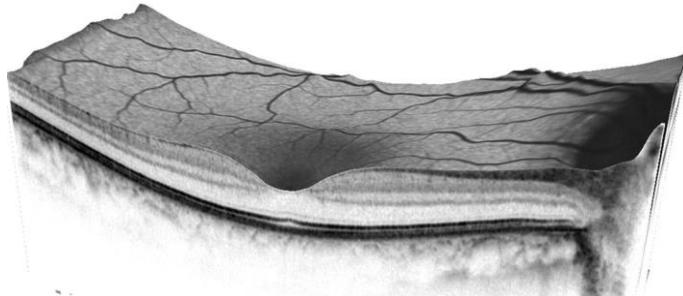




Geometry Processing Pipeline

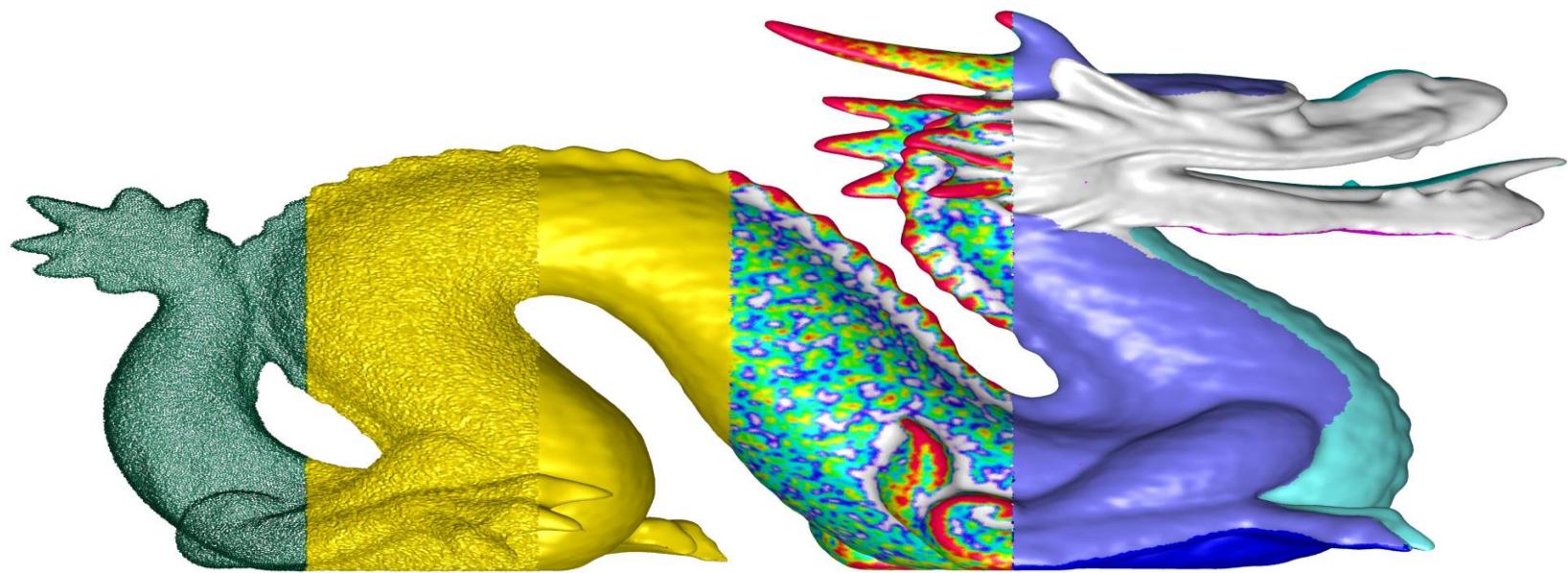
3D Scanning, Smoothing...., 3D Printing and Medical Imaging Applications

