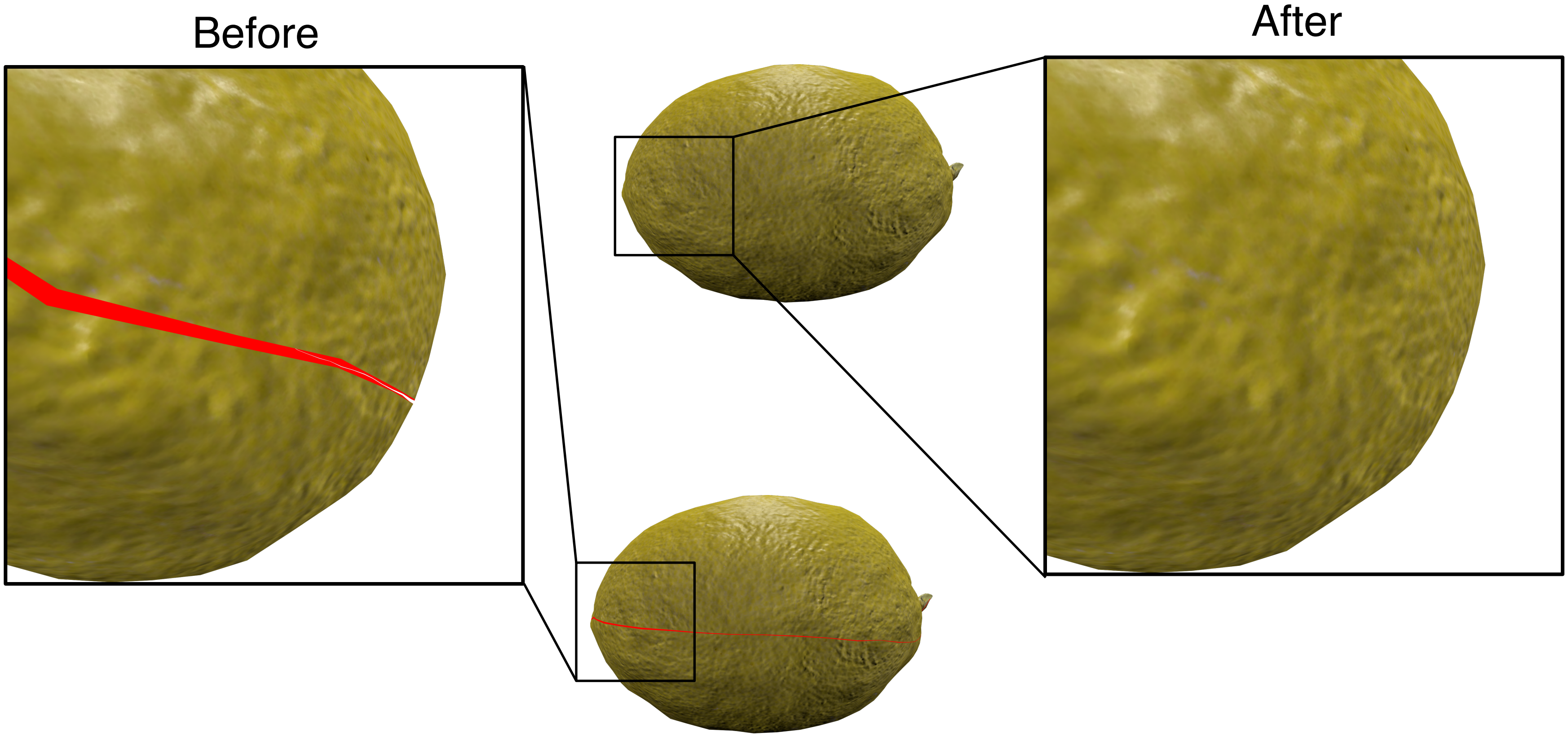
DISCONTINUITIES IN GEOMETRY IMAGES

Before

After



DISCONTINUITIES IN GEOMETRY IMAGES



CONTRIBUTIONS

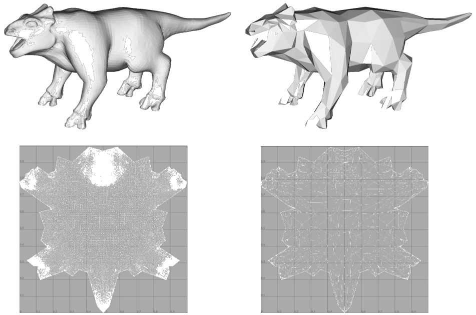
CONTRIBUTIONS

Seam Erasure

CONTRIBUTIONS

Seam Erasure

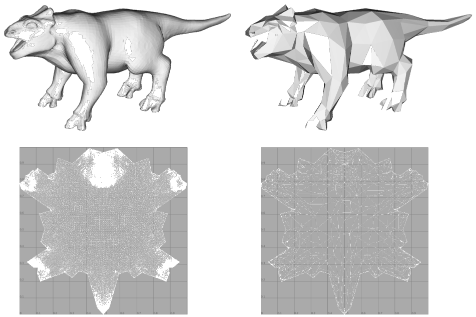
Seam Aware Decimation



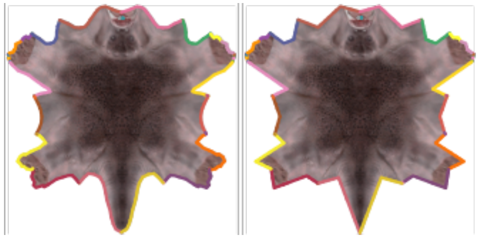
CONTRIBUTIONS

Seam Erasure

Seam Aware Decimation



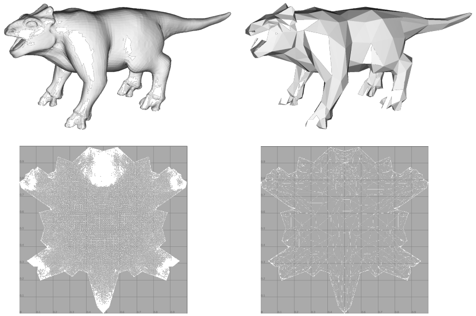
Seam Straightener



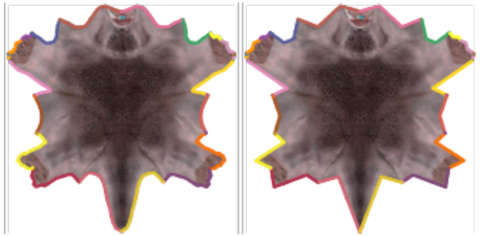
CONTRIBUTIONS

Seam Erasure

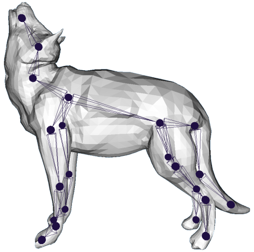
Seam Aware Decimation



Seam Straightener



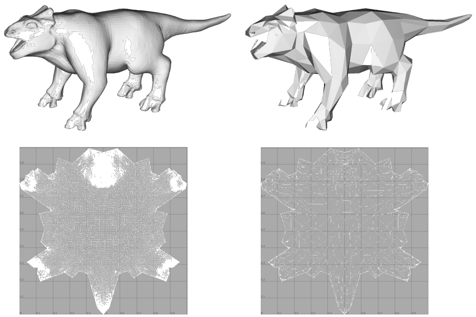
Weight Maps



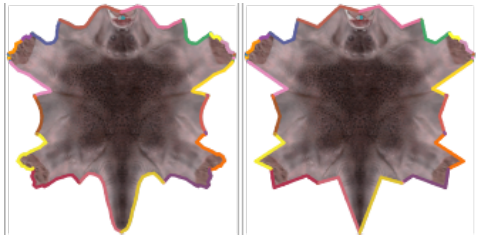
CONTRIBUTIONS

Seam Erasure

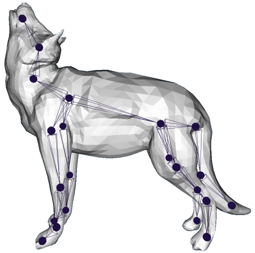
Seam Aware Decimation



Seam Straightener



Weight Maps



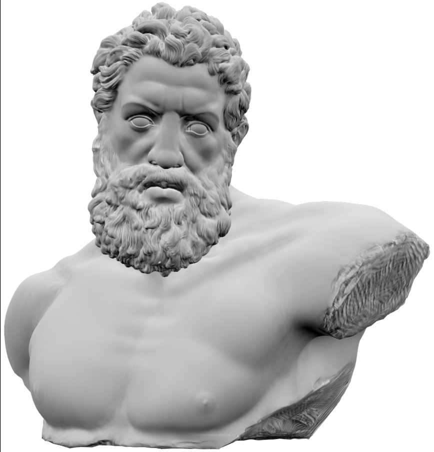
OVERVIEW

INPUT:

OUTPUT:

OVERVIEW

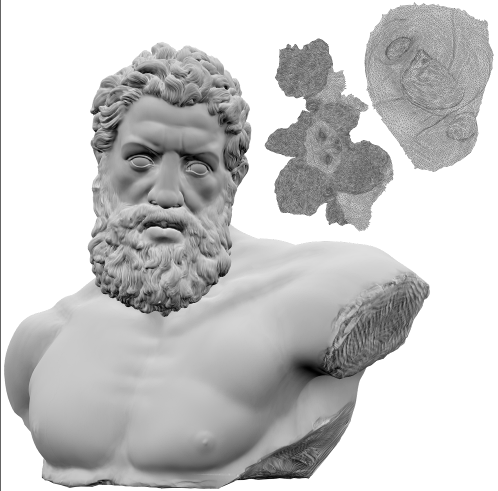
INPUT:



OUTPUT:

OVERVIEW

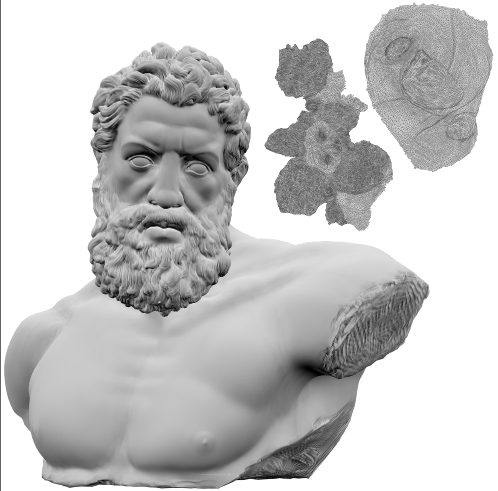
INPUT:



OUTPUT:

OVERVIEW

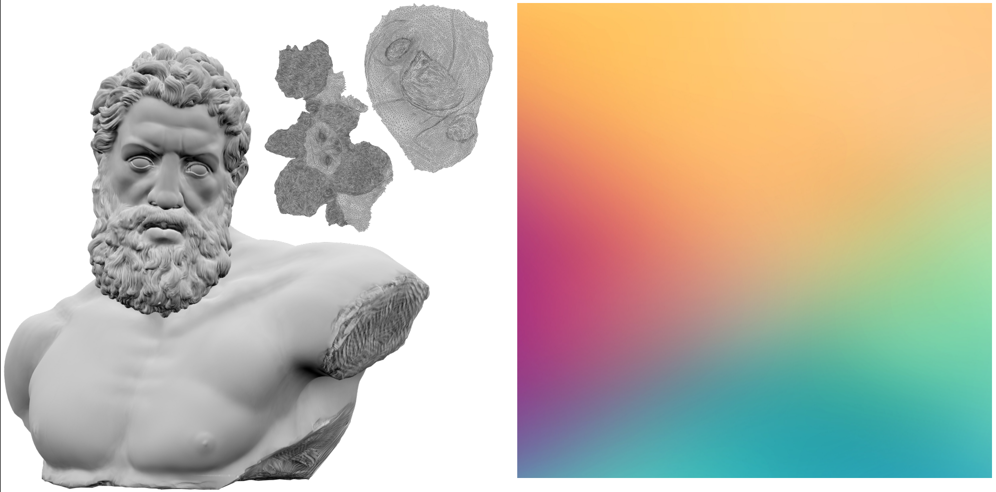
INPUT:



OUTPUT:

OVERVIEW

INPUT:

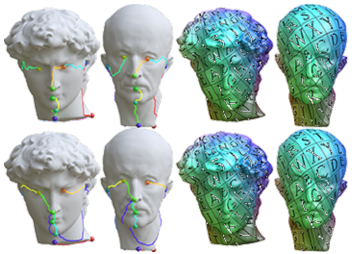


OUTPUT:

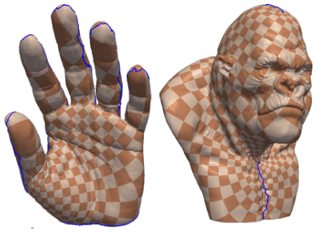
RELATED WORKS

RELATED WORKS

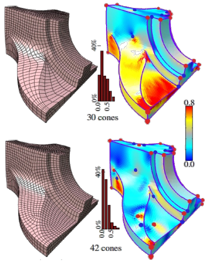
Control the Parameterization



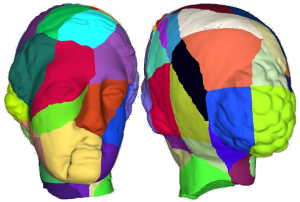
[Aigerman et al. 2015]



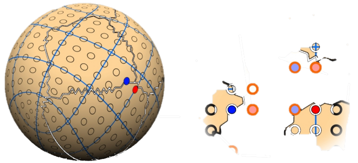
[Kovalsky et al. 2016]



[Myles and Zorin 2013]



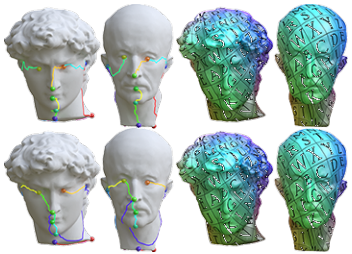
[Purnomo et al. 2004]



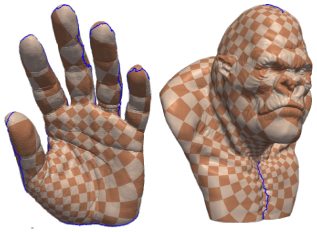
[Ray et al. 2010]

RELATED WORKS

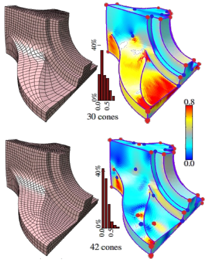
Control the Parameterization



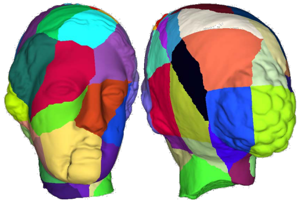
[Aigerman et al. 2015]



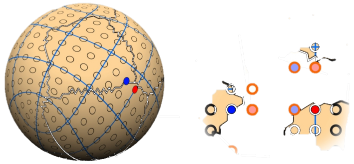
[Kovalsky et al. 2016]



[Myles and Zorin 2013]

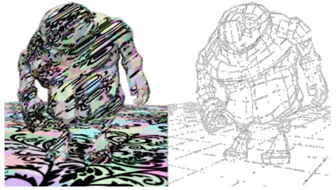


[Purnomo et al. 2004]

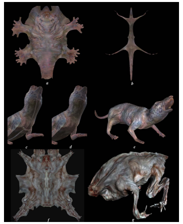


[Ray et al. 2010]

Modify Rendering Pipeline



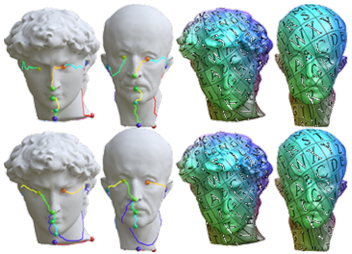
[Toth 2013]



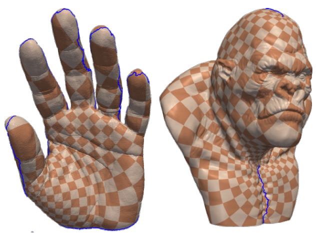
[Piponi and Borshukov 2000]

RELATED WORKS

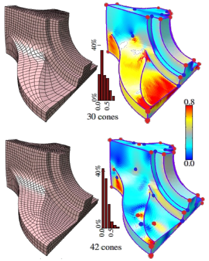
Control the Parameterization



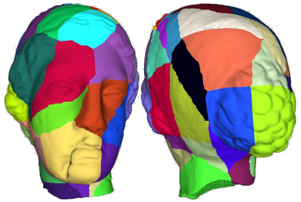
[Aigerman et al. 2015]



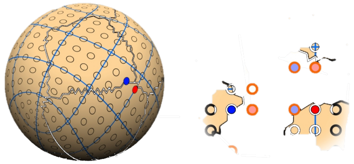
[Kovalsky et al. 2016]



[Myles and Zorin 2013]

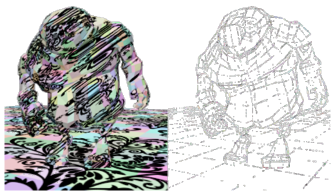


[Purnomo et al. 2004]

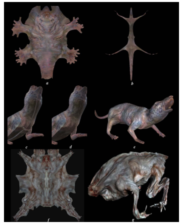


[Ray et al. 2010]

Modify Rendering Pipeline

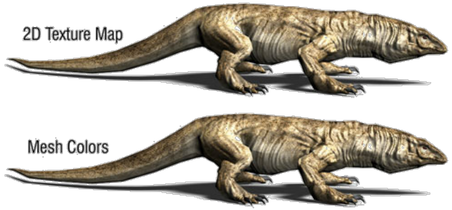


[Toth 2013]



[Piponi and Borshukov 2000]

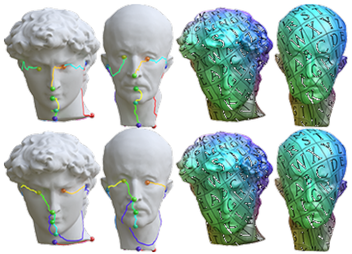
Avoid Parameterization



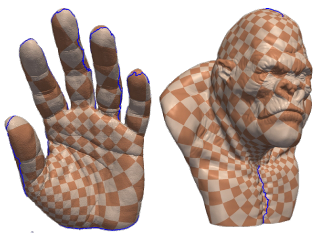
[Yuksel et al. 2010]

RELATED WORKS

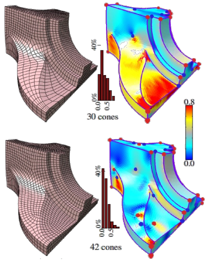
Control the Parameterization



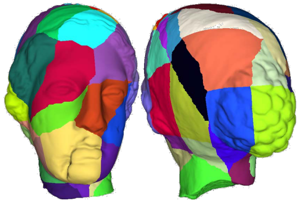
[Aigerman et al. 2015]



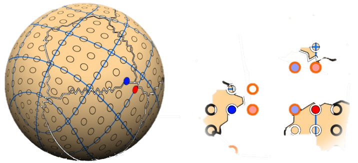
[Kovalsky et al. 2016]



[Myles and Zorin 2013]

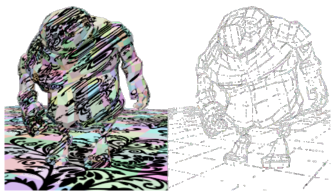


[Purnomo et al. 2004]

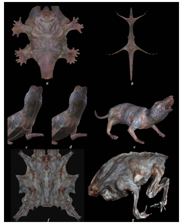


[Ray et al. 2010]

Modify Rendering Pipeline

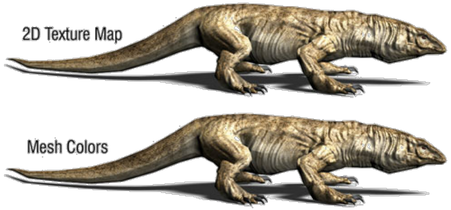


[Toth 2013]



[Piponi and Borshukov 2000]

Avoid Parameterization



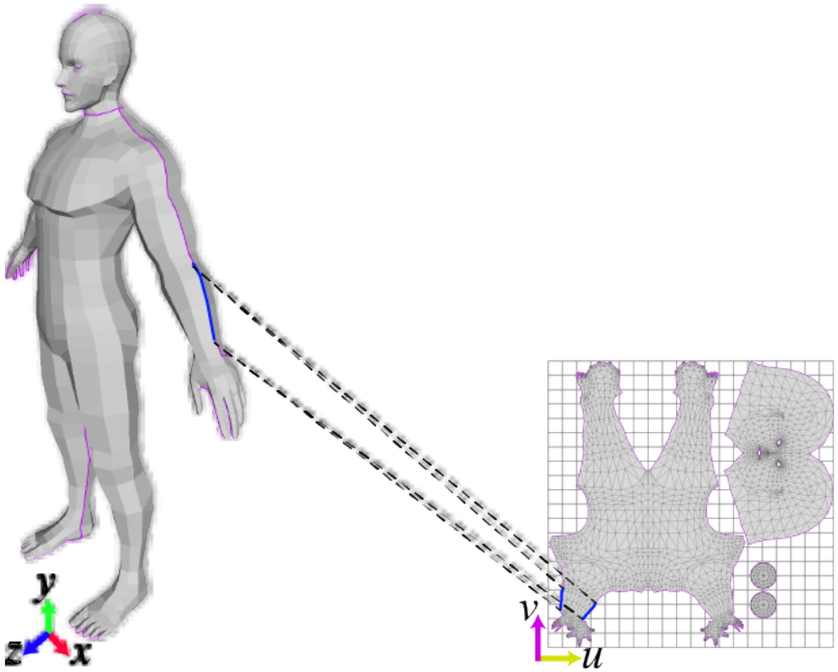
[Yuksel et al. 2010]