Sunil Yadav
ABV Seminar
17.08.2017





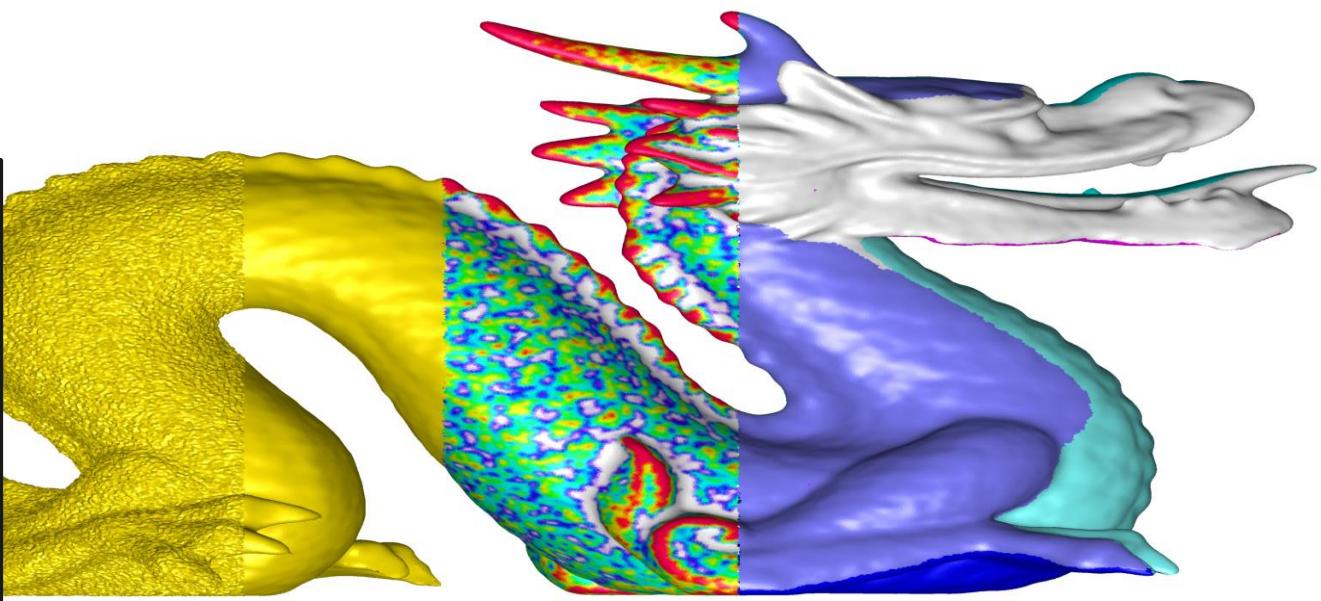
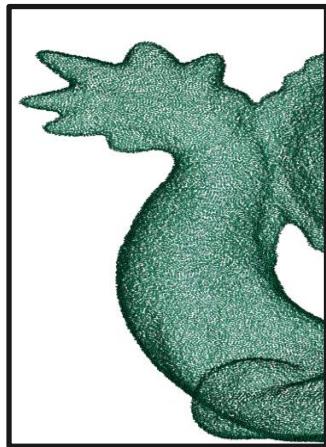
Outline