Optimize Texture Values

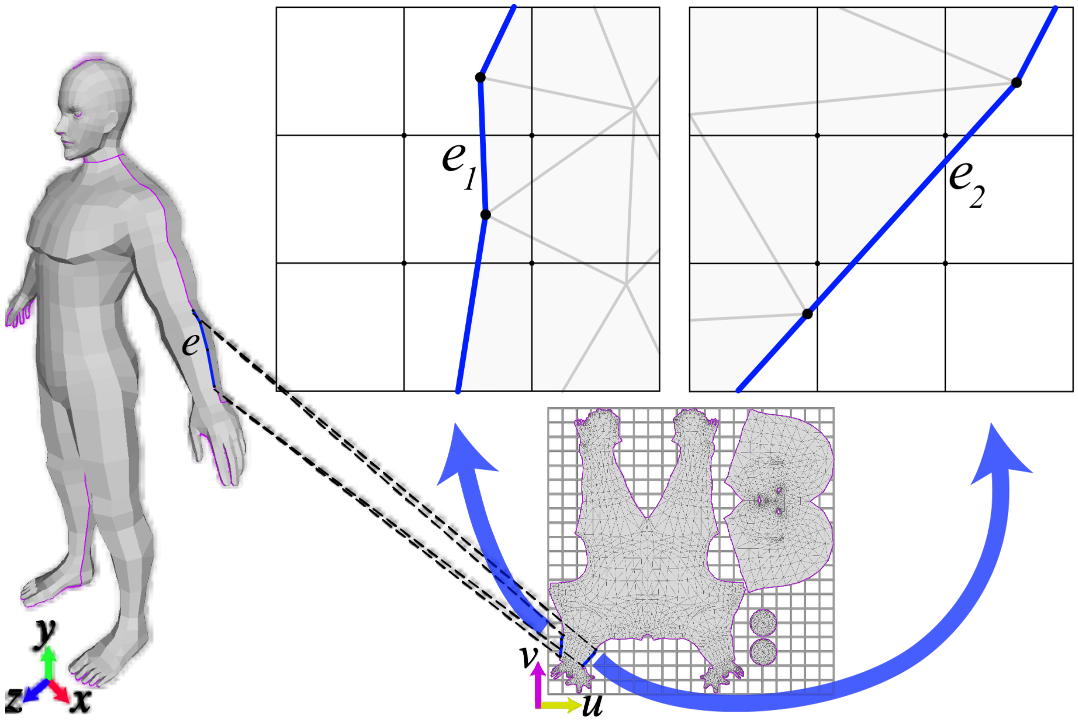
[Iwanicki 2013]

VALUE ALONG AN EDGE

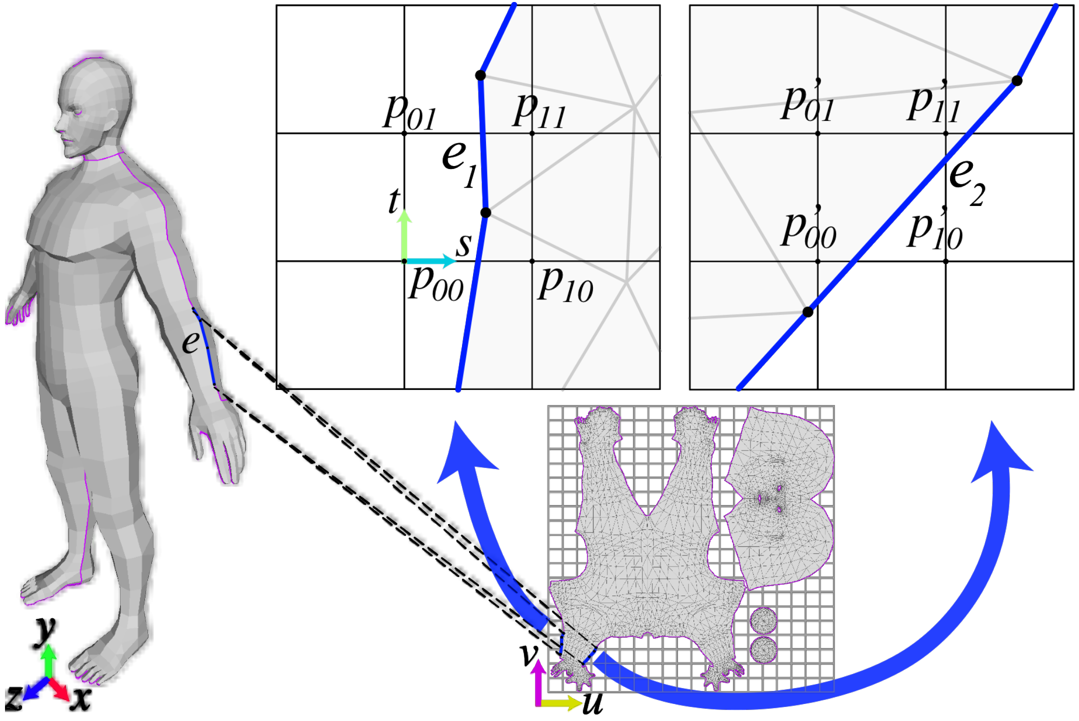
VALUE ALONG AN EDGE



VALUE ALONG AN EDGE



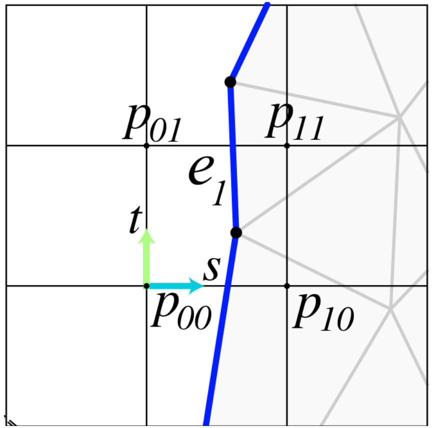
VALUE ALONG AN EDGE



BILINEAR INTERPOLATION

Bilinear interpolation:

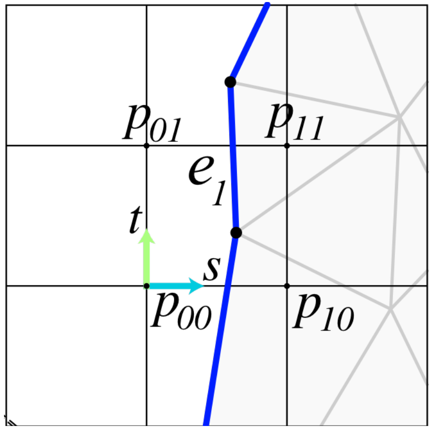
$$\text{Bilerp}(s,t) = (1-t)((p_{10}-p_{00})s + p_{00}) + t((p_{11}-p_{01})s + p_{01})$$



BILINEAR INTERPOLATION

Bilinear interpolation:

$$\text{Bilerp}(s,t) = (1-t)((p_{10}-p_{00})s + p_{00}) + t((p_{11}-p_{01})s + p_{01})$$



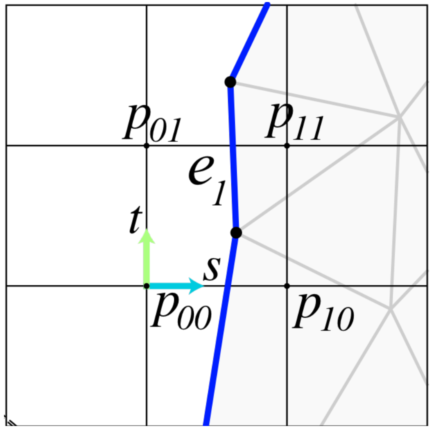
This is linear in $\mathbf{p}$ and quadratic in edge parameter γ:

$$\text{Bilerp}(e) = m(e(\gamma))\mathbf{p}$$

BILINEAR INTERPOLATION

Bilinear interpolation:

$$\text{Bilerp}(s,t) = (1-t)((p_{10}-p_{00})s + p_{00}) + t((p_{11}-p_{01})s + p_{01})$$



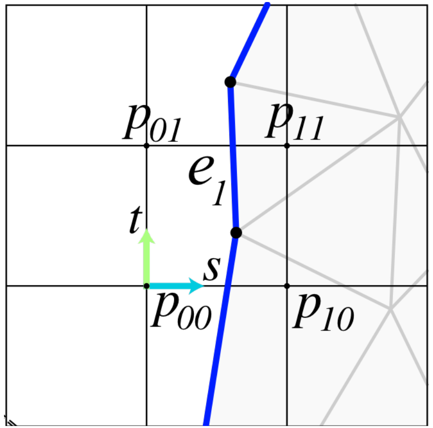
This is linear in $\mathbf{p}$ and quadratic in edge parameter γ:

$$\text{Bilerp}(e) = m(e(\gamma))\mathbf{p} = \gamma^2 \cdot a(\gamma)^\mathsf{T}\mathbf{p} + \gamma \cdot b(\gamma)^\mathsf{T}\mathbf{p} + c(\gamma)^\mathsf{T}\mathbf{p}$$

BILINEAR INTERPOLATION

Bilinear interpolation:

$$\text{Bilerp}(s,t) = (1-t)((p_{10}-p_{00})s + p_{00}) + t((p_{11}-p_{01})s + p_{01})$$



This is linear in $\mathbf{p}$ and quadratic in edge parameter γ:

$$\text{Bilerp}(e) = m(e(\gamma))\mathbf{p} = \gamma^2 \cdot a(\gamma)^\mathsf{T}\mathbf{p} + \gamma \cdot b(\gamma)^\mathsf{T}\mathbf{p} + c(\gamma)^\mathsf{T}\mathbf{p}$$

$\gamma \in [0,1], a, b, c$ are sparse column vectors of coefficients for e, and $\mathbf{p}$ is the column vector of all samples in the texture.

SEAM ENERGY

$$\int_0^1 \|m(e_1)\mathbf{p} - m(e_2)\mathbf{p}\|^2 d\gamma$$

SEAM ENERGY

$$\mathbf{p}^{\mathsf{T}} \left(\int_0^1 \| m(e_1) \quad - m(e_2) \quad \|^2 d\gamma \right) \mathbf{p}$$

SEAM ENERGY

$$\mathbf{p}^{\mathsf{T}} \left(\qquad M_{e_1,e_2} \qquad \right) \mathbf{p}$$

SEAM ENERGY

$$\mathbf{p}^{\mathsf{T}} M \mathbf{p} = \sum_{e_1, e_2 \in \text{seams}} \mathbf{p}^{\mathsf{T}} \left(M_{e_1, e_2} \right) \mathbf{p}$$

POSSIBLE SOLUTIONS

$$\mathbf{p}^\top M \mathbf{p} = 0$$

POSSIBLE SOLUTIONS

OPTIMIZATION

Our total energy is:

$$E(\mathbf{p}) =$$

OPTIMIZATION

Our total energy is:

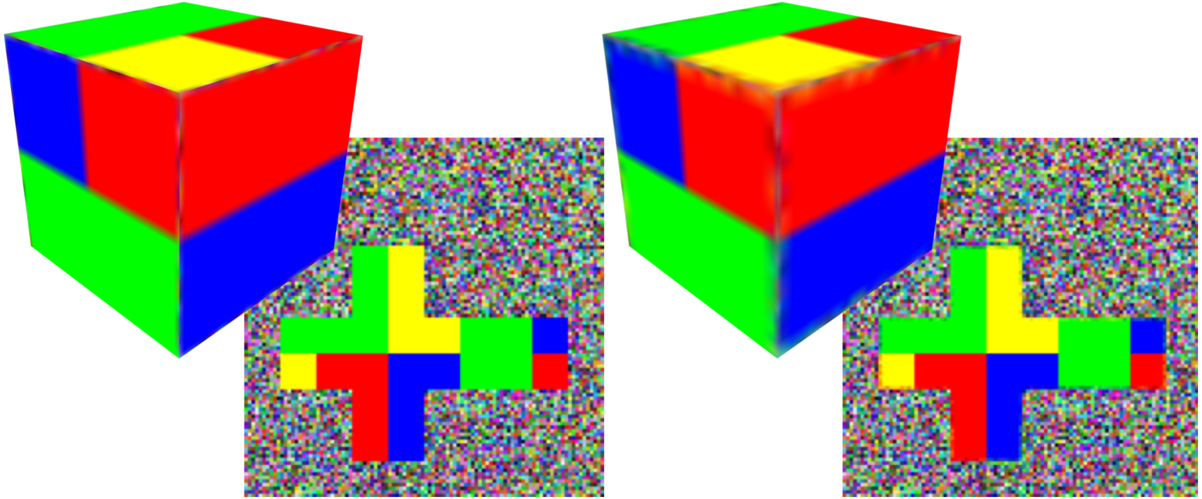
$$E(\mathbf{p}) = w_{\text{change}} \|\mathbf{p} - \mathbf{p_0}\|^2$$

OPTIMIZATION

Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}} \|\mathbf{p} - \mathbf{p_0}\|^2$$

Original | With Only E_{Change}



OPTIMIZATION

Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}} \|\mathbf{p} - \mathbf{p_0}\|^2 \qquad + \qquad w_{\nabla} \|\nabla \mathbf{p} - \nabla \mathbf{p_0}\|^2$$

OPTIMIZATION

Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}} \|\mathbf{p} - \mathbf{p_0}\|^2 \quad + \quad w_{\nabla} \|\nabla\mathbf{p} - \nabla\mathbf{p_0}\|^2$$

OPTIMIZATION

Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}} \|\mathbf{p} - \mathbf{p_0}\|^2 \qquad + \qquad w_{\nabla} \|\nabla\mathbf{p} - \nabla\mathbf{p_0}\|^2$$

OPTIMIZATION

Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}} \|\mathbf{p} - \mathbf{p_0}\|^2 \qquad + \qquad w_{\nabla} \|\nabla \mathbf{p} - \nabla \mathbf{p_0}\|^2$$

OPTIMIZATION

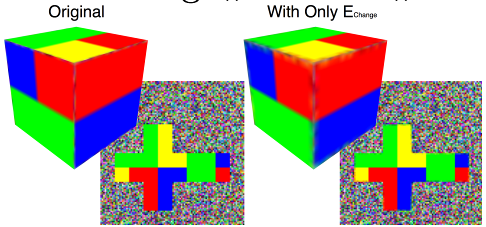
Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}} \|\mathbf{p} - \mathbf{p_0}\|^2 \quad + \quad w_{\nabla} \|\nabla\mathbf{p} - \nabla\mathbf{p_0}\|^2 \quad + \quad w_{C^1} E_{C^1}(\mathbf{p})$$

OPTIMIZATION

Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}}\left\|\mathbf{p}-\mathbf{p_0}\right\|^2 \quad + \quad w_{\nabla}\left\|\nabla\mathbf{p}-\nabla\mathbf{p_0}\right\|^2 \quad + \quad w_{C^1}E_{C^1}(\mathbf{p})$$

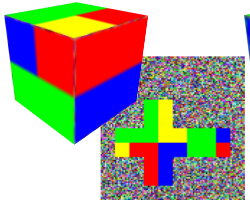


OPTIMIZATION

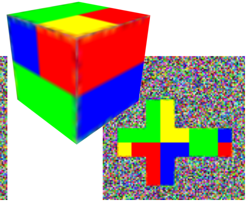
Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}}\|\mathbf{p}-\mathbf{p_0}\|^2 \quad + \quad w_{\nabla}\|\nabla\mathbf{p}-\nabla\mathbf{p_0}\|^2 \quad + \quad w_{C^1}E_{C^1}(\mathbf{p})$$

Original



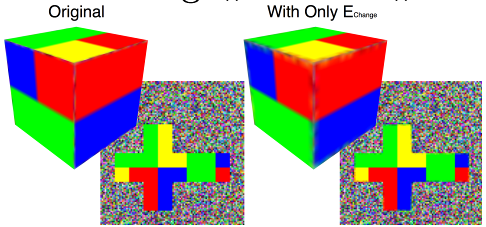
With Only E_{Change}



OPTIMIZATION

Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}} \|\mathbf{p} - \mathbf{p_0}\|^2 \quad + \quad w_{\nabla} \|\nabla \mathbf{p} - \nabla \mathbf{p_0}\|^2 \quad + \quad w_{C^1} E_{C^1}(\mathbf{p})$$

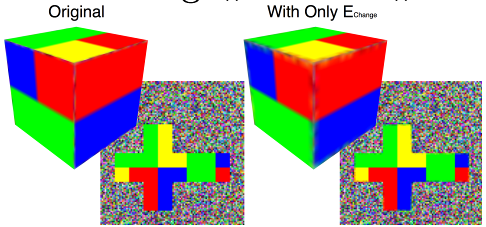


Subject to $E_{\text{seam}}(\mathbf{p}) = \mathbf{p}^{\mathsf{T}} M \mathbf{p} = 0$

OPTIMIZATION

Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}} \|\mathbf{p} - \mathbf{p_0}\|^2 \qquad + \qquad w_{\nabla} \|\nabla \mathbf{p} - \nabla \mathbf{p_0}\|^2 \qquad + \qquad w_{C^1} E_{C^1}(\mathbf{p})$$



Subject to $E_{\text{seam}}(\mathbf{p}) = \mathbf{p}^{\mathsf{T}} M \mathbf{p} = 0$

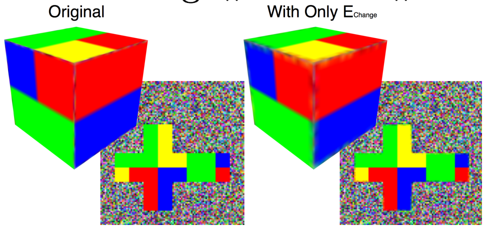
We impose the null space constraint via the penalty method by adding:

$$w_{\text{seam}} E_{\text{seam}}(\mathbf{p})$$

OPTIMIZATION

Our total energy is:

$$E(\mathbf{p}) = w_{\text{change}}\|\mathbf{p} - \mathbf{p_0}\|^2 \quad + \quad w_{\nabla}\|\nabla\mathbf{p} - \nabla\mathbf{p_0}\|^2 \quad + \quad w_{C^1}E_{C^1}(\mathbf{p})$$



Subject to $E_{\text{seam}}(\mathbf{p}) = \mathbf{p}^{\mathsf{T}}M\mathbf{p} = 0$

We impose the null space constraint via the penalty method by adding:

$$w_{\text{seam}}E_{\text{seam}}(\mathbf{p})$$

with weights

$$w_{\text{seam}} \gg w_{\text{change}}, w_{\nabla}, w_{C^1}$$

Seam Erasure: Results

COLOR MAP

Before

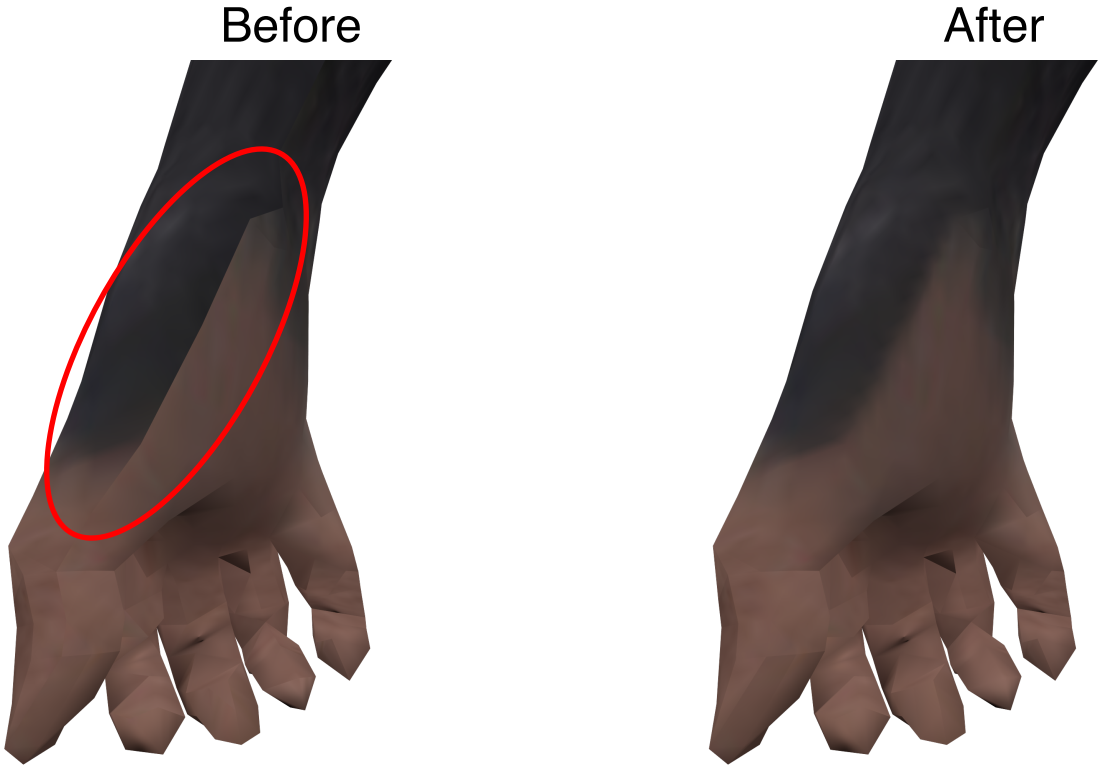
After

COLOR MAP

Before

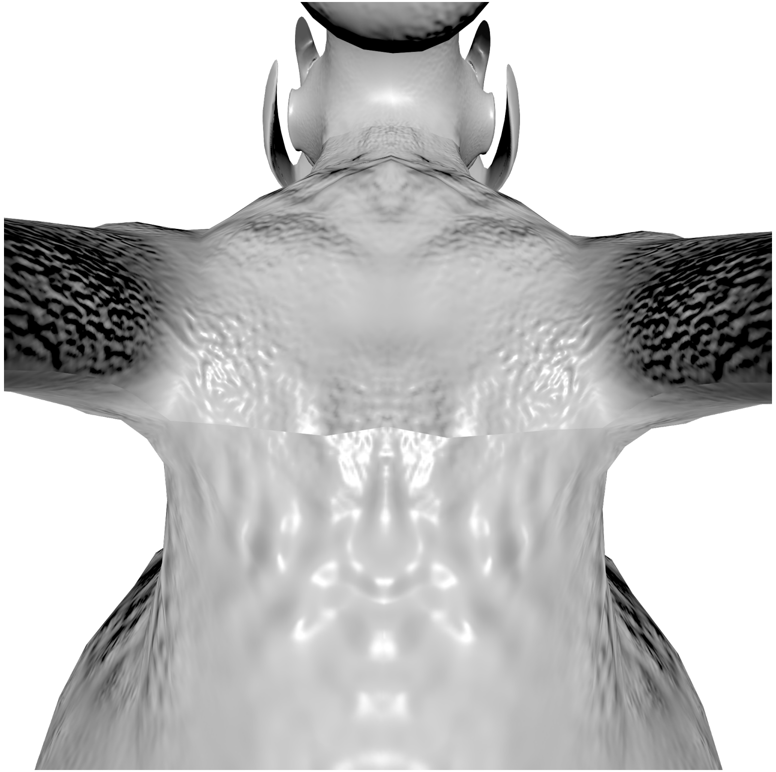
After

COLOR MAP



NORMAL MAP

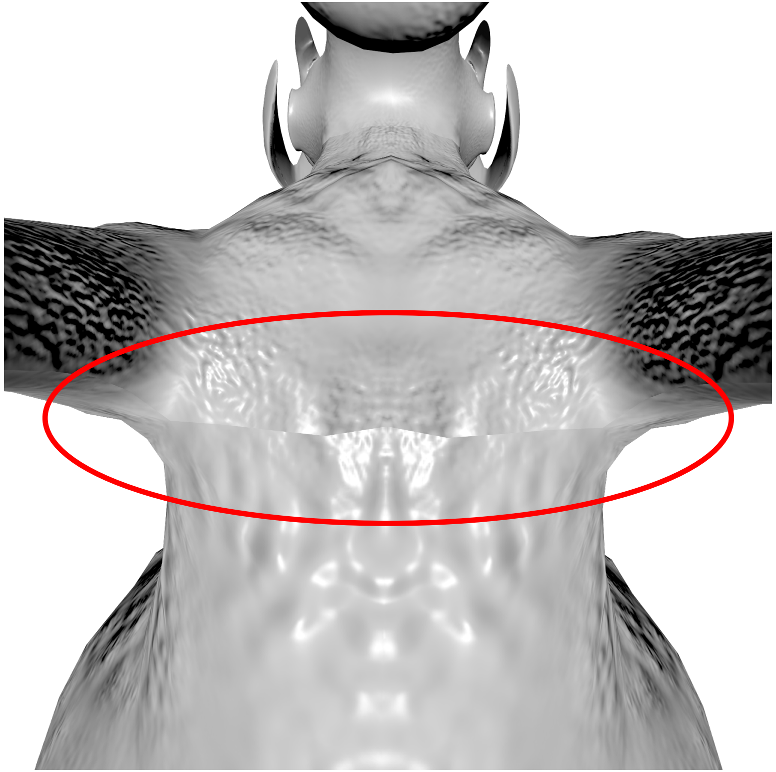
Before



After

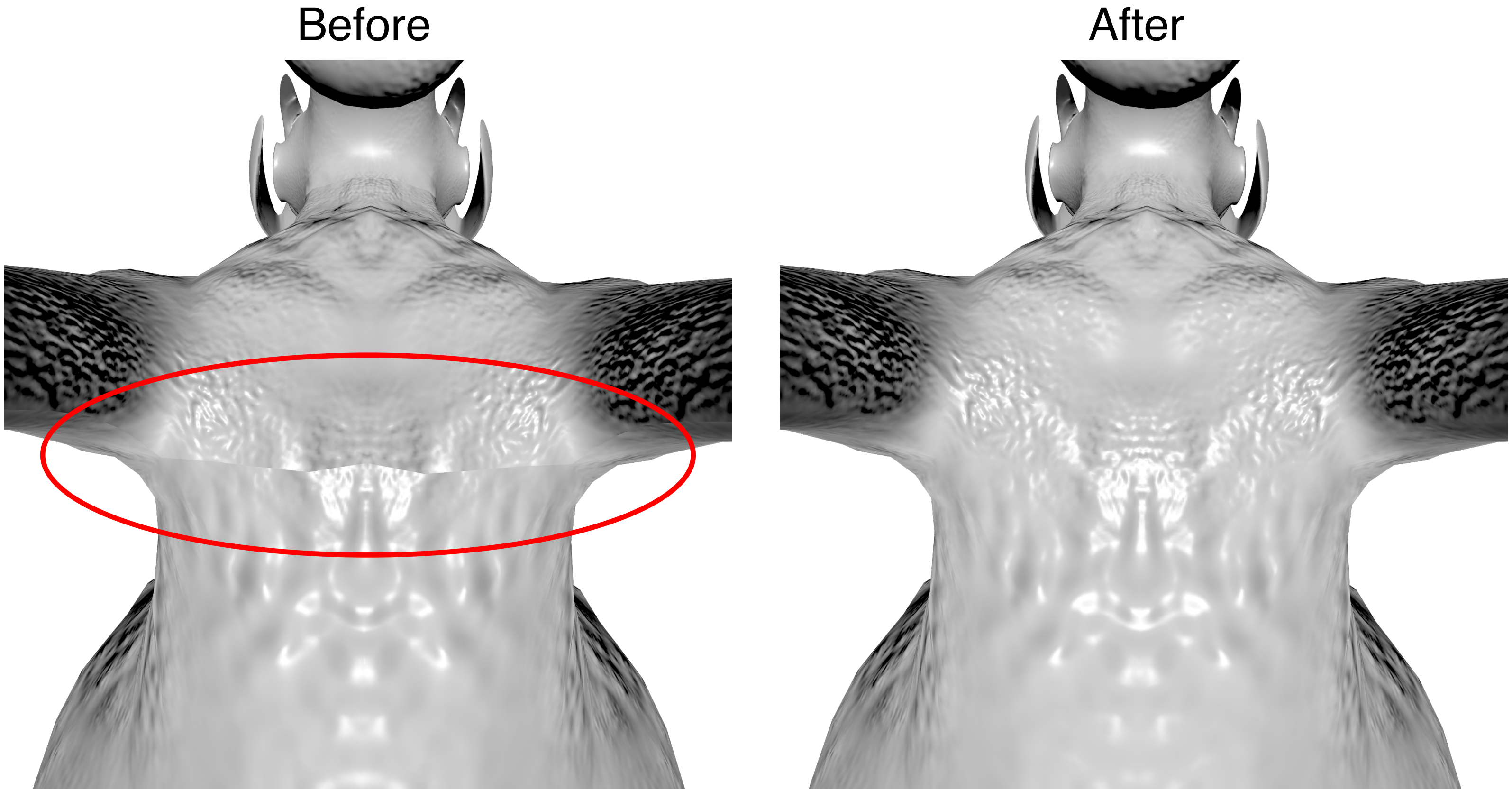
NORMAL MAP

Before



After

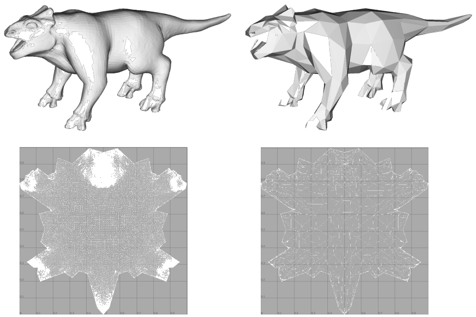
NORMAL MAP



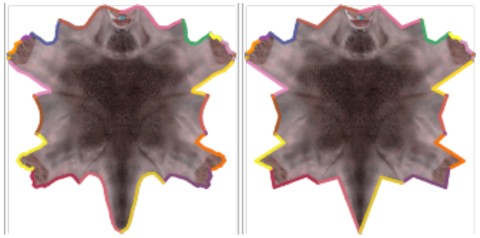
CONTRIBUTIONS

Seam Erasure

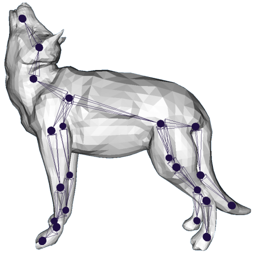
Seam Aware Decimation



Seam Straightener



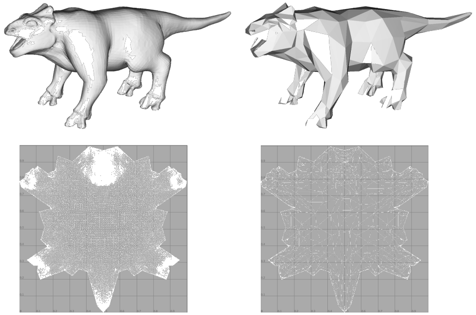
Weight Texture Maps



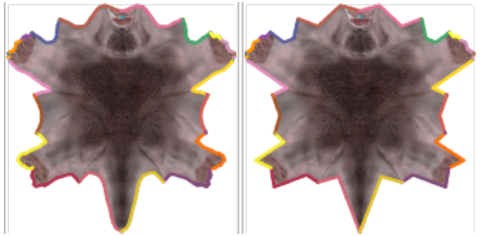
CONTRIBUTIONS

Seam Erasure

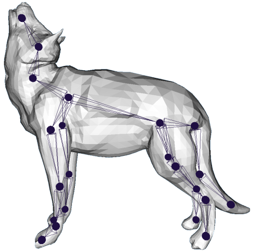
Seam Aware Decimation



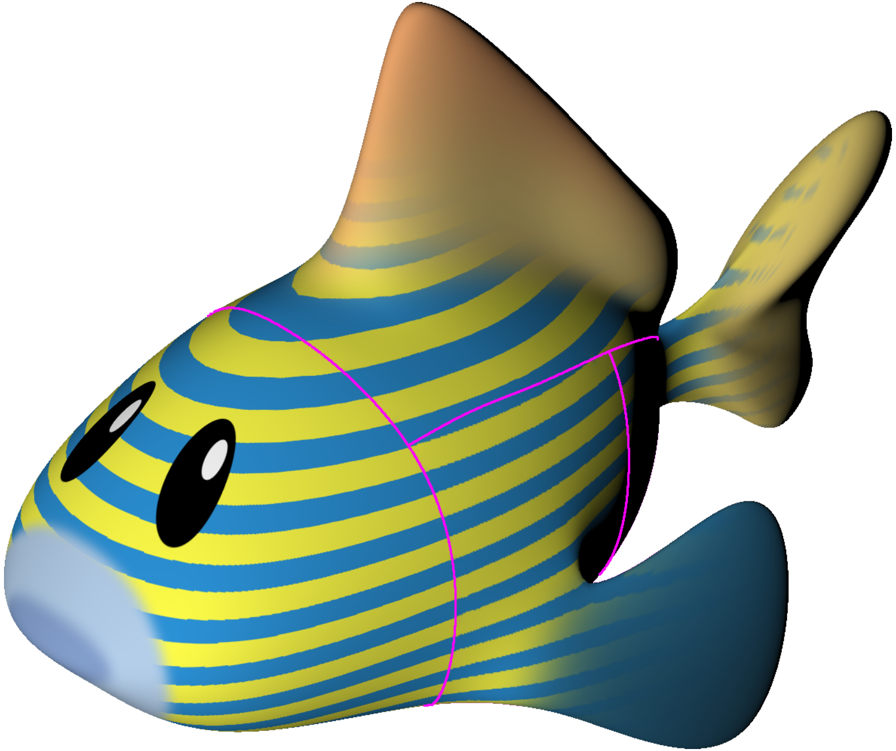
Seam Straightener

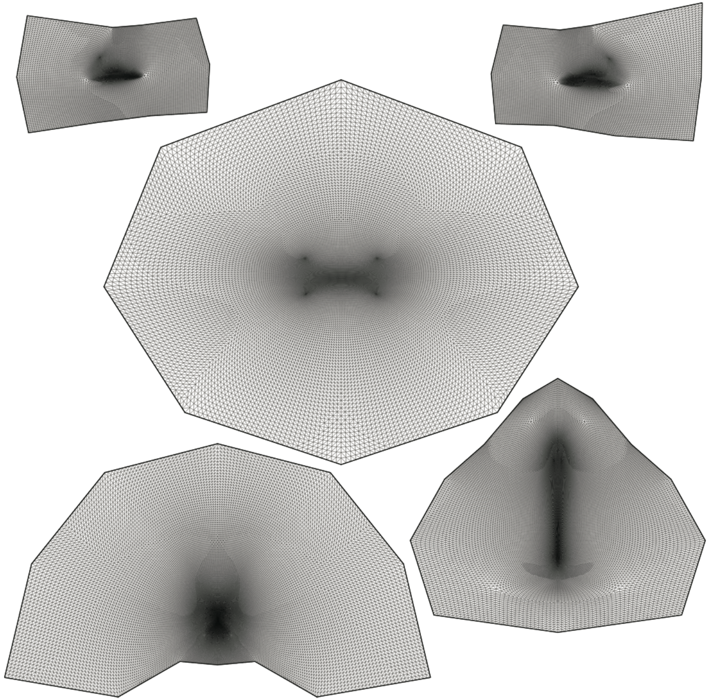


Weight Texture Maps

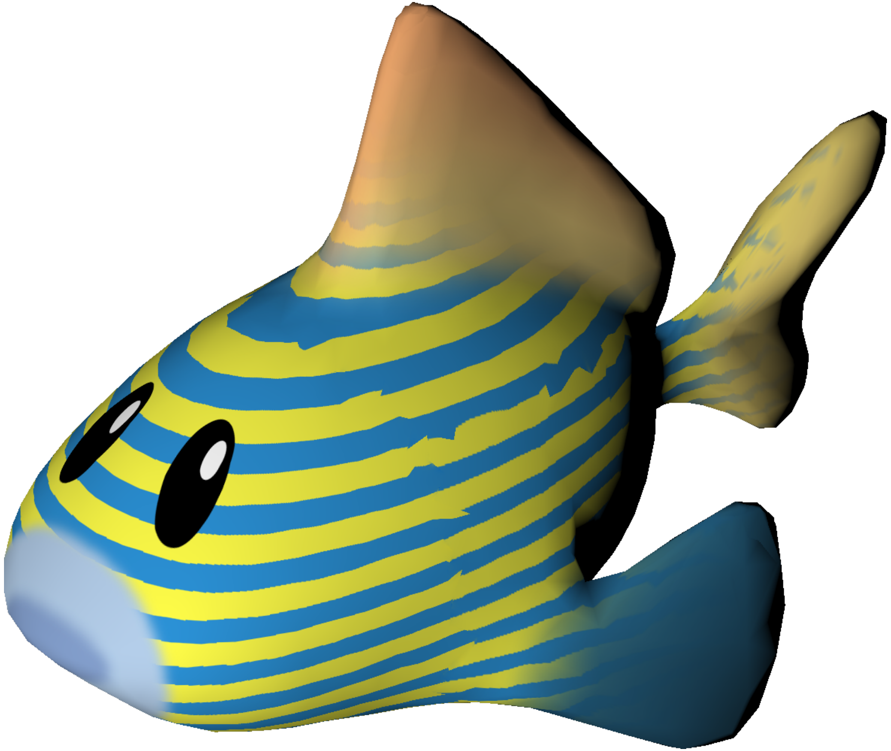


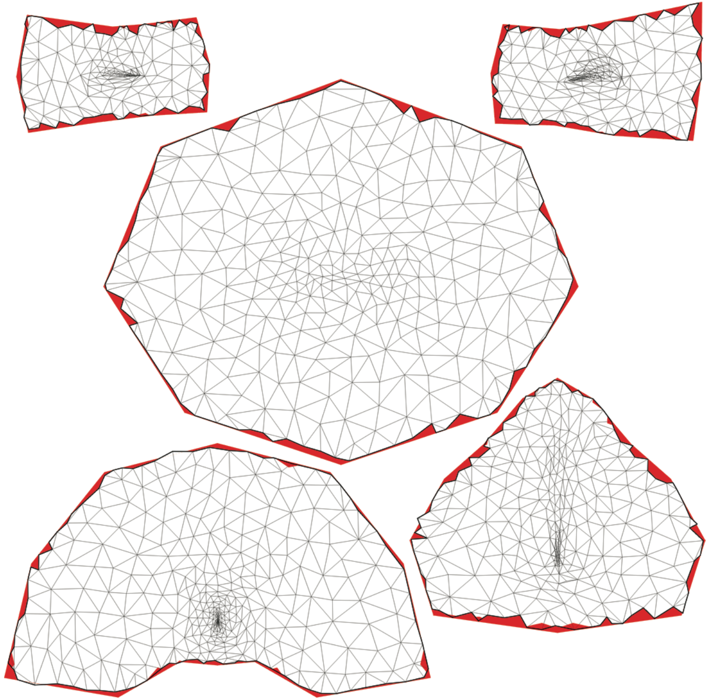
ORIGINAL MESH



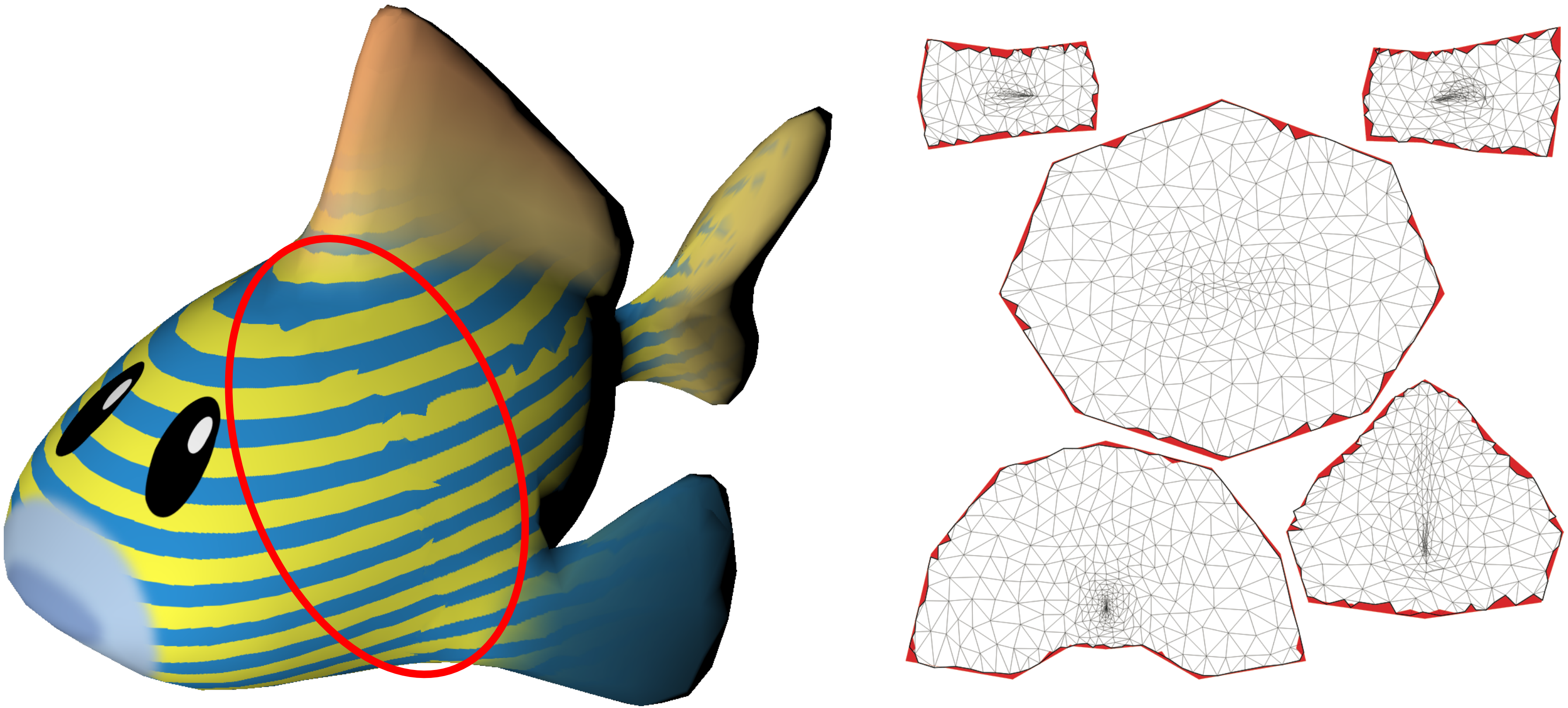


GARLAND AND HECKBERT [1998]

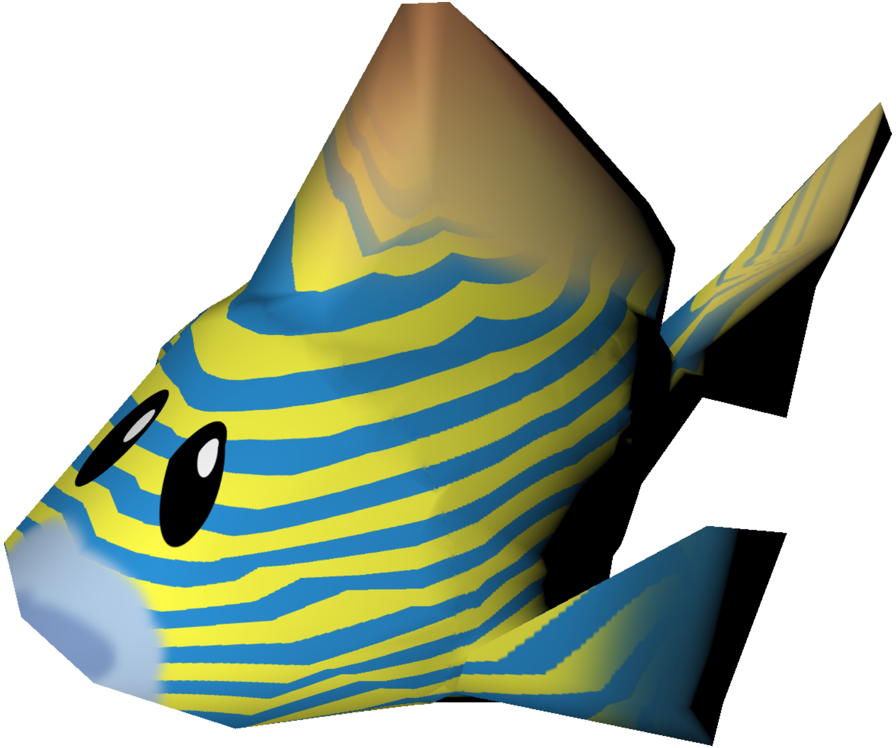


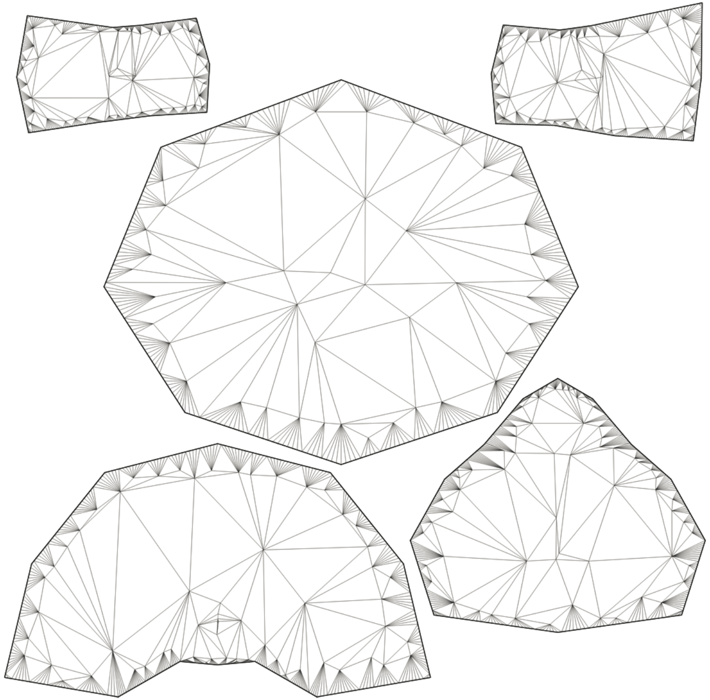


GARLAND AND HECKBERT [1998]