Outline



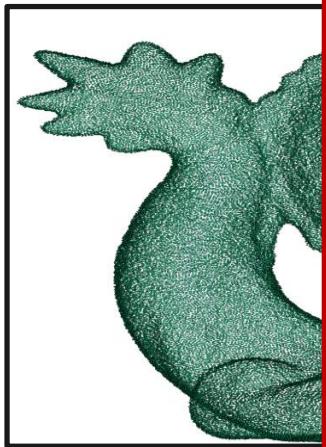
Data Acquisition



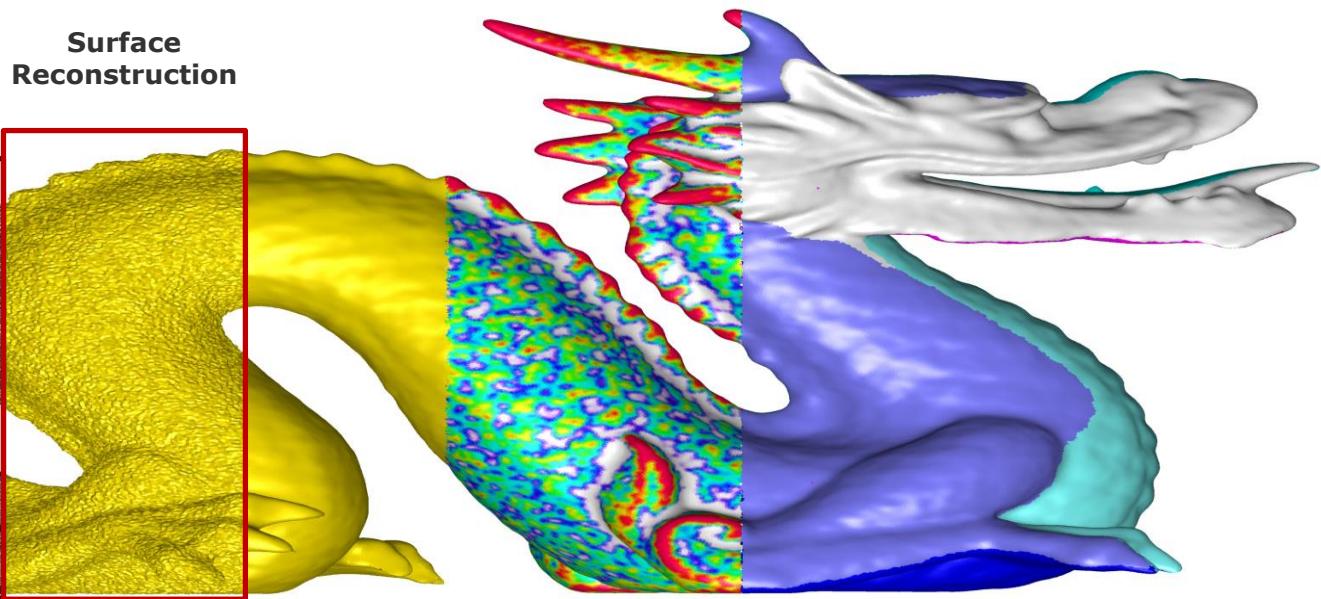
Outline



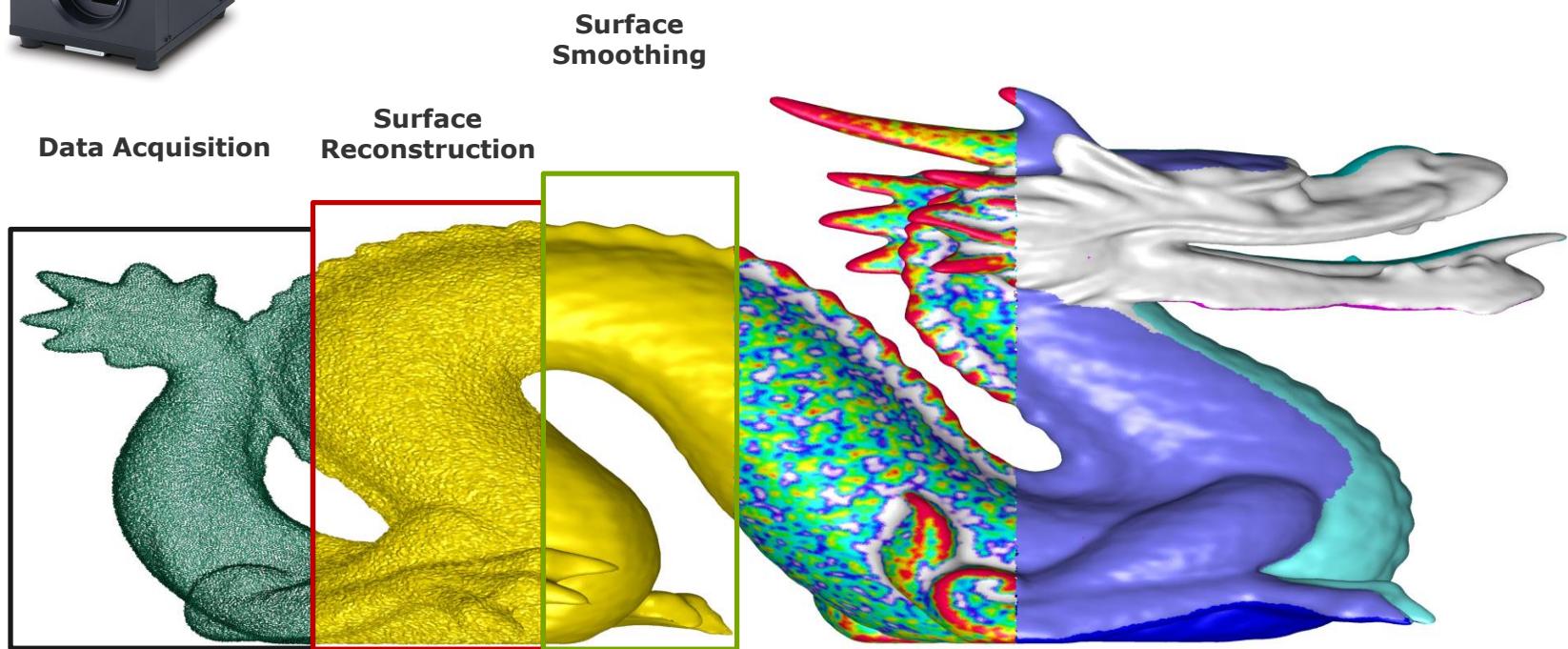
Data Acquisition



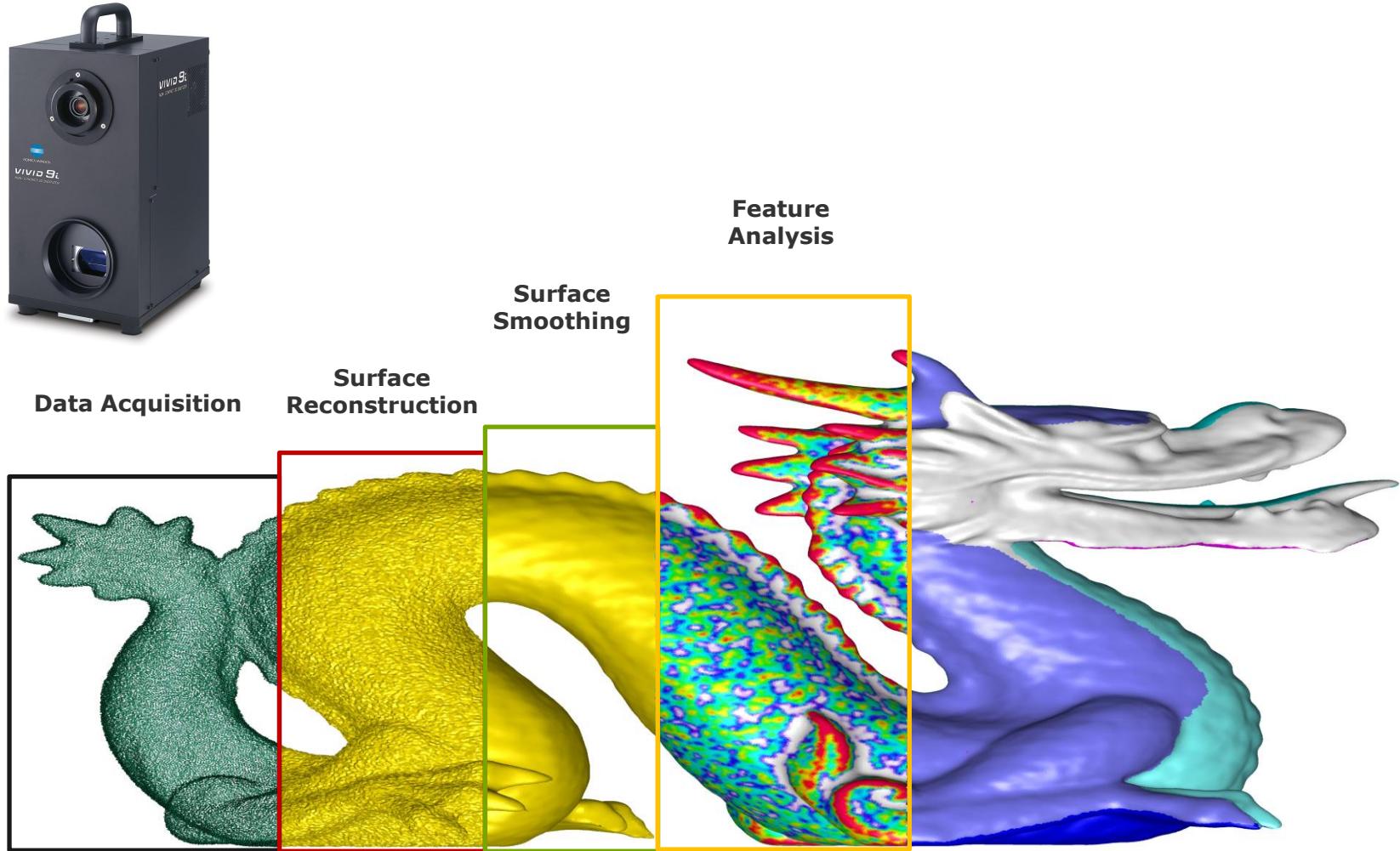
Surface Reconstruction



Outline

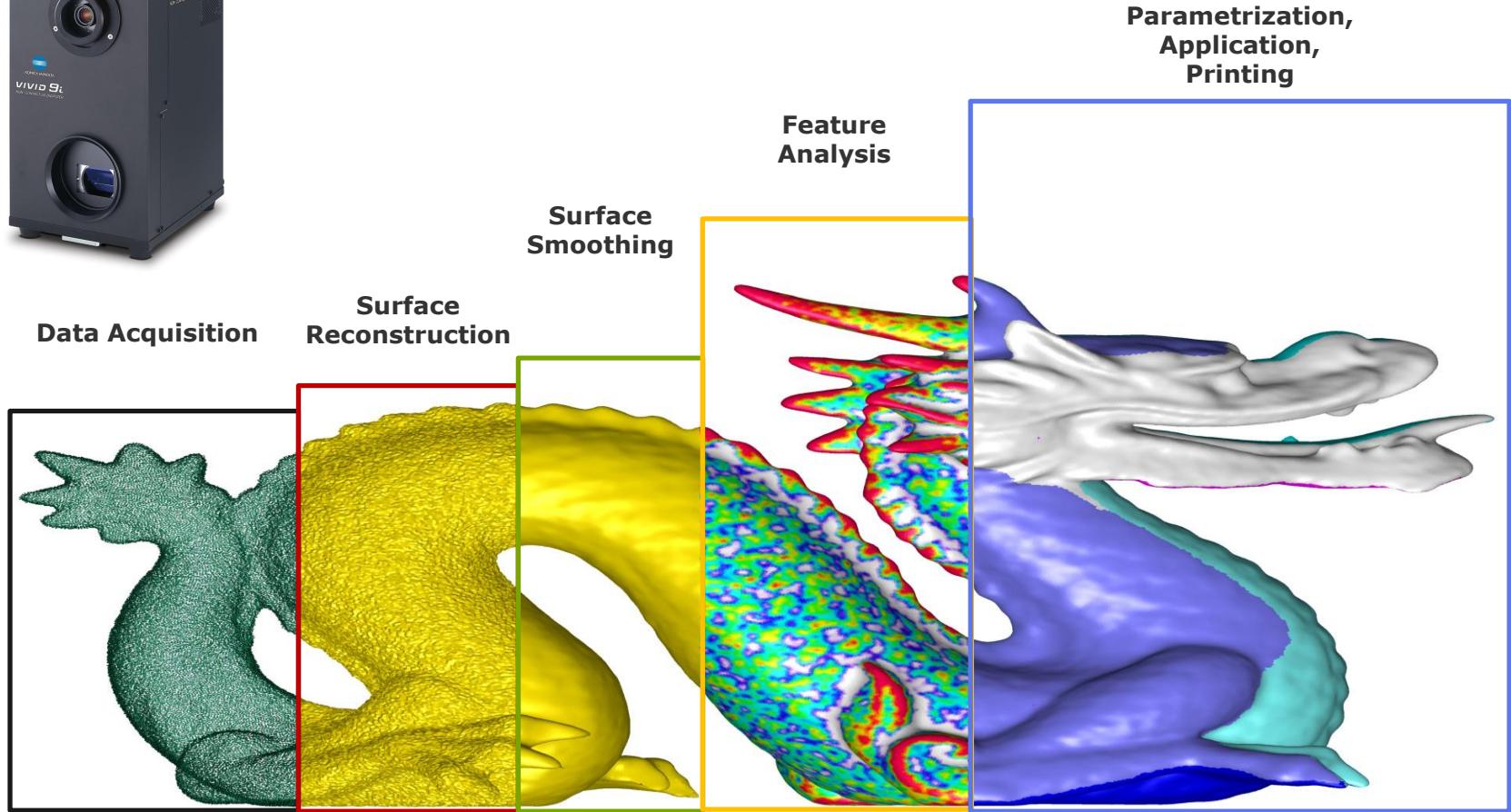


Outline



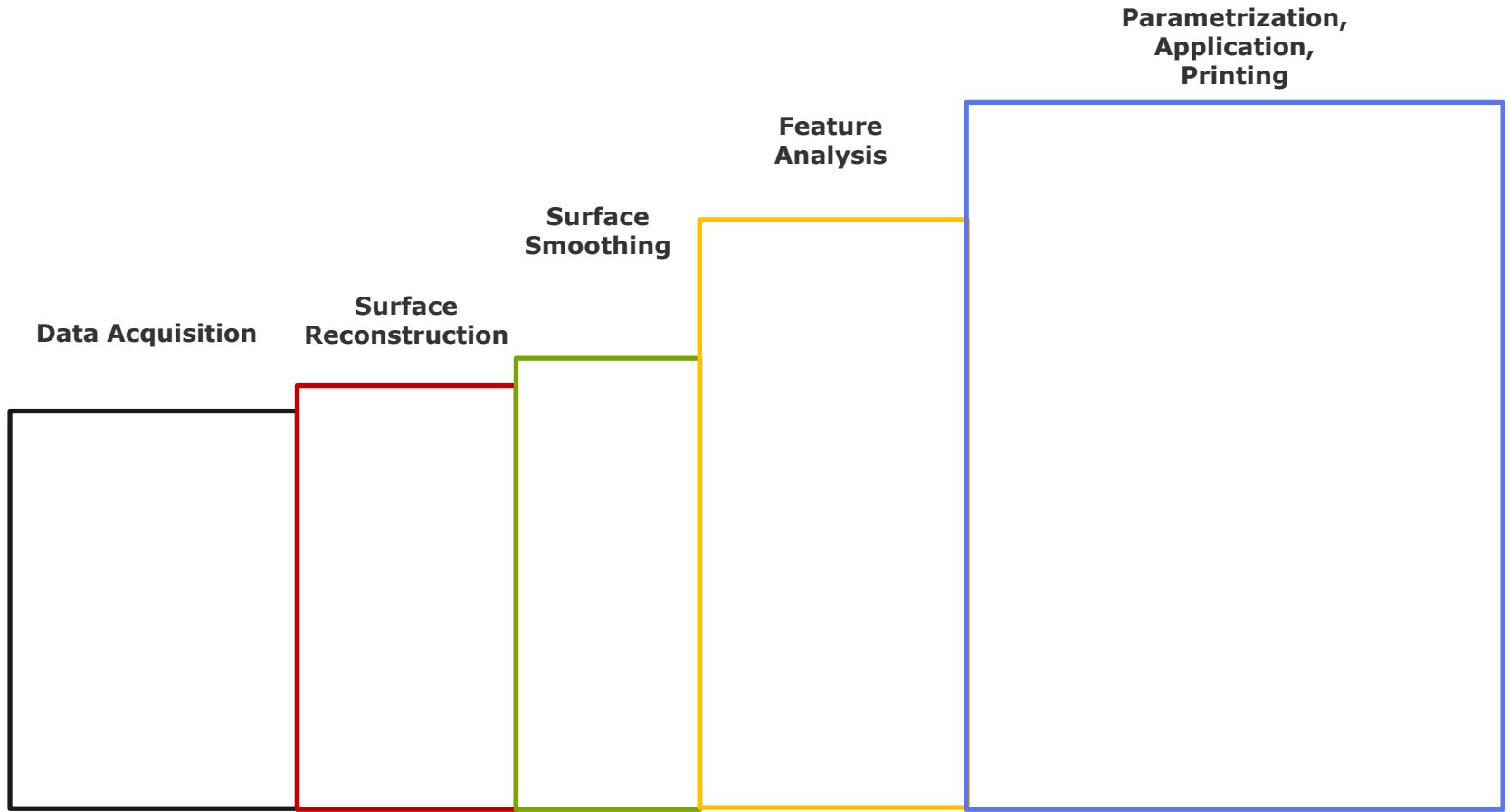


Outline





GPP - Stairs





Data Acquisition – 3D Laser Scanner

Consist of two basic elements:

- Laser Light as the light emitting source.