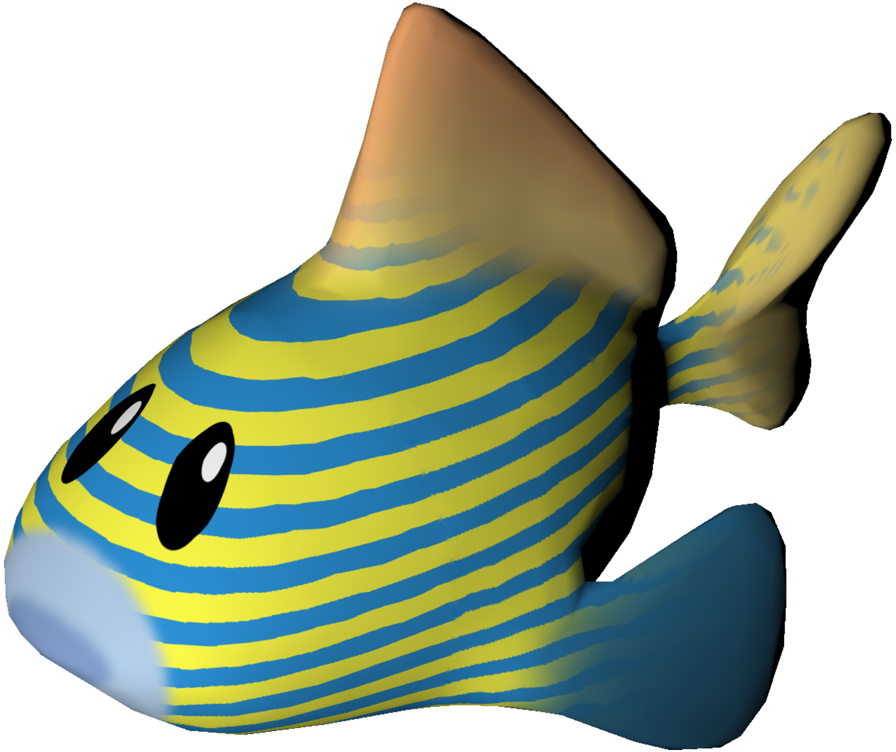


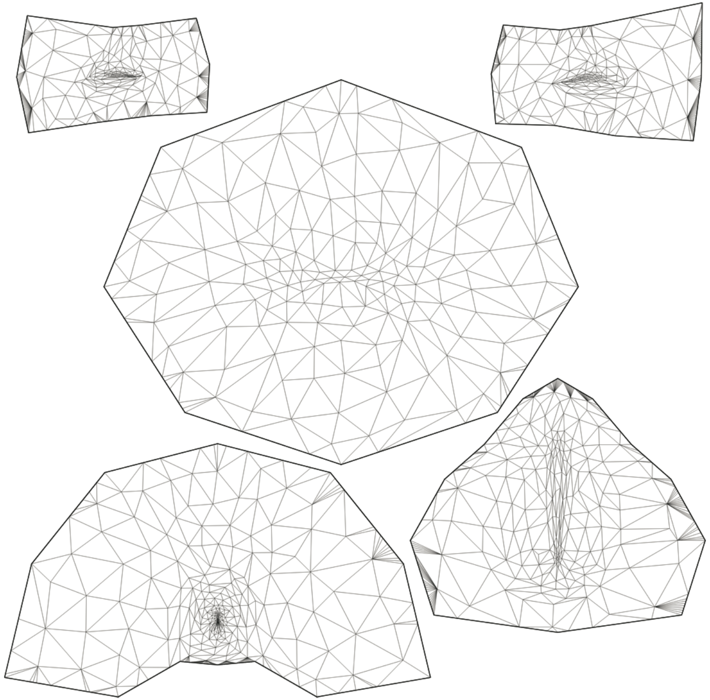
MAYA DECIMATION





OUR APPROACH



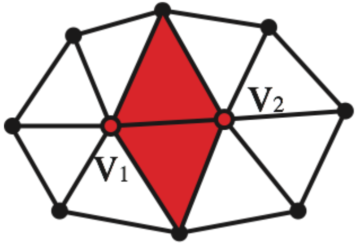


GREEDY EDGE COLLAPSE

Based on Garland and Heckbert [1998]'s n-D Quadric Error Metric

GREEDY EDGE COLLAPSE

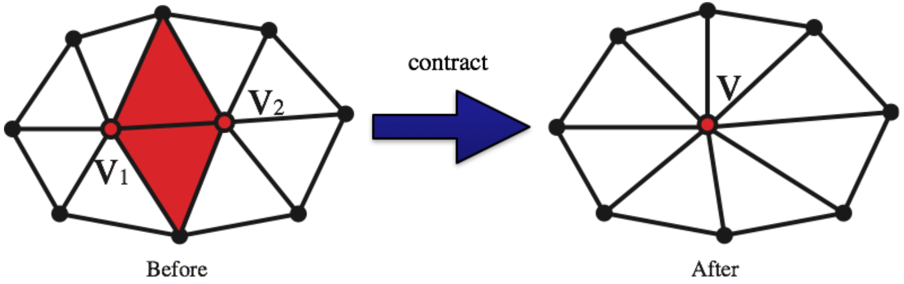
Based on Garland and Heckbert [1998]'s n-D Quadric Error Metric



Before

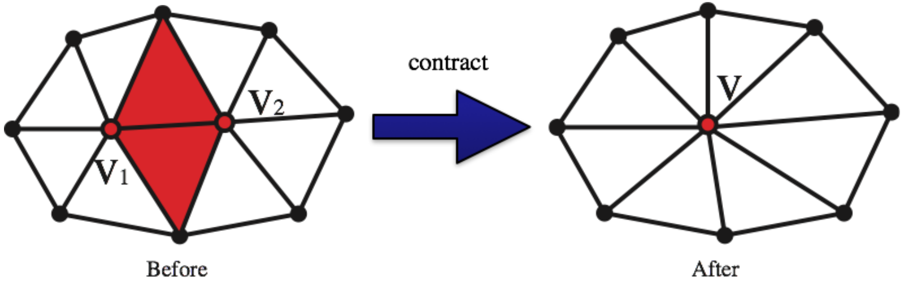
GREEDY EDGE COLLAPSE

Based on Garland and Heckbert [1998]'s n-D Quadric Error Metric



GREEDY EDGE COLLAPSE

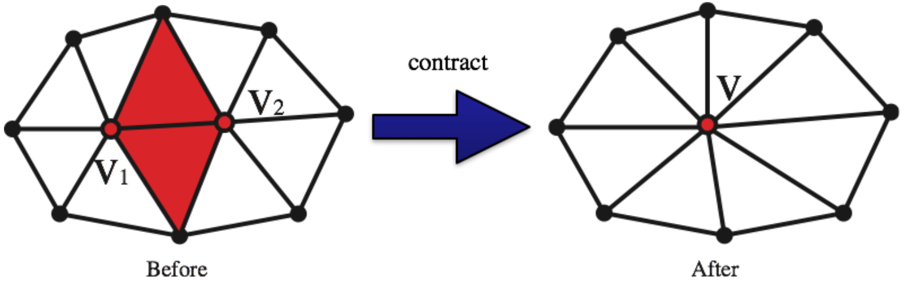
Based on Garland and Heckbert [1998]'s n-D Quadric Error Metric



- Each face defines a plane (e.g. 5-D for [x, y, z, u, v])

GREEDY EDGE COLLAPSE

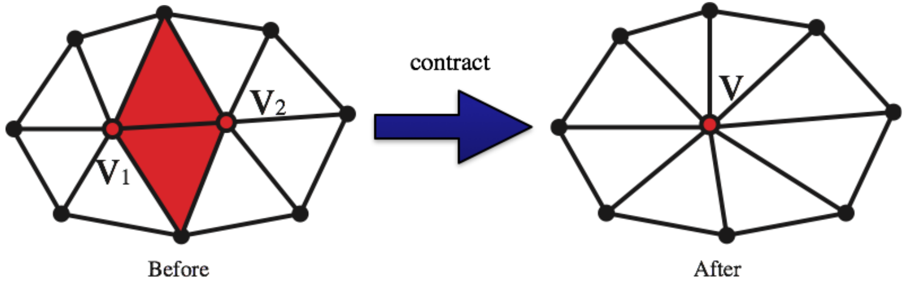
Based on Garland and Heckbert [1998]'s n-D Quadric Error Metric



- Each face defines a plane (e.g. 5-D for [x, y, z, u, v])
- Edge error metric = sum of squared distances to face's planes

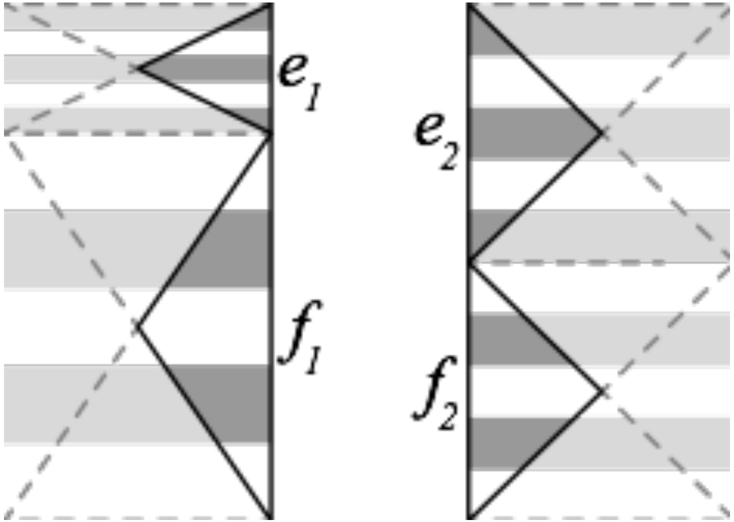
GREEDY EDGE COLLAPSE

Based on Garland and Heckbert [1998]'s n-D Quadric Error Metric

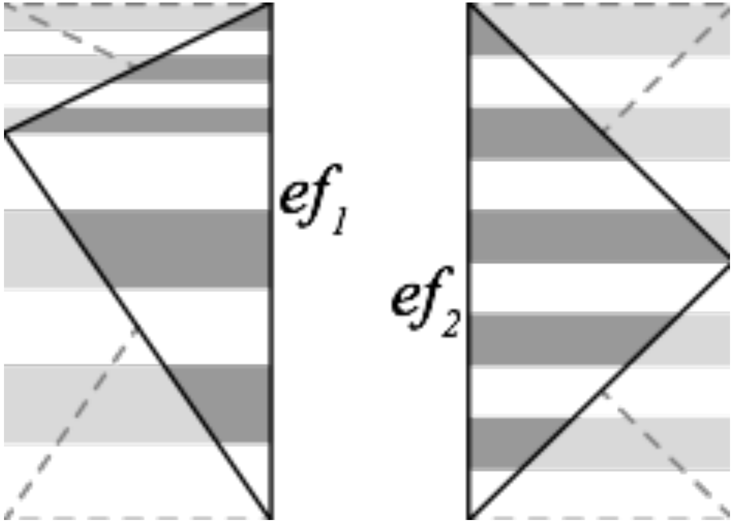


- Each face defines a plane (e.g. 5-D for [x, y, z, u, v])
- Edge error metric = sum of squared distances to face's planes
- New vertex position minimizes the edge error metric and keeps the edge error metric.

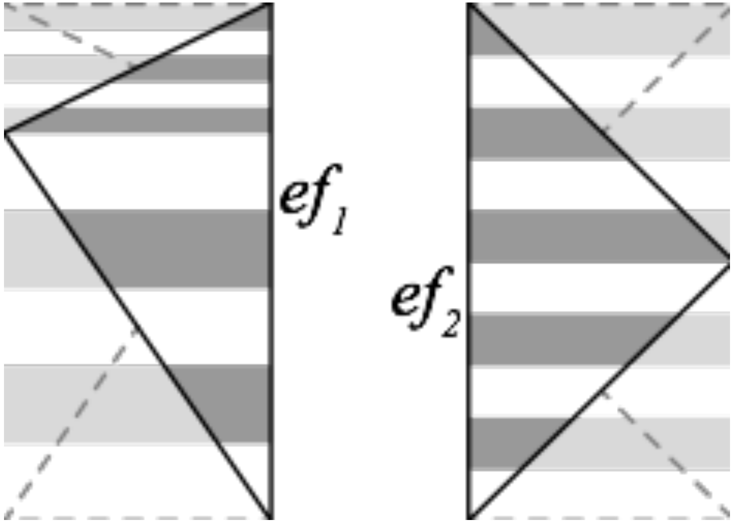
LENGTH RATIO CRITERIA



LENGTH RATIO CRITERIA



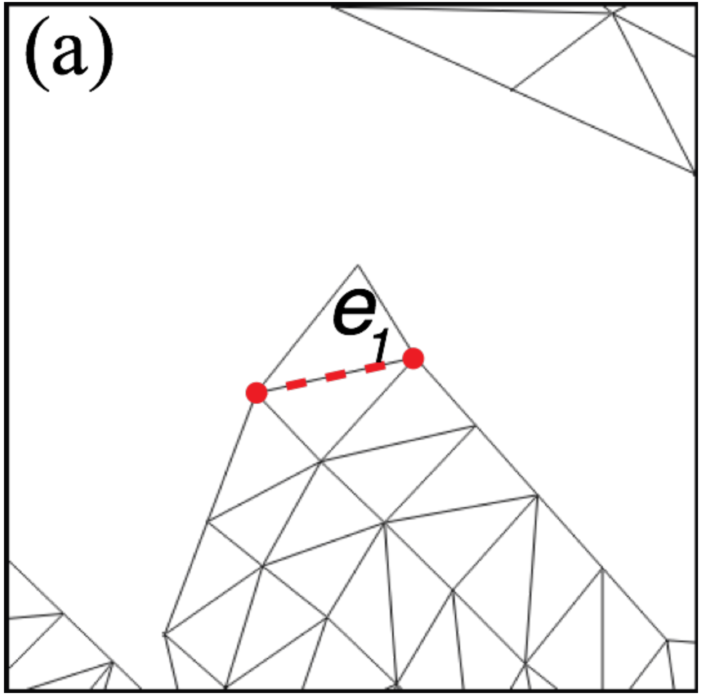
LENGTH RATIO CRITERIA



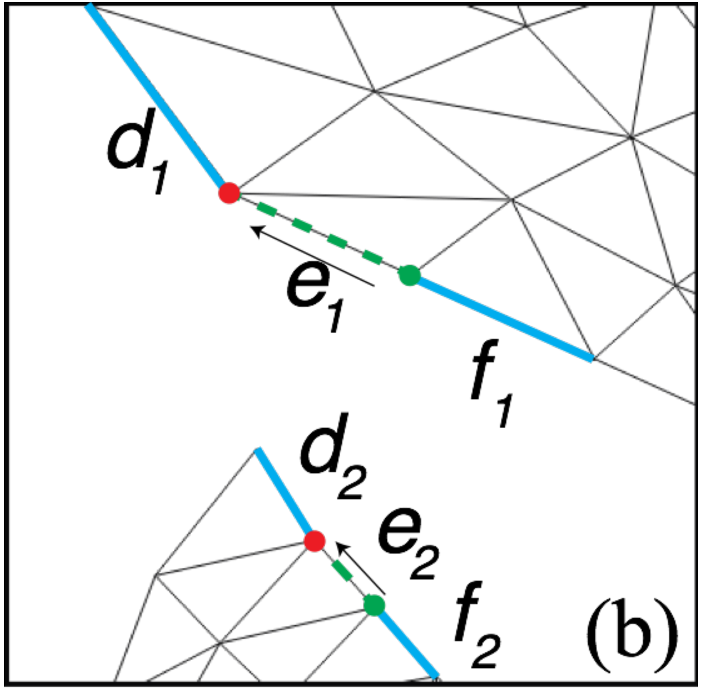
- Merging e_1 f_1 and e_2 f_2 will cause the stripe texture to be misaligned across the seam.
- Length Ratio Criteria:

$$\frac{\|e_1\|}{\|f_1\|} = \frac{\|e_2\|}{\|f_2\|}$$

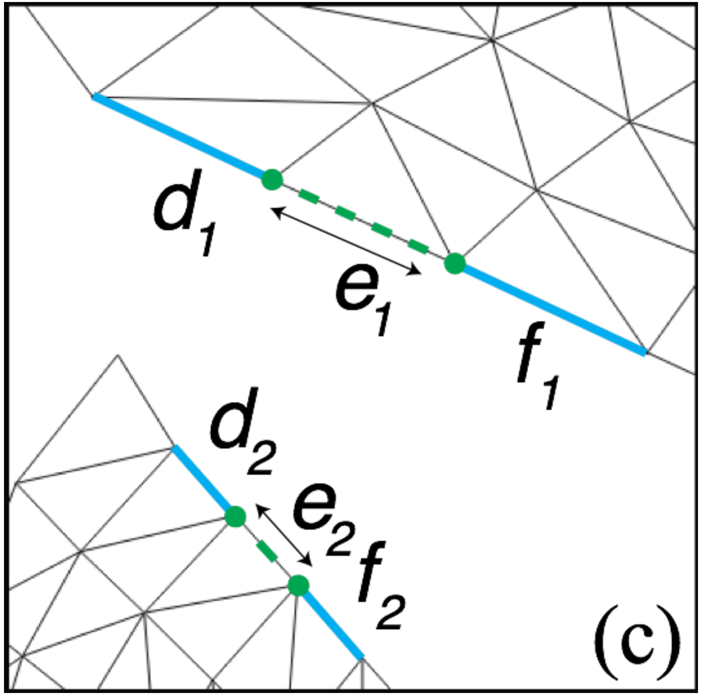
LINK CONDITION



TWO UNIFIABLE EDGES

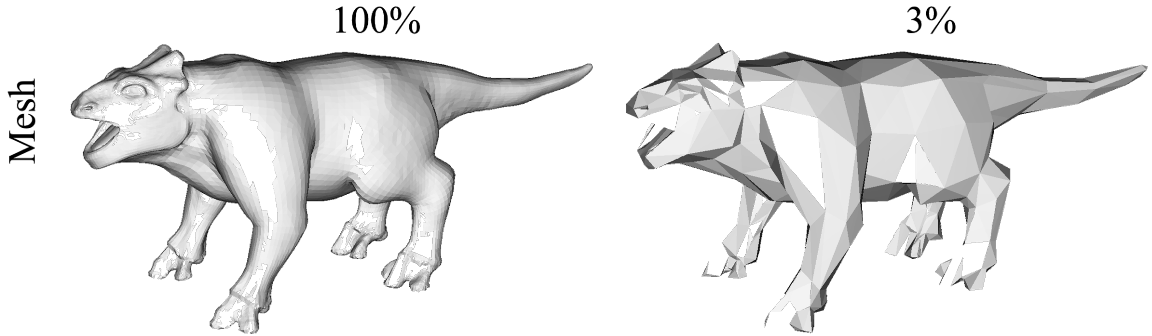


THREE UNIFIABLE EDGES

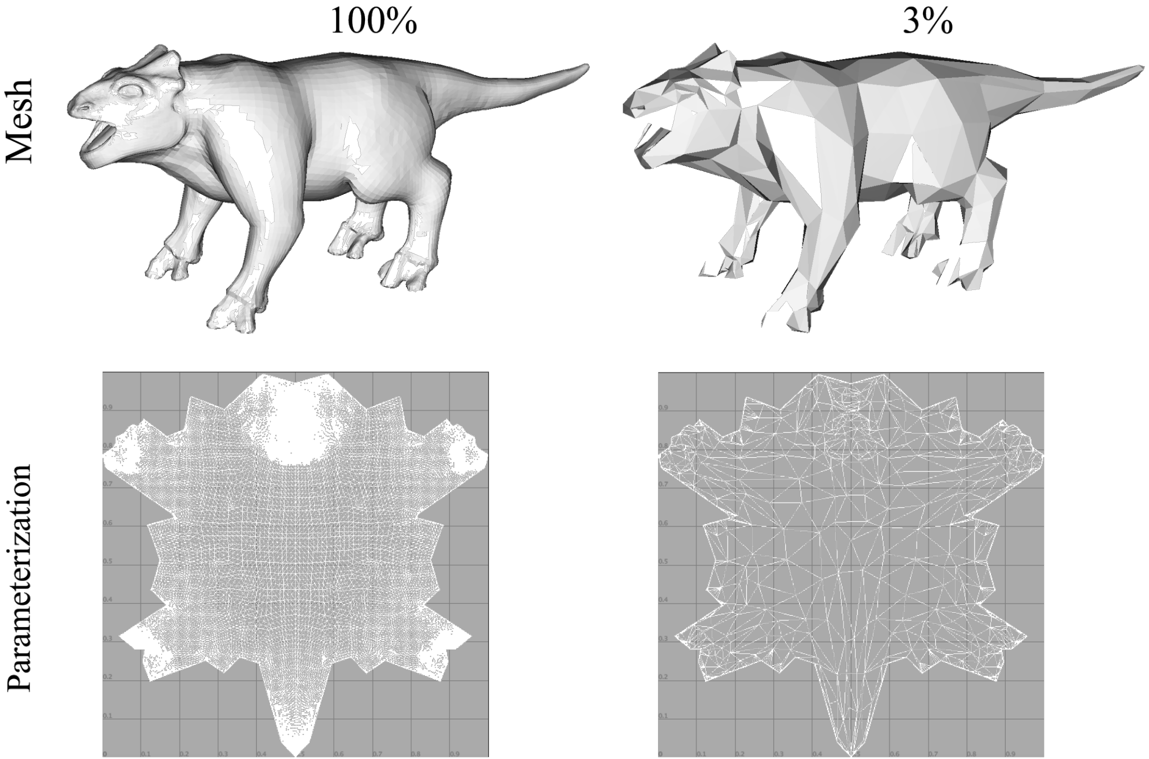


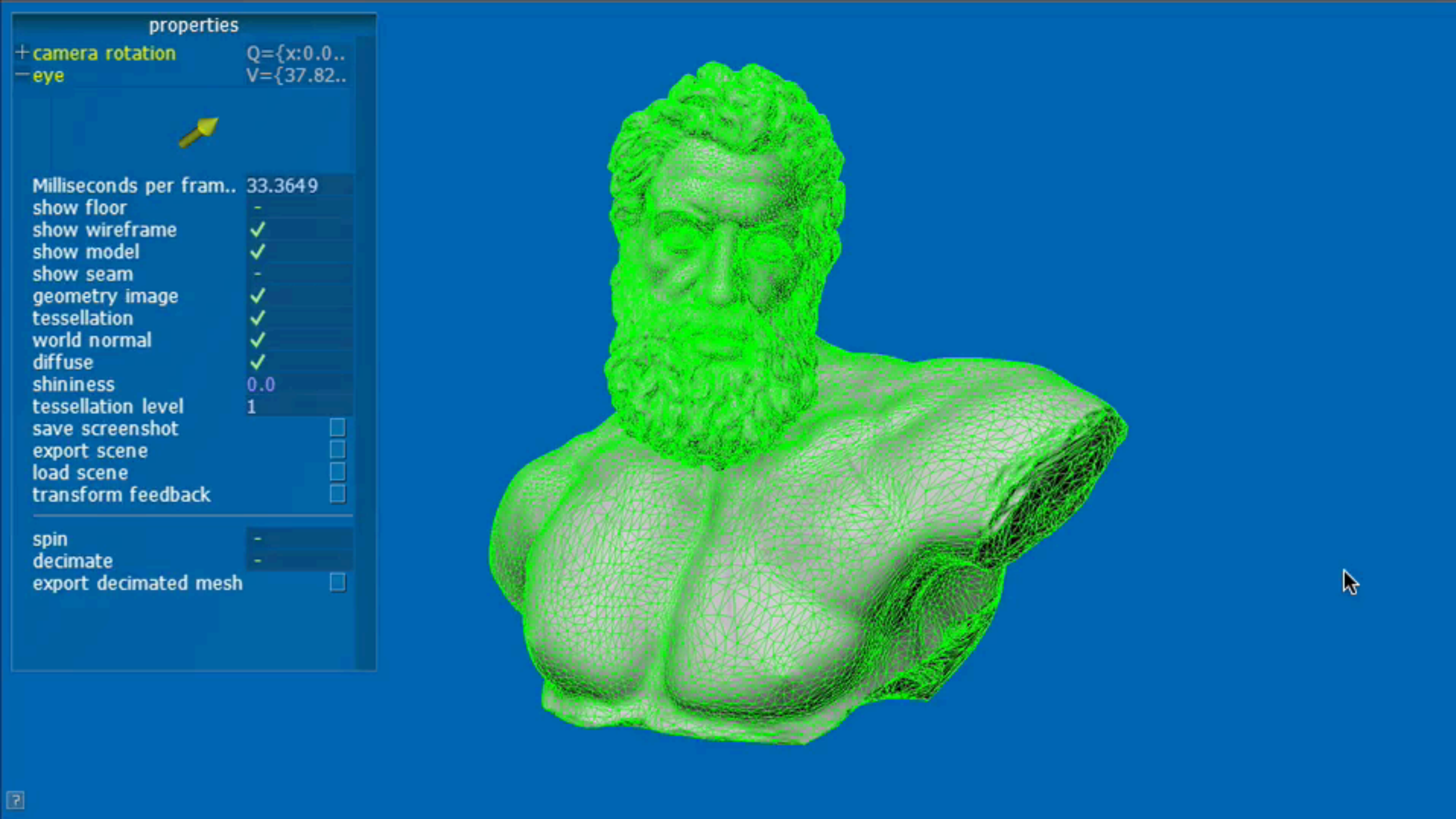
Seam Aware Decimation: Results

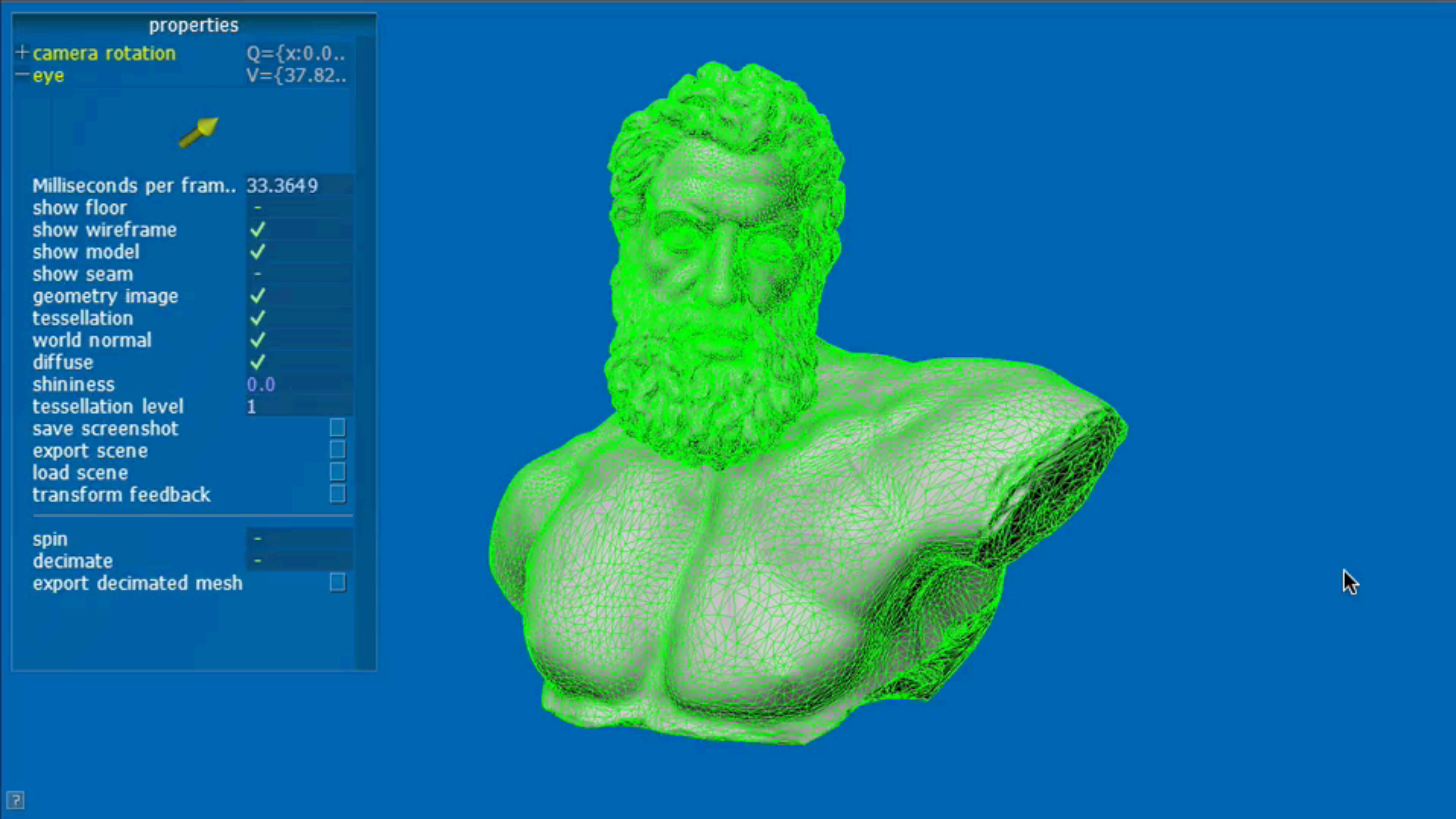
DECIMATION RESULT

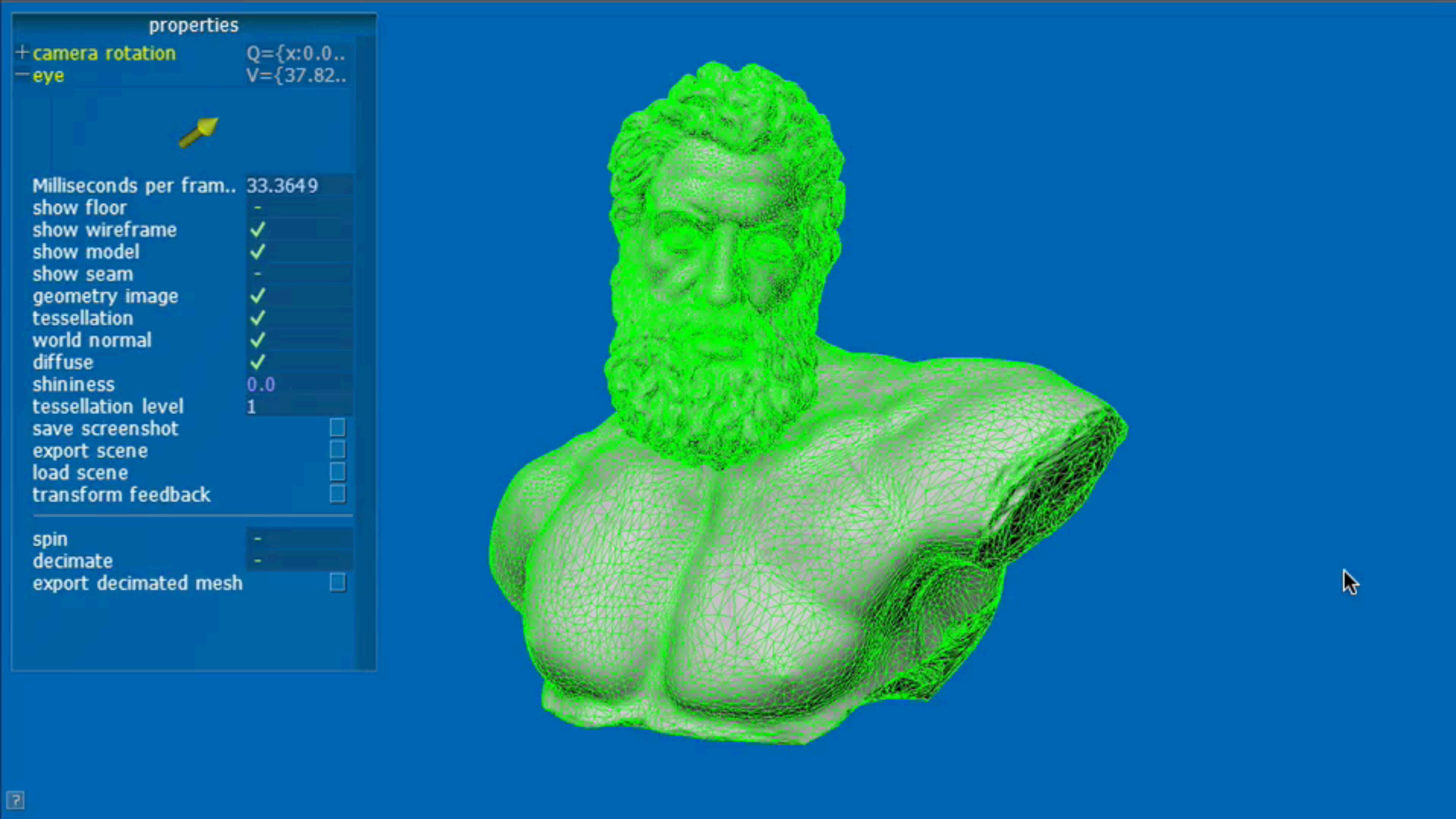


DECIMATION RESULT




properties
+ camera rotation Q={x:0.0..
— eye V={37.82..
Milliseconds per fram.. 33.3649
show floor -
show wireframe ✓
show model ✓
show seam -
geometry image ✓
tessellation ✓
world normal ✓
diffuse ✓
shininess 0.0
tessellation level 1
save screenshot
export scene
load scene
transform feedback
spin -
decimate -
export decimated mesh

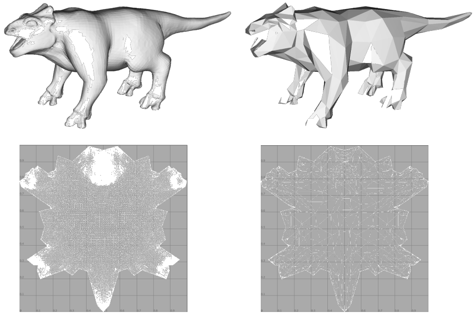

properties
camera rotation
Q={x:0.0..
eye
V={37.82..
Milliseconds per fram..
33.3649
show floor
show wireframe
show model
show seam
geometry image
tessellation
world normal
diffuse
shininess
0.0
tessellation level
1
save screenshot
export scene
load scene
transform feedback
spin
decimate
export decimated mesh


properties
camera rotation Q={x:0.0..
eye V={37.82..
Milliseconds per fram.. 33.3649
show floor -
show wireframe ✓
show model ✓
show seam -
geometry image ✓
tessellation ✓
world normal ✓
diffuse ✓
shininess 0.0
tessellation level 1
save screenshot
export scene
load scene
transform feedback
spin -
decimate -
export decimated mesh