Data Acquisition – 3D Laser Scanner

Consist of two basic elements:

- Laser Light as the light emitting source.
- CCD (charge coupled device) sensors as the detector of the laser light



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Laser source is connected to rotor.





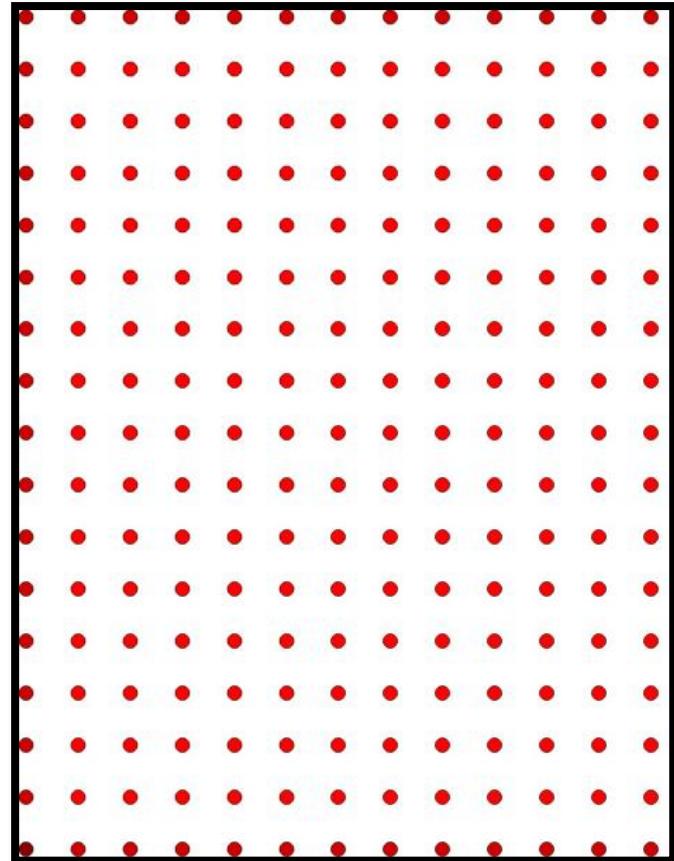
Data Acquisition – 3D Laser Scanner

Consist of two basic elements:

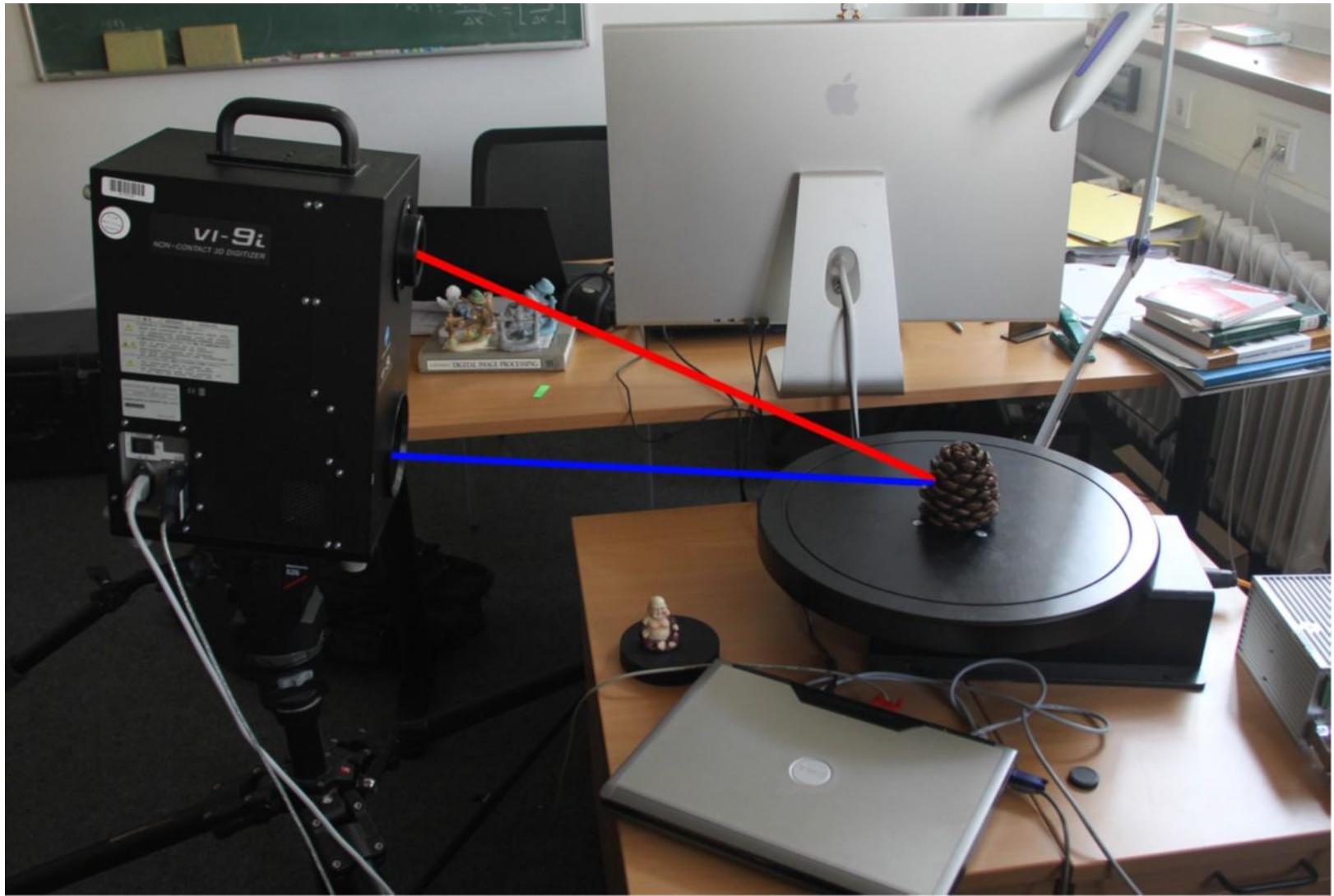
- Laser Light as the light emitting source.
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Laser source is connected to rotor.