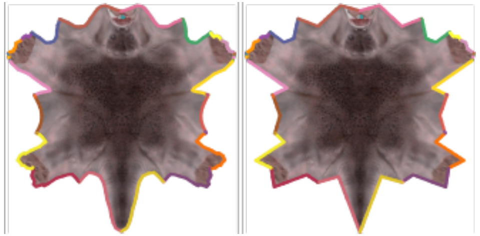
CONTRIBUTIONS

Seam Erasure

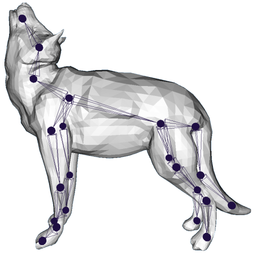
Seam Aware Decimation



Seam Straightener



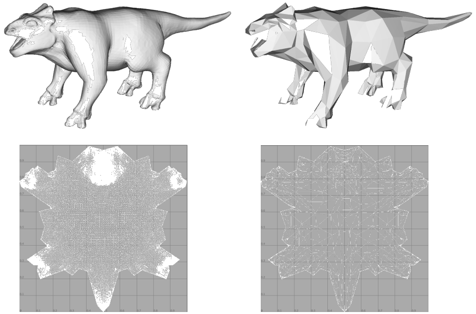
Weight Maps



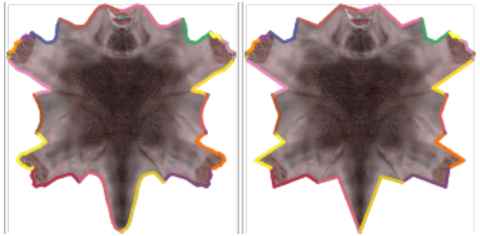
CONTRIBUTIONS

Seam Erasure

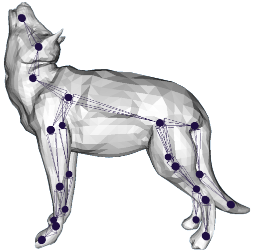
Seam Aware Decimation



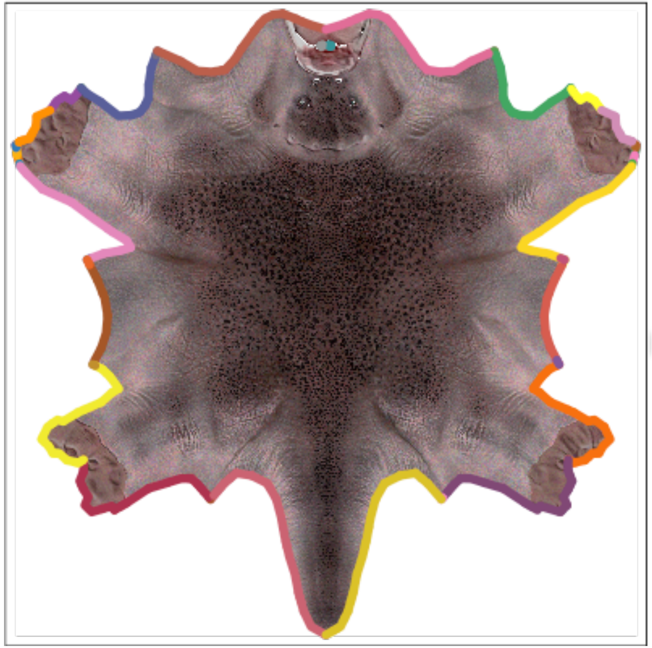
Seam Straightener



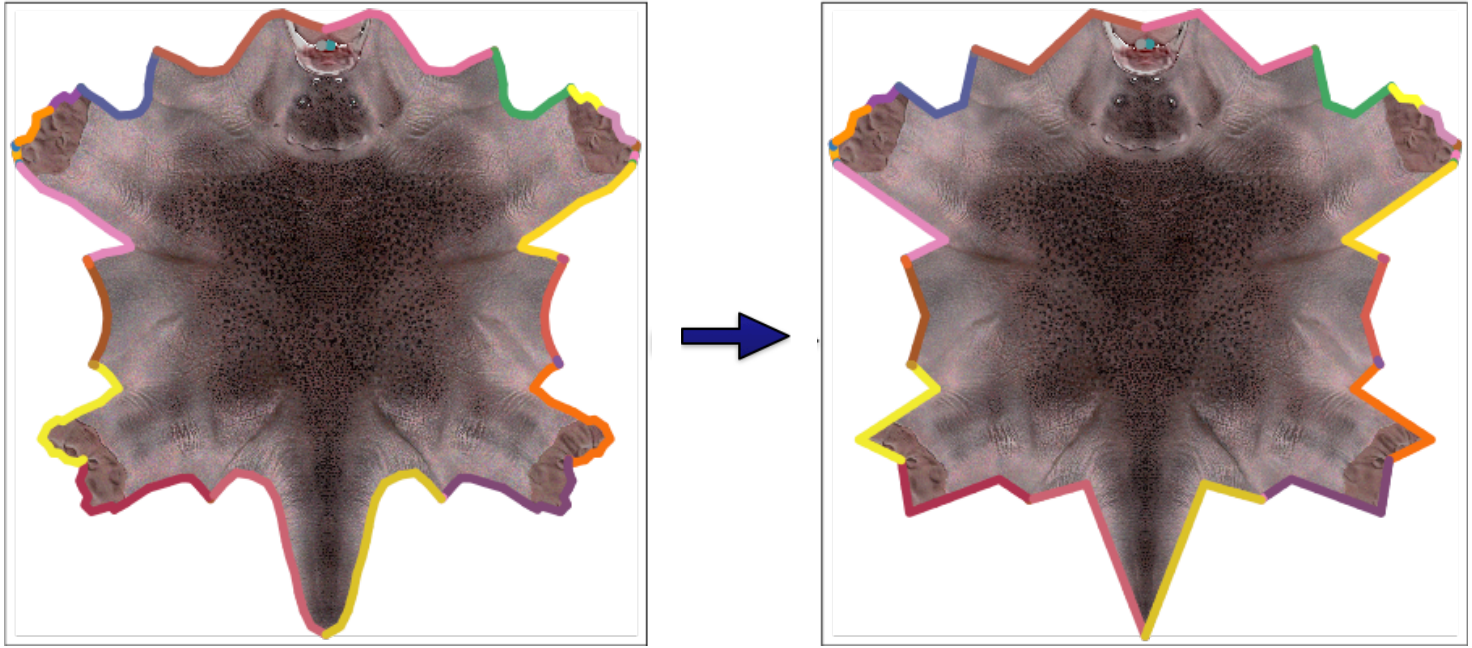
Weight Maps



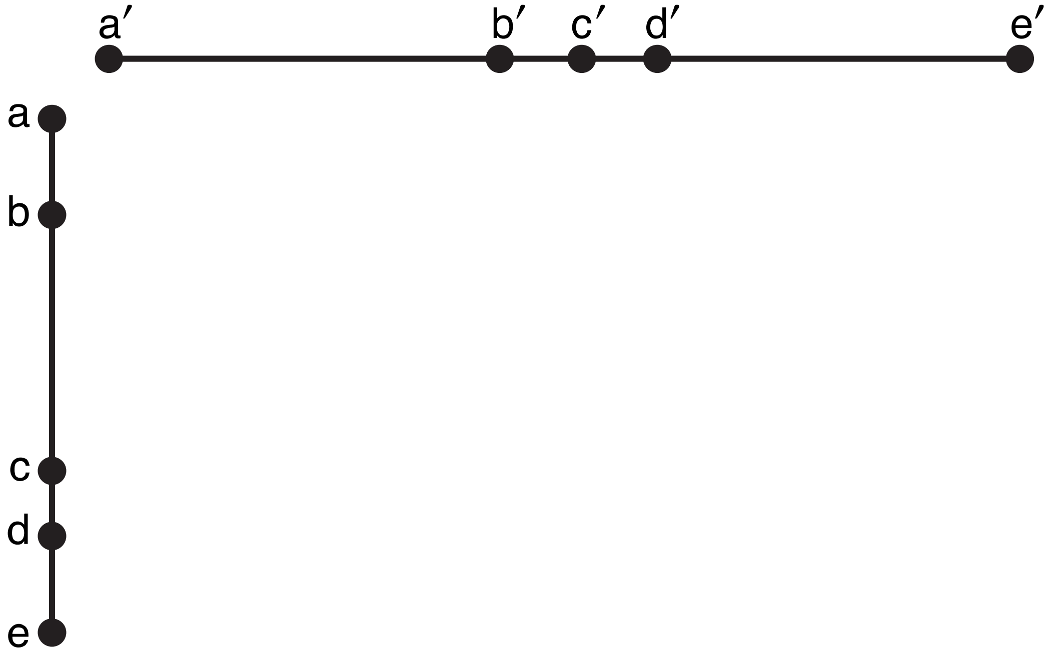
SEAM STRAIGHTENER



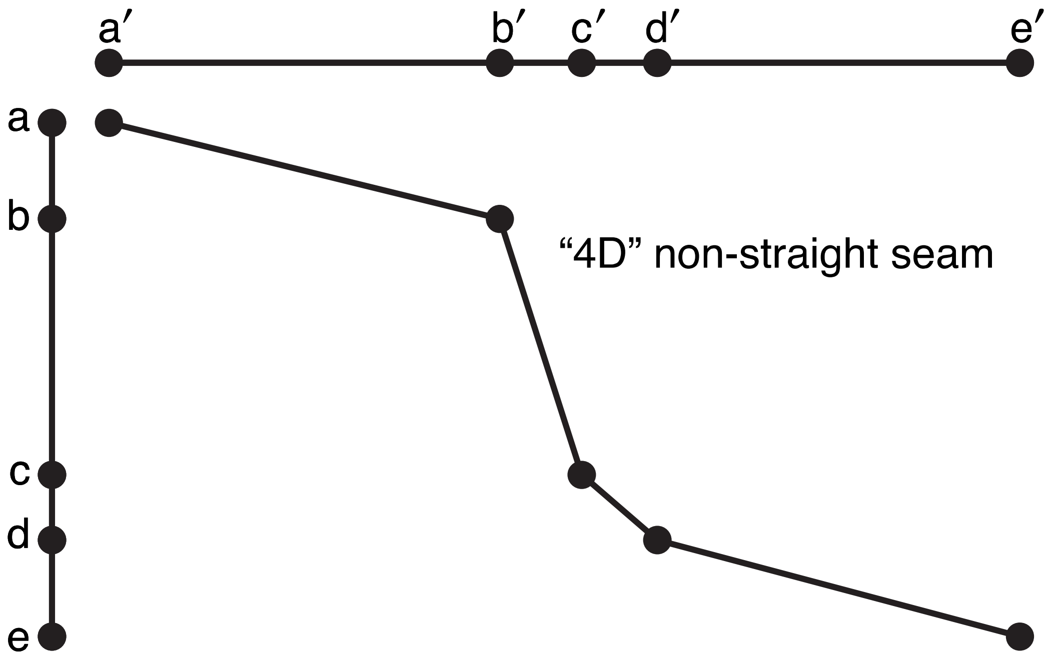
SEAM STRAIGHTENER



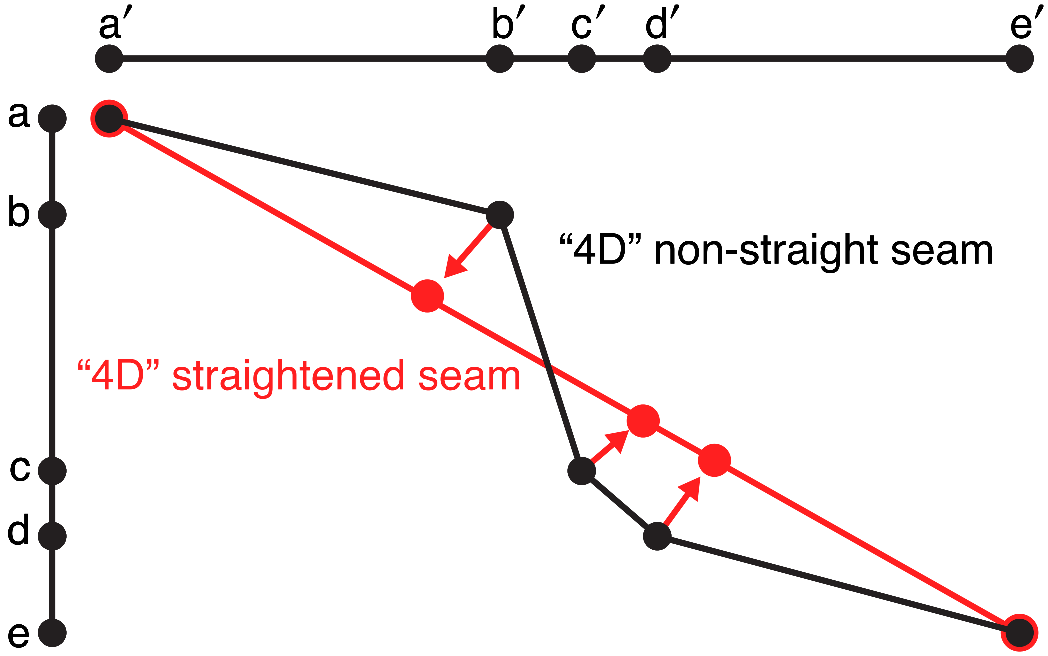
EDGE COMPONENT STRAIGHTENING



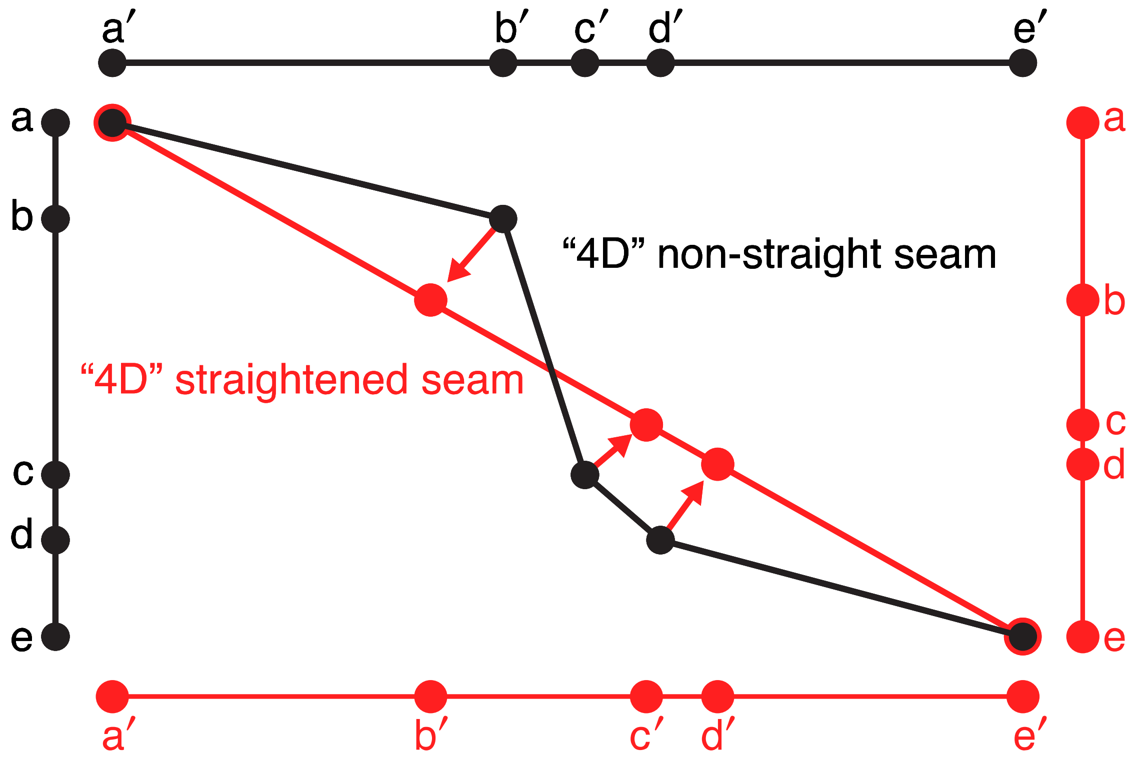
EDGE COMPONENT STRAIGHTENING



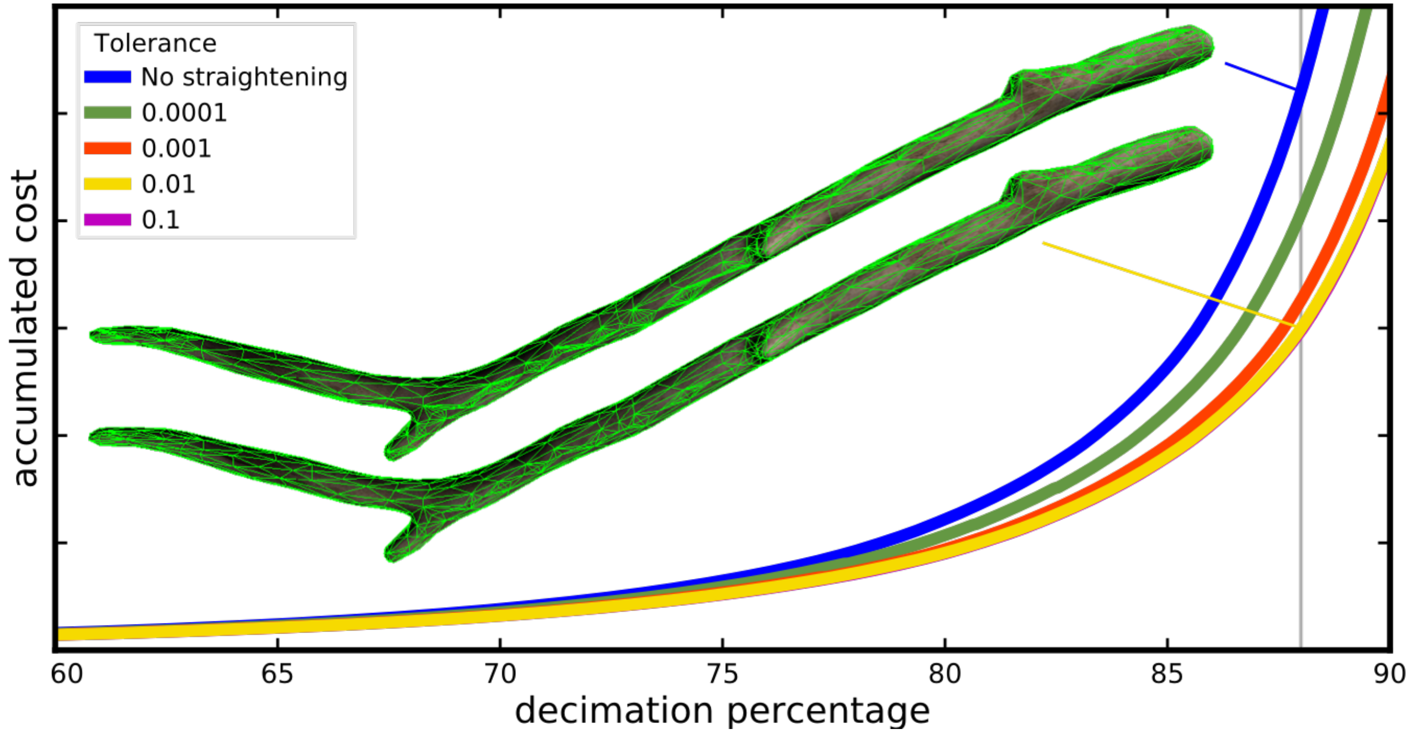
EDGE COMPONENT STRAIGHTENING



EDGE COMPONENT STRAIGHTENING



SEAM STRAIGHTENING RESULTS



UN-COLLAPSIBLE EDGES

Example	# Un-Collapsible Edges Before	# Un-Collapsible Edges After
Chimp	805	171
Hercules	626	290
Animal	369	17
Wolf	374	173

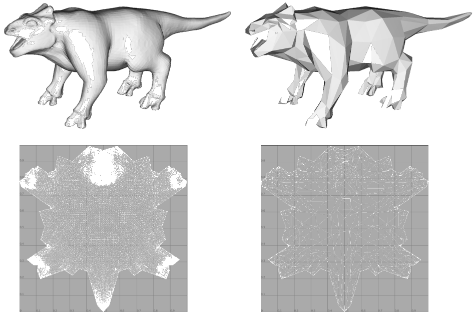
UN-COLLAPSIBLE EDGES

Example	# Un-Collapsible Edges Before	# Un-Collapsible Edges After
Chimp	805	171
Hercules	626	290
Animal	369	17
Wolf	374	173

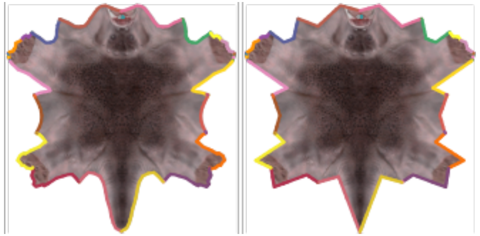
CONTRIBUTIONS

Seam Erasure

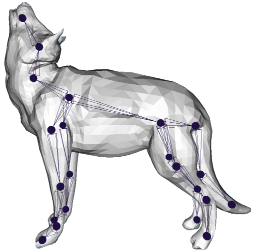
Seam Aware Decimation



Seam Straightener



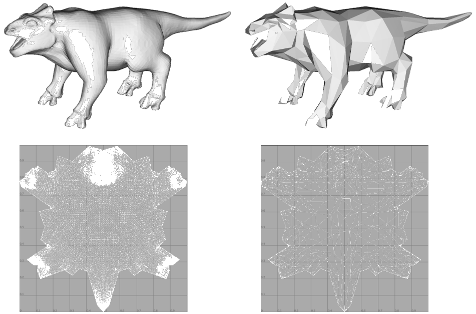
Weight Maps



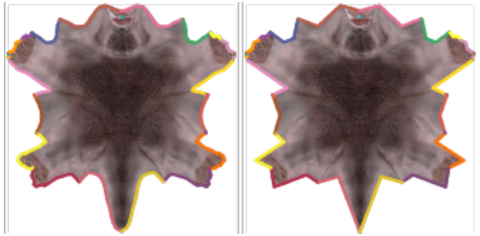
CONTRIBUTIONS

Seam Erasure

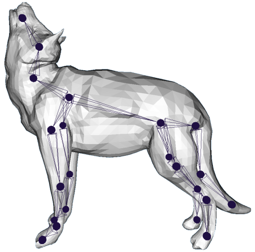
Seam Aware Decimation



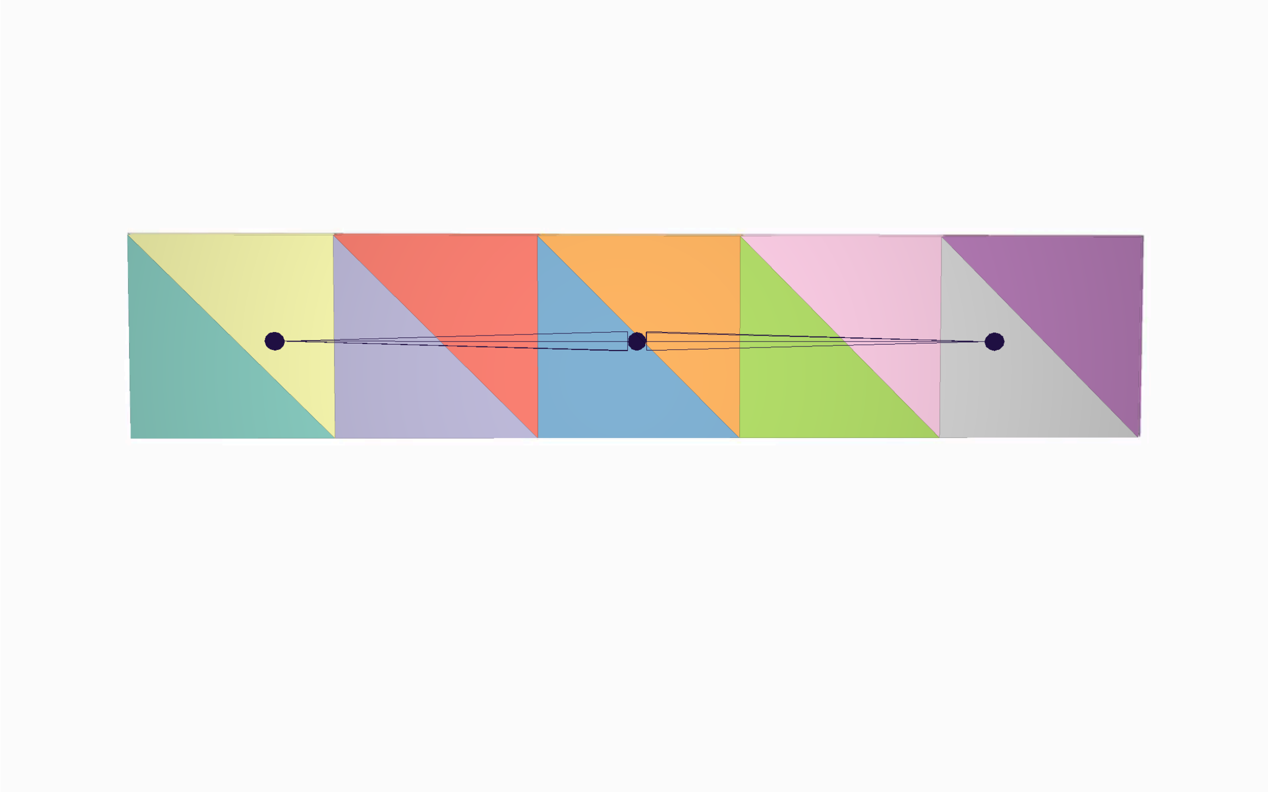
Seam Straightener



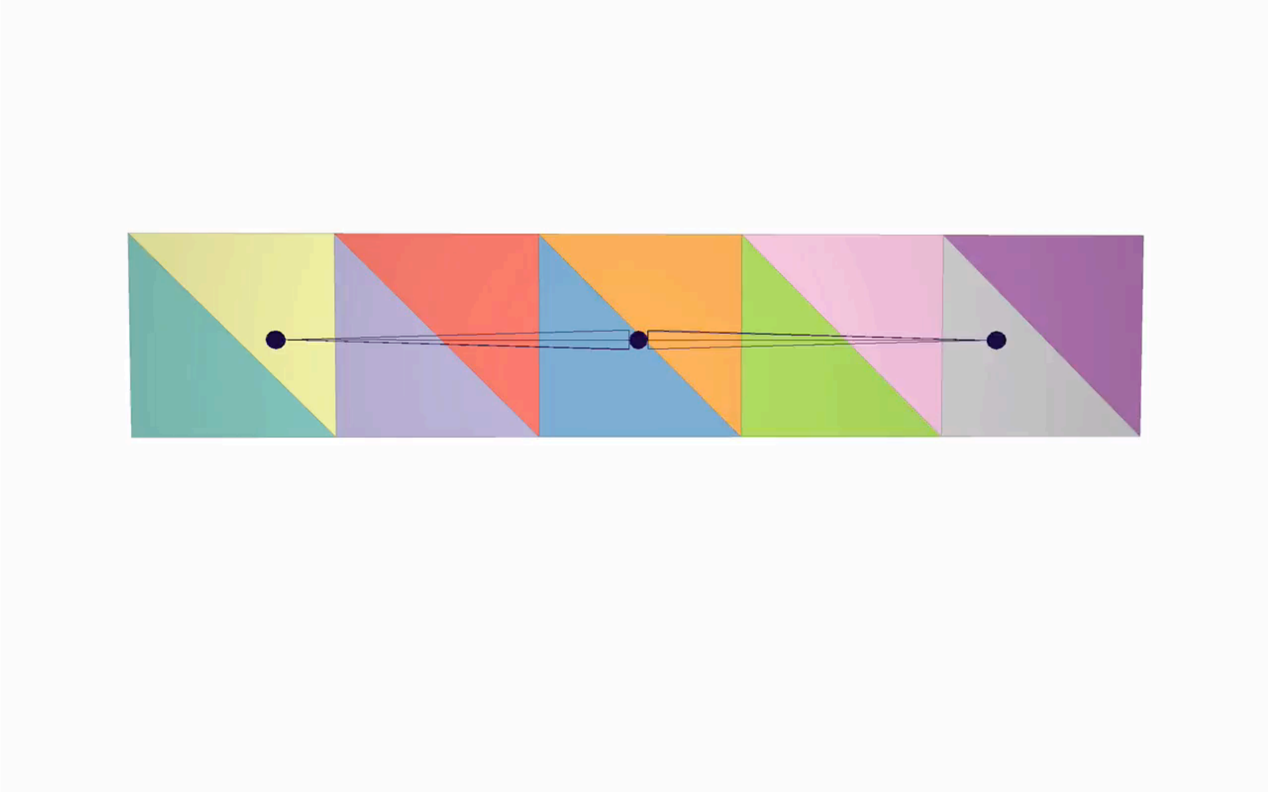
Weight Maps



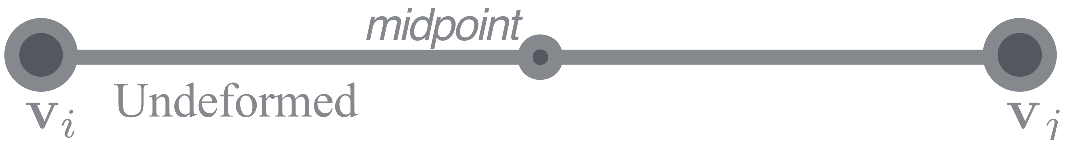
PER-VERTEX SKINNING



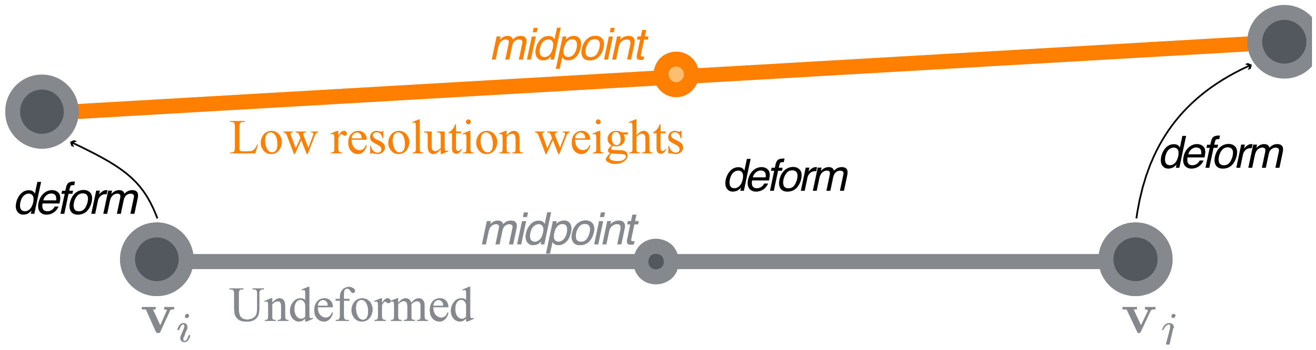
PER-VERTEX SKINNING



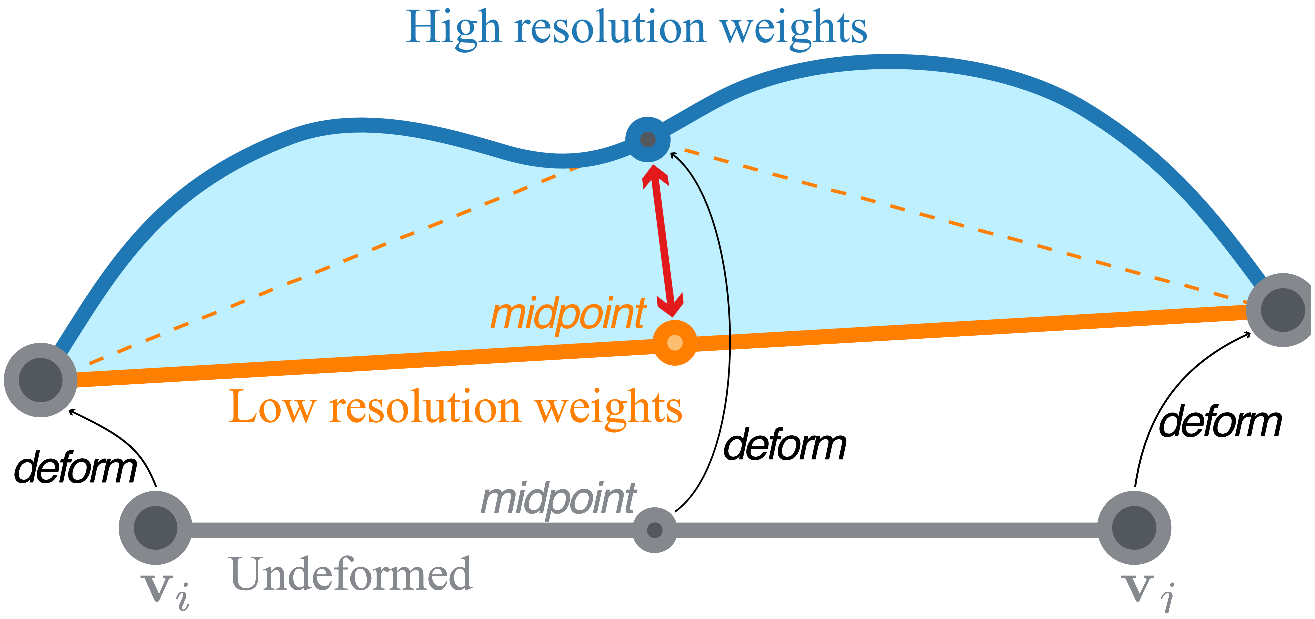
PER-VERTEX SKINNING



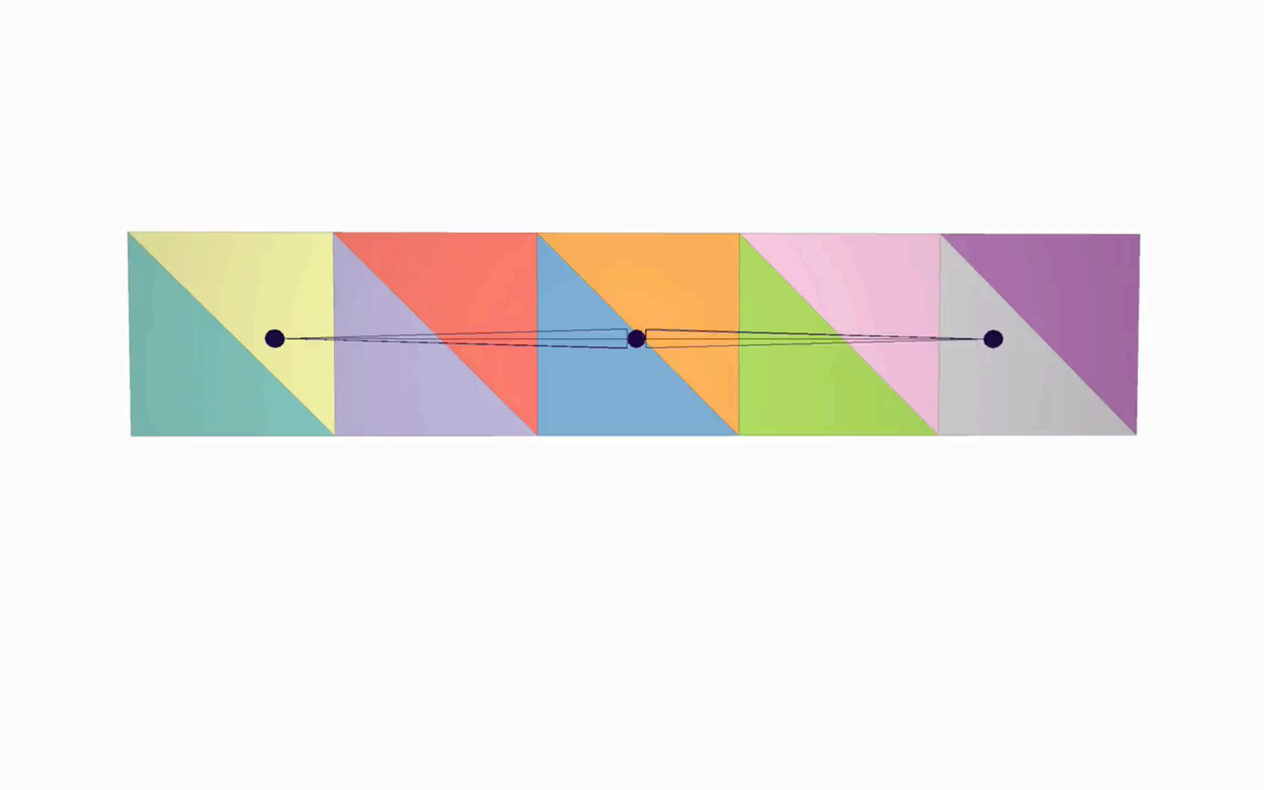
PER-VERTEX SKINNING



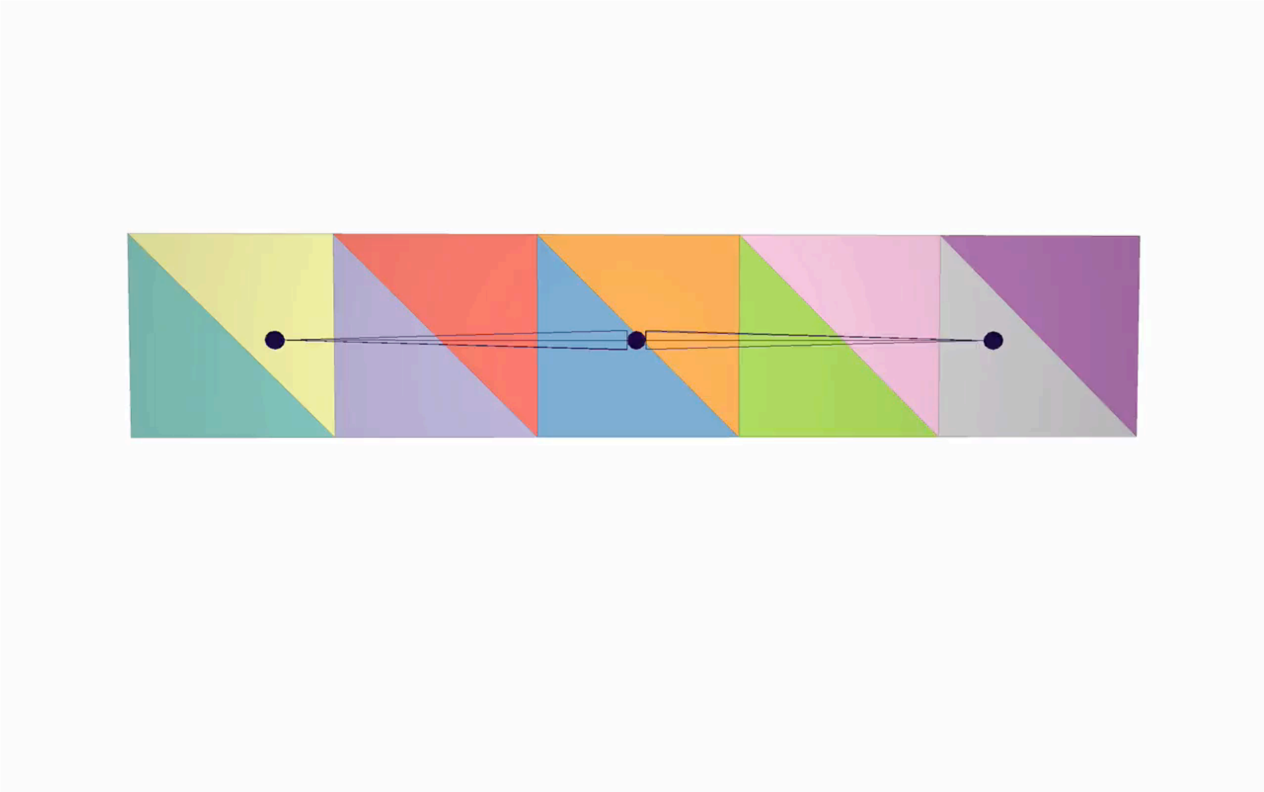
PER-VERTEX SKINNING



SKINNING WITH HIGH-RESOLUTION WEIGHTS

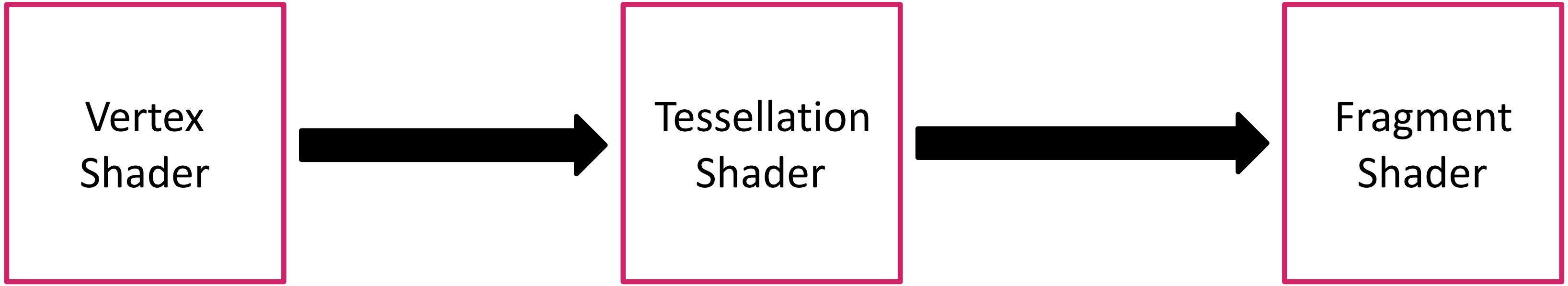


SKINNING WITH HIGH-RESOLUTION WEIGHTS

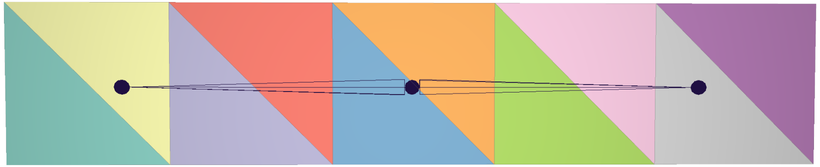


MODERN GPU PIPELINE

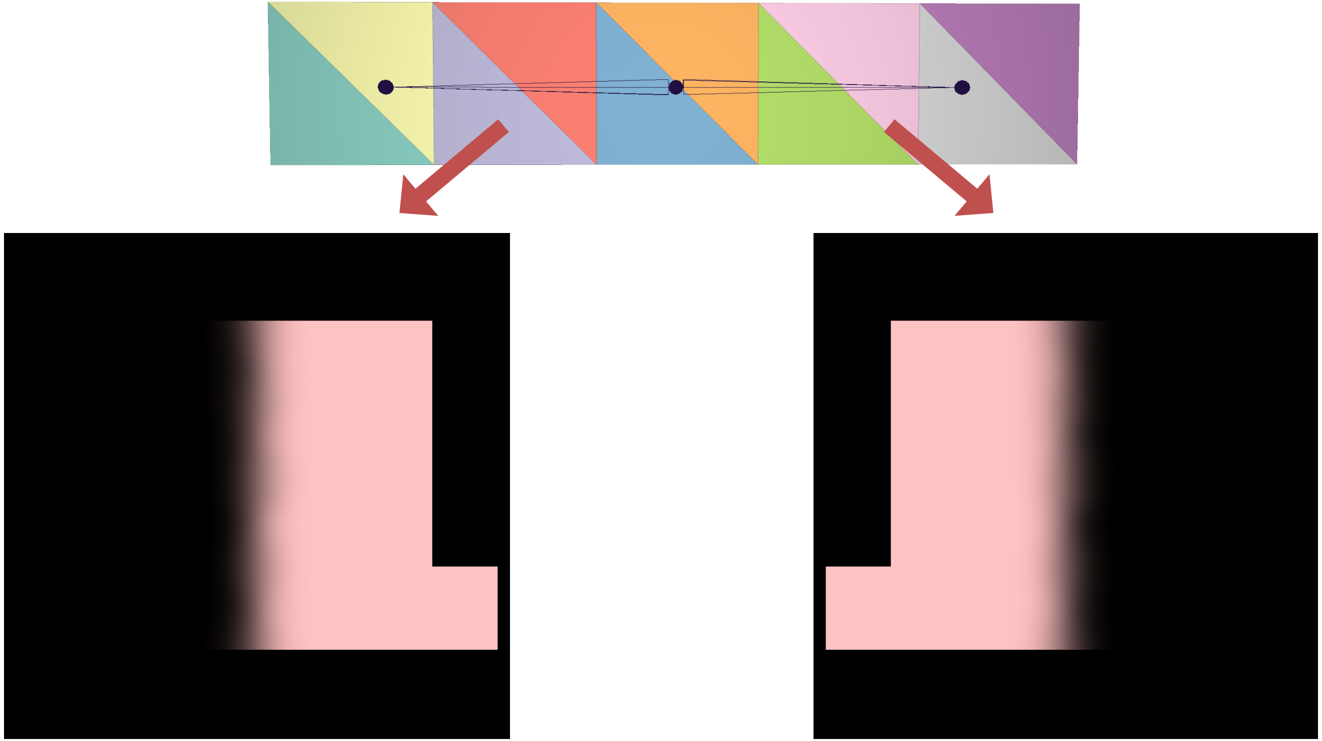
MODERN GPU PIPELINE



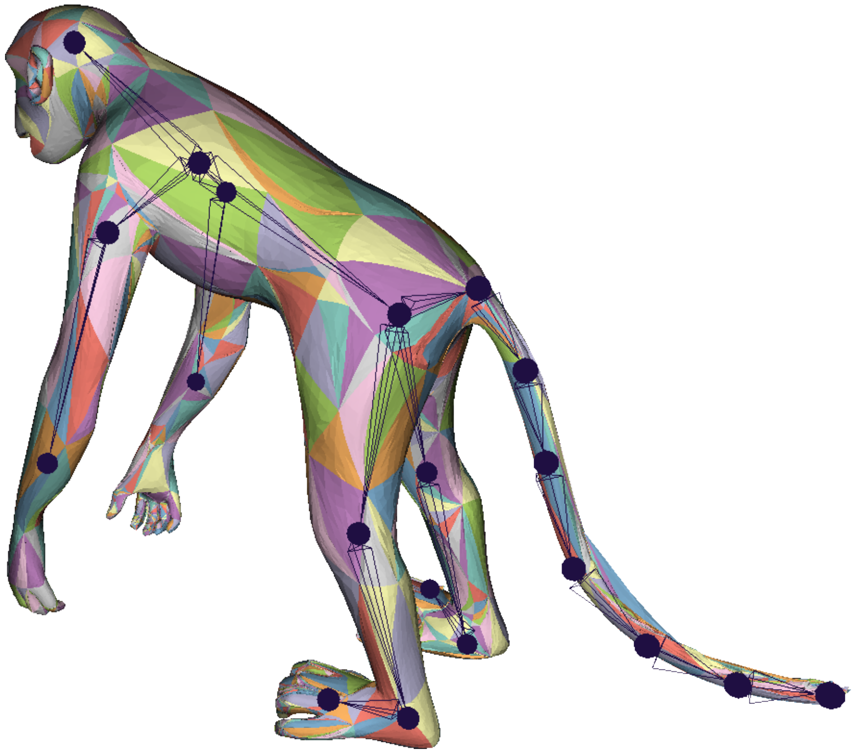
WEIGHTS MAP AS TEXTURES



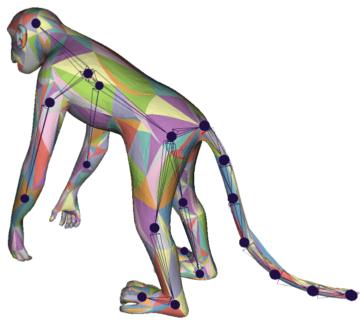
WEIGHTS MAP AS TEXTURES

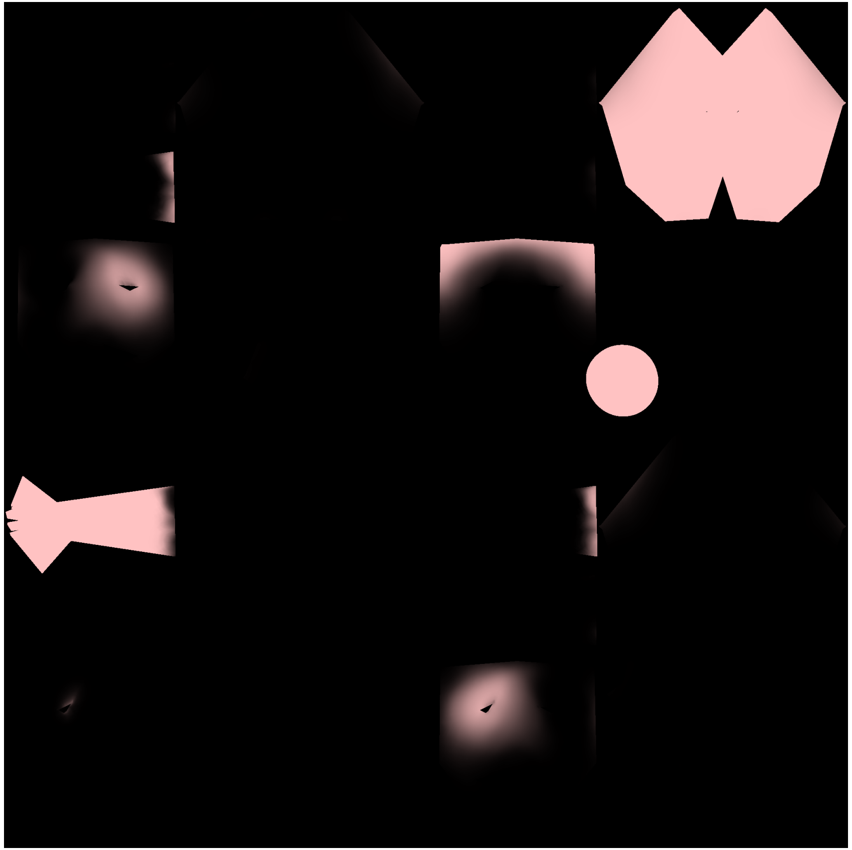


SKIN COMPLICATED MODEL WITH WEIGHT TEXTURES

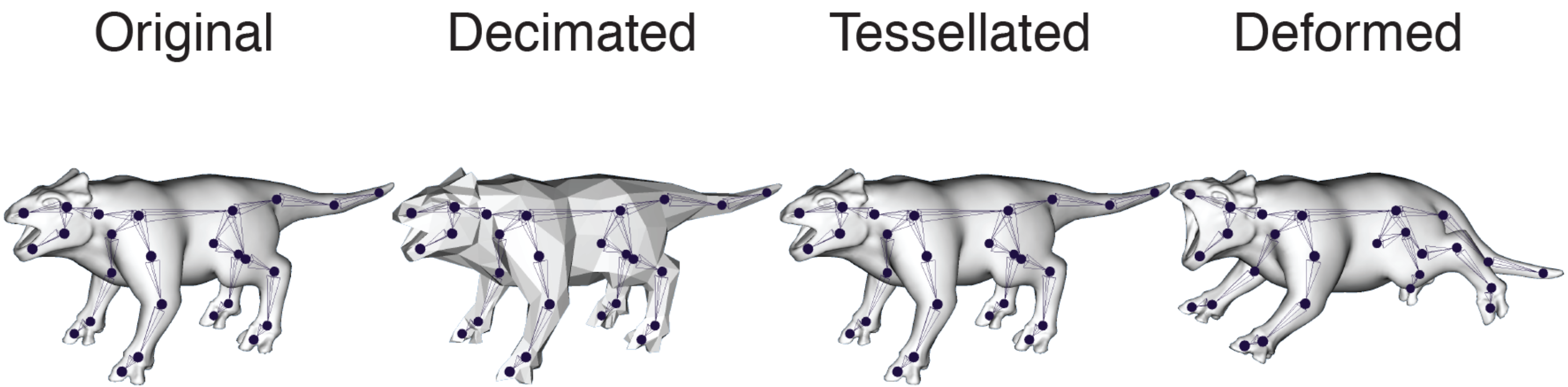


SKIN COMPLICATED MODEL WITH WEIGHT TEXTURES

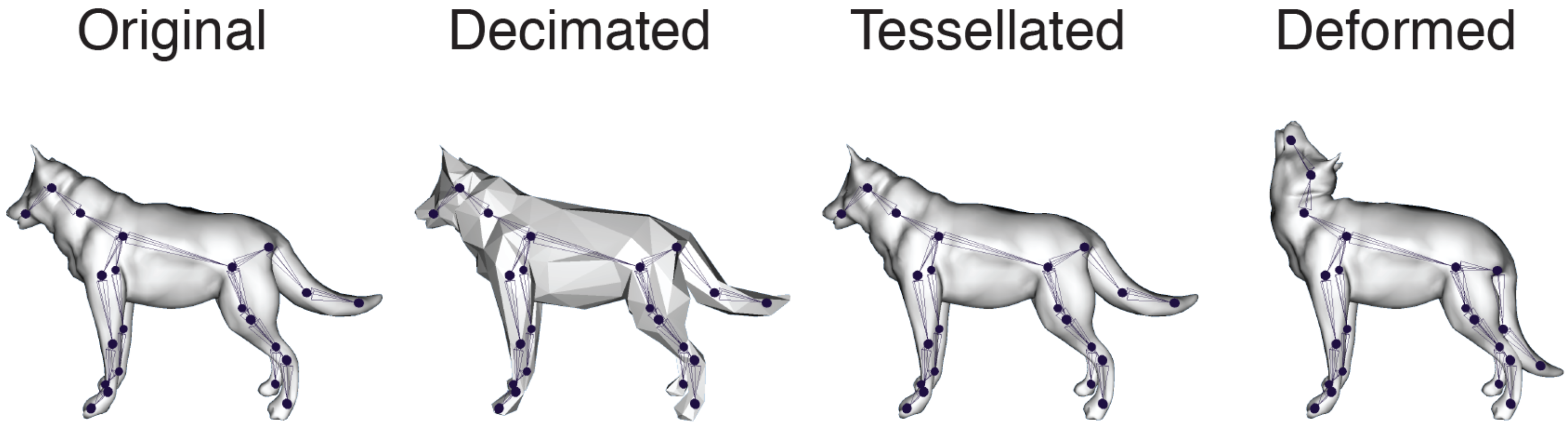




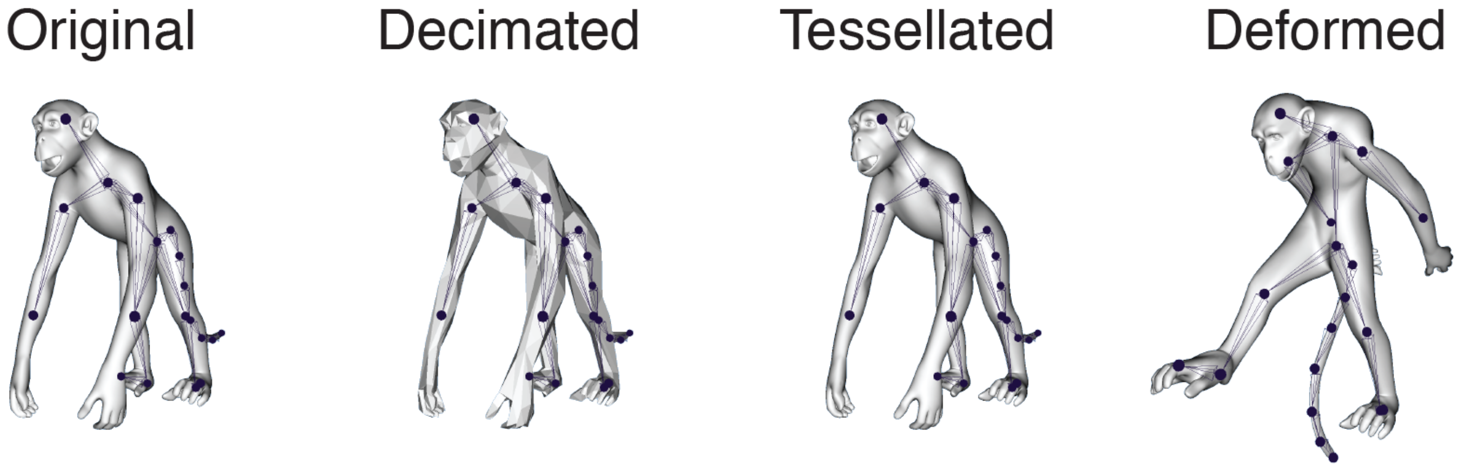
DEFORMATION WITH WEIGHT MAPS



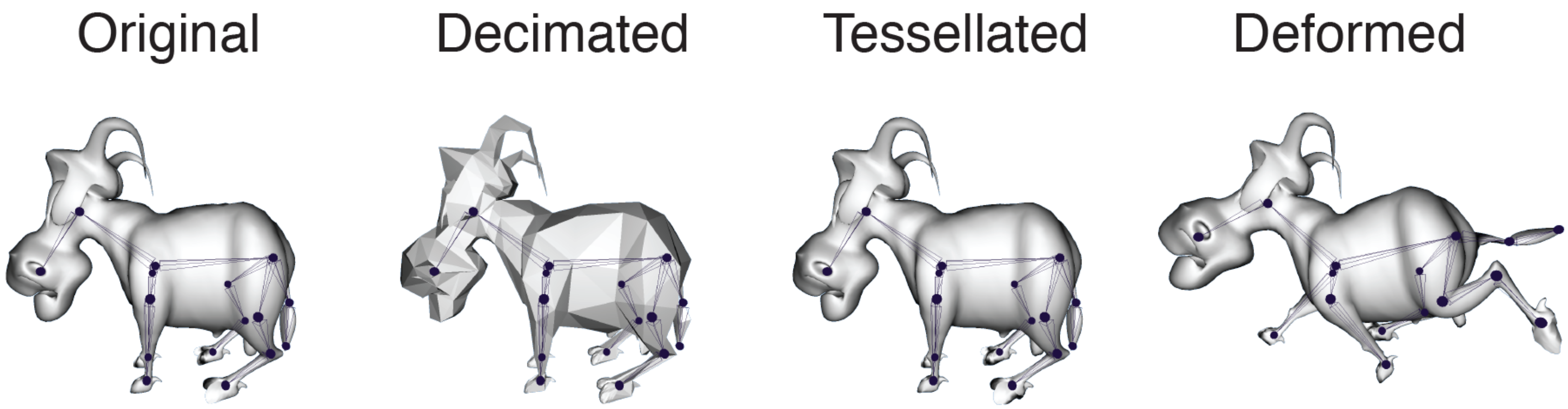
DEFORMATION WITH WEIGHT MAPS



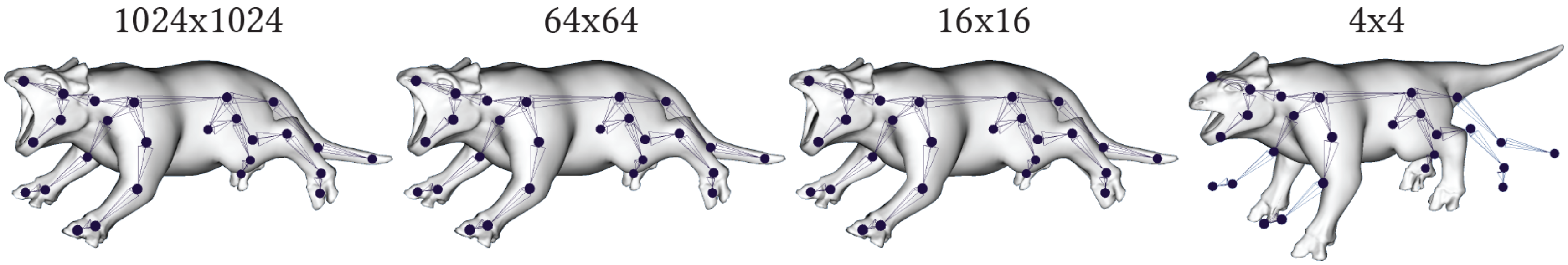
DEFORMATION WITH WEIGHT MAPS



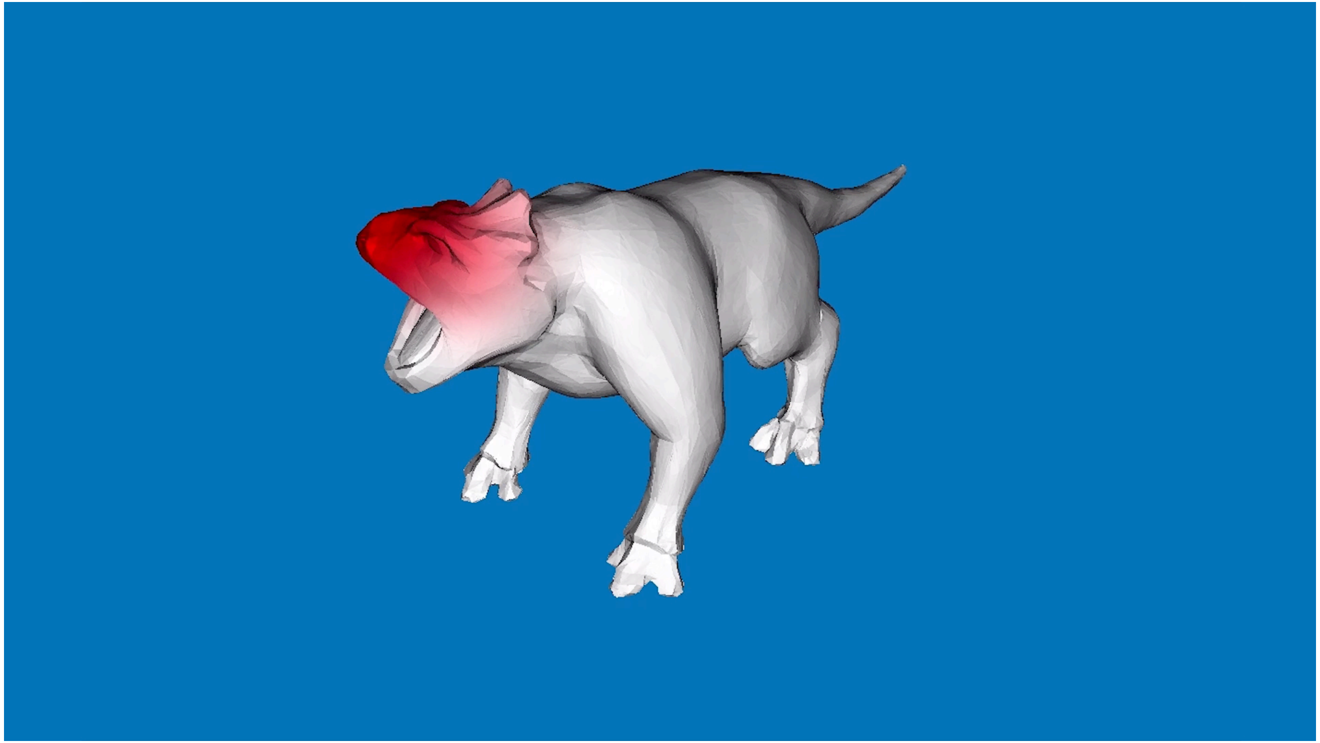
DEFORMATION WITH WEIGHT MAPS