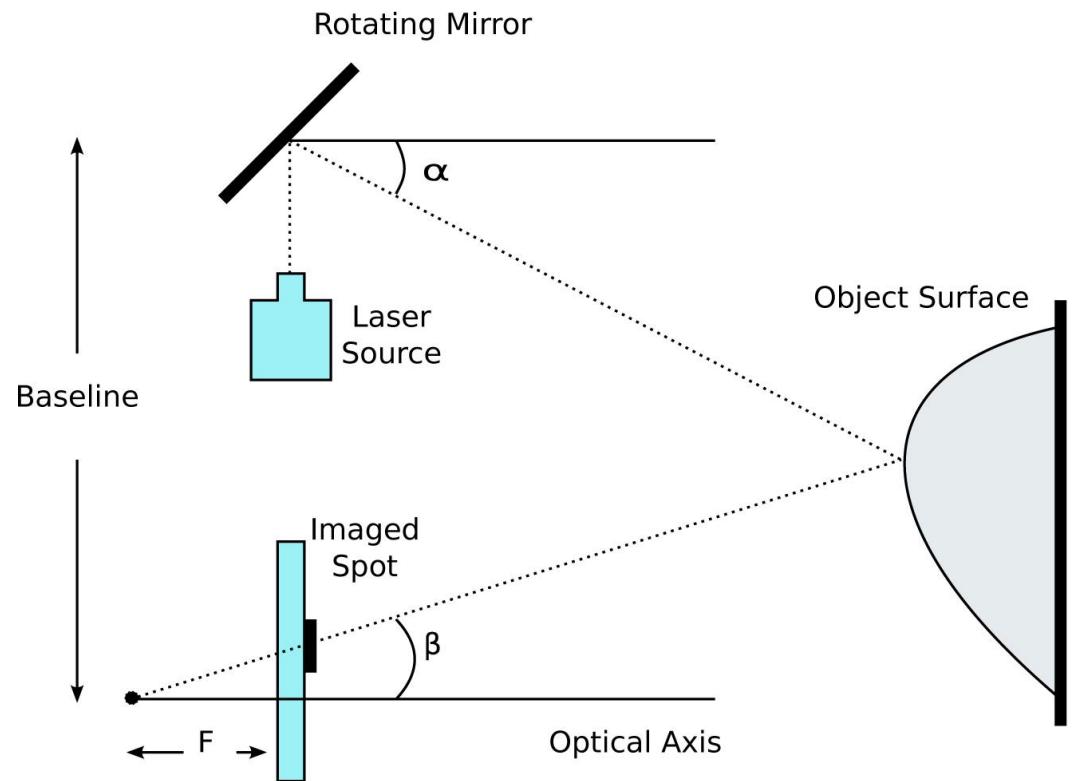
CCD sensors are uniformly arranged in a rectangular grid (640x480).