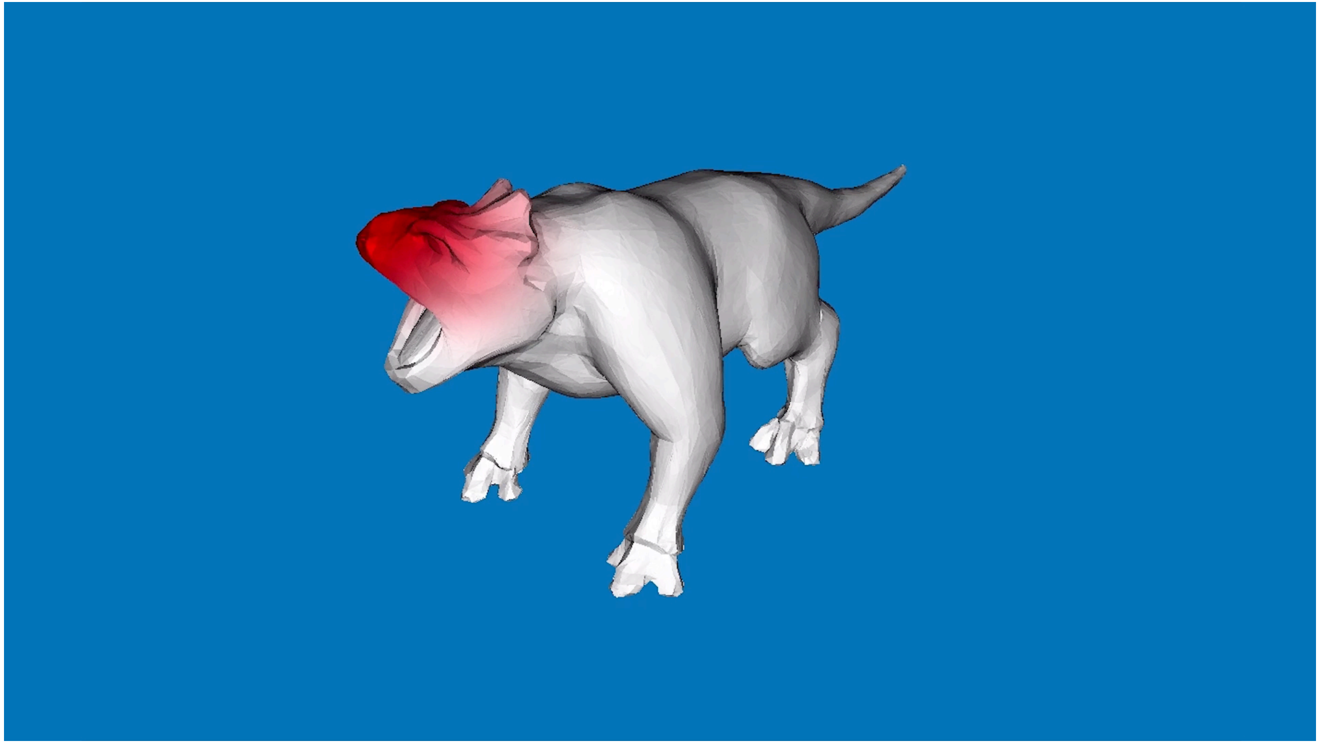
RESOLUTION OF WEIGHT MAPS



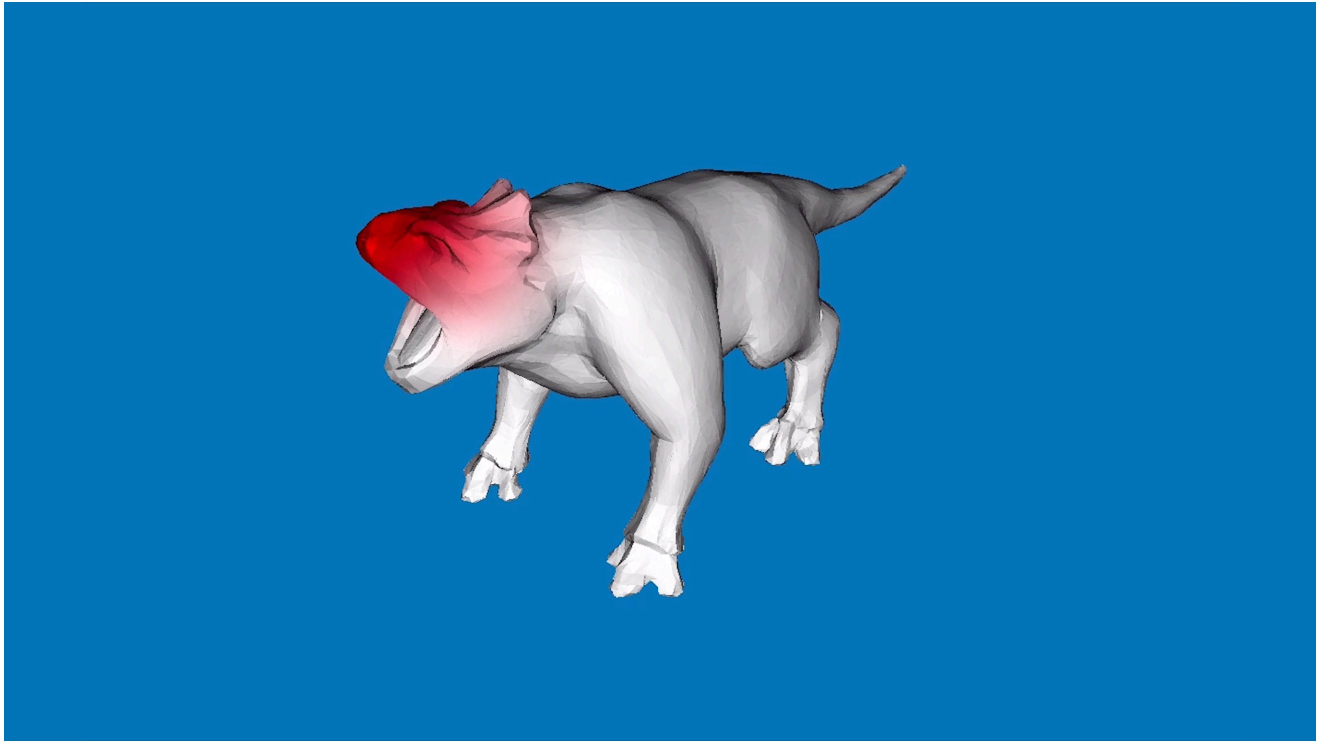
WEIGHT PAINTING



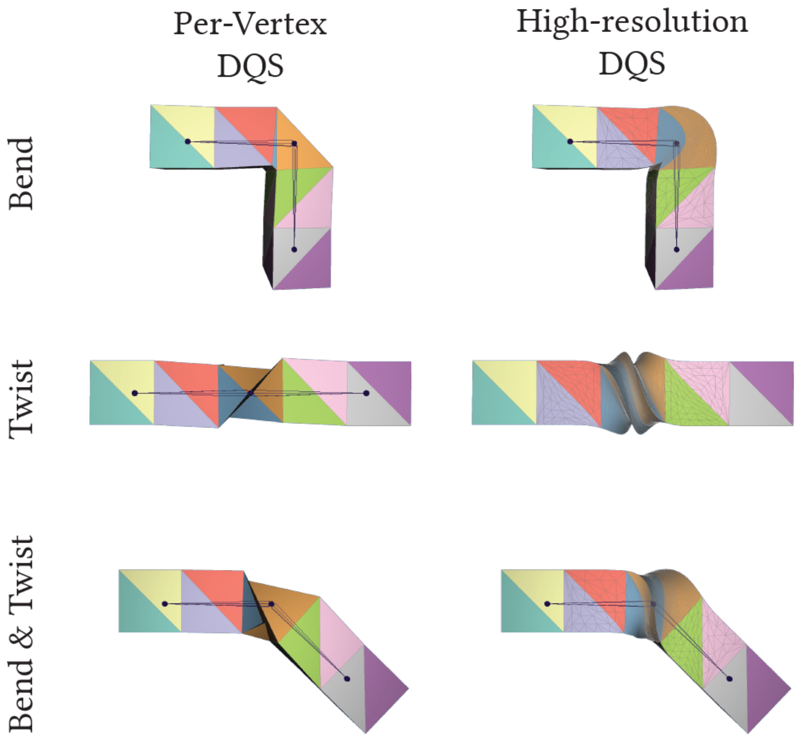
WEIGHT PAINTING



WEIGHT PAINTING



DUAL QUATERNION SKINNING WITH WEIGHT MAPS



FREE-FORM DEFORMATION WITH WEIGHT MAPS

CONCLUSION

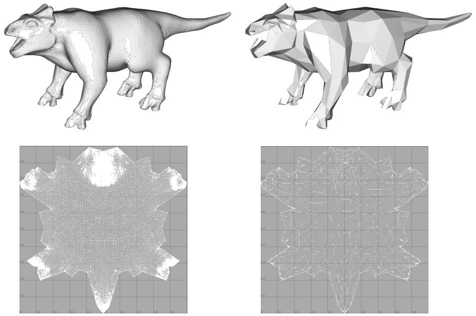
CONCLUSION

Seam Erasure

CONCLUSION

Seam Erasure

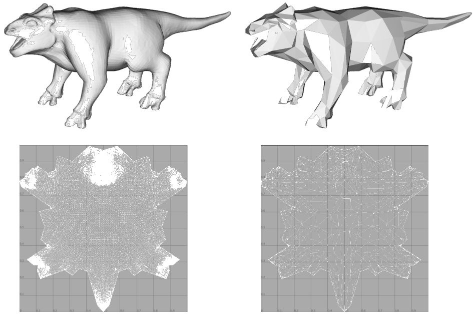
Seam Aware Decimation



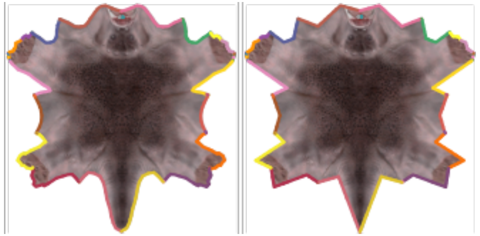
CONCLUSION

Seam Erasure

Seam Aware Decimation



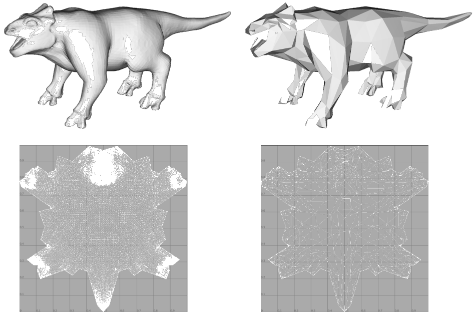
Seam Straightener



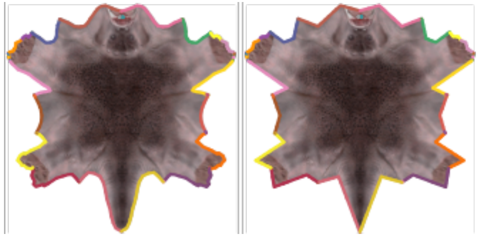
CONCLUSION

Seam Erasure

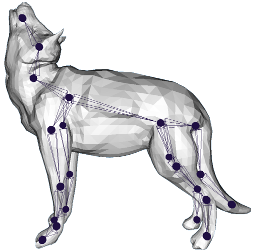
Seam Aware Decimation



Seam Straightener



Weight Maps



LIMITATIONS AND FUTURE WORK

- Limitations:
  - Low resolution result is constant
  - Non-overlapping parametrization
  - Tangent space normal maps
- Future Work:
  - Minimize the bilinear reconstruction error of the displacement and geometry images
  - Volumetric textures (trilinear interpolation)

SEAMLESS: SEAM ERASURE AND SEAM-AWARE DECOUPLING OF SHAPE FROM MESH RESOLUTION

Project page and Source code:

https://cragl.cs.gmu.edu/seamless/

Contact:

Zachary Ferguson, zfergus@nyu.edu

Songrun Liu, sliu11@gmu.edu

CraGL Creativity and Graphics Lab

dgp dynamic graphics project

George Mason University

Computer Science University of Toronto

We are grateful to Guilin Liu and Jyh-Ming Lien, Keenan Crane, and Turbosquid users Sumatra3d, Deniz Ozemre, SpinQuad1976, Pabong, Tornado Studio, and mnphmnmn.

This work was supported by the US NSF, Google, NSERC, and Adobe Systems Inc.