Data Acquisition – 3D Laser Scanner



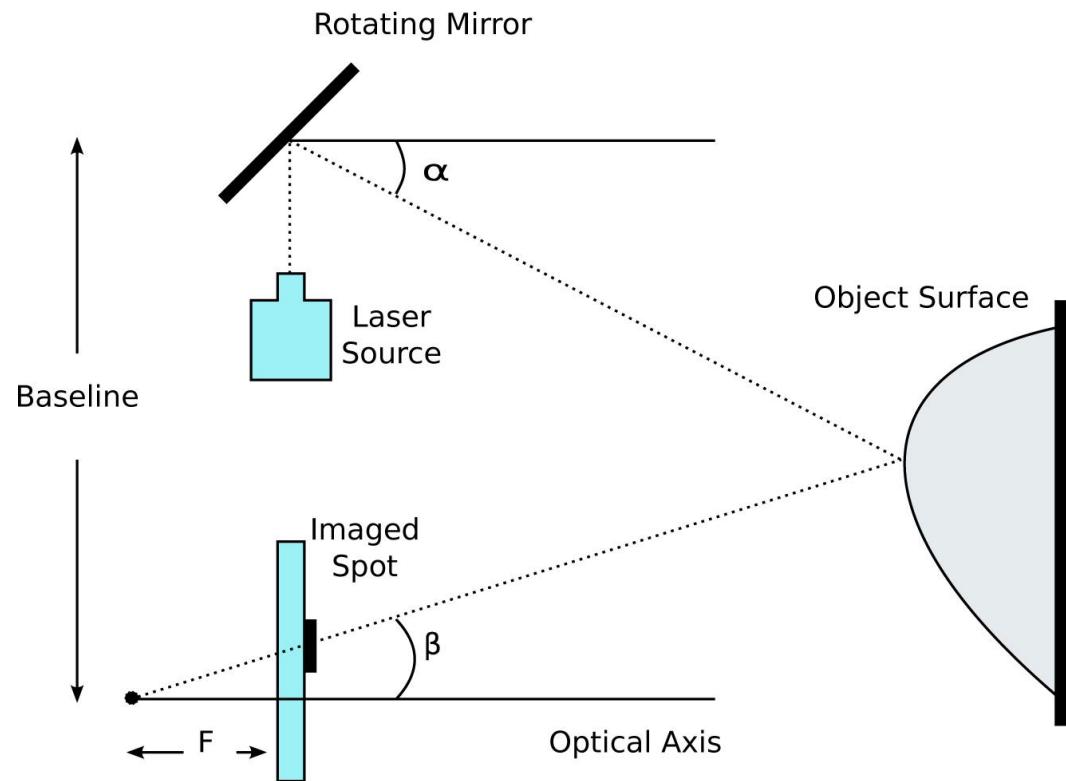
Data Acquisition – 3D Laser Scanner



Data Acquisition – 3D Laser Scanner

Height value is calculated as:

$$z = \frac{\text{baseline} - F \tan \beta}{\tan \alpha + \tan \beta}$$



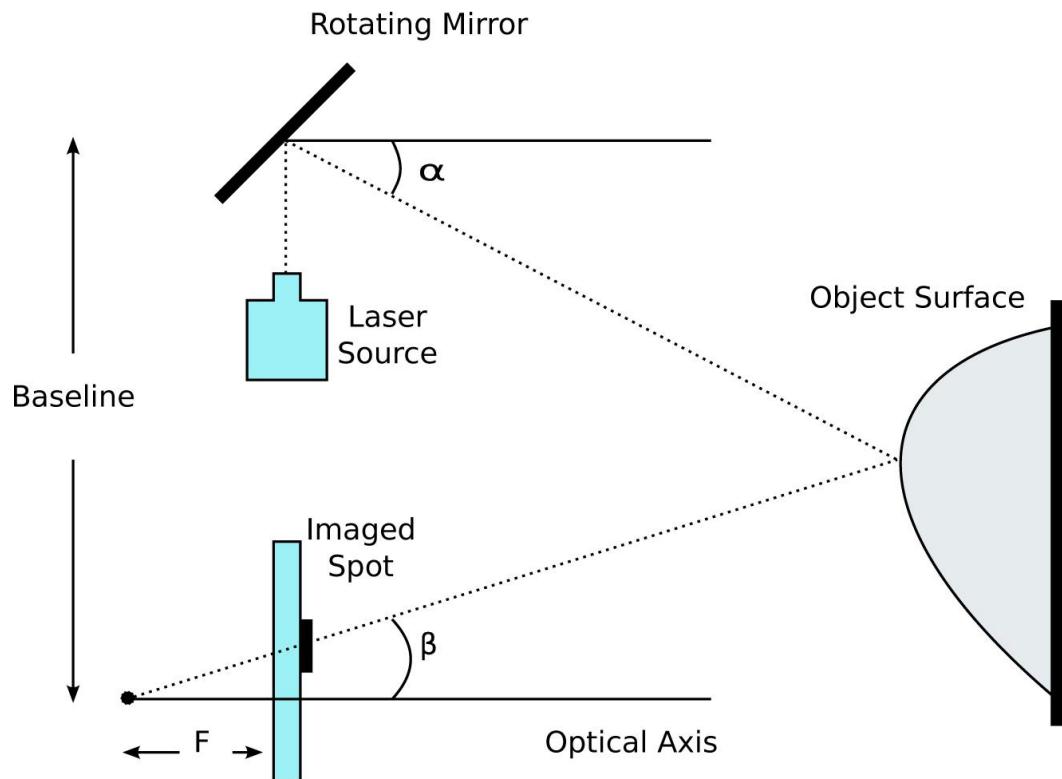
Data Acquisition – 3D Laser Scanner

Height value is calculated as:

$$z = \frac{\text{baseline} - F \tan \beta}{\tan \alpha + \tan \beta}$$

F, focal length of the camera (8,14 and 25 mm).

Measurement accuracy depends on β .





CCD Sensors and Laser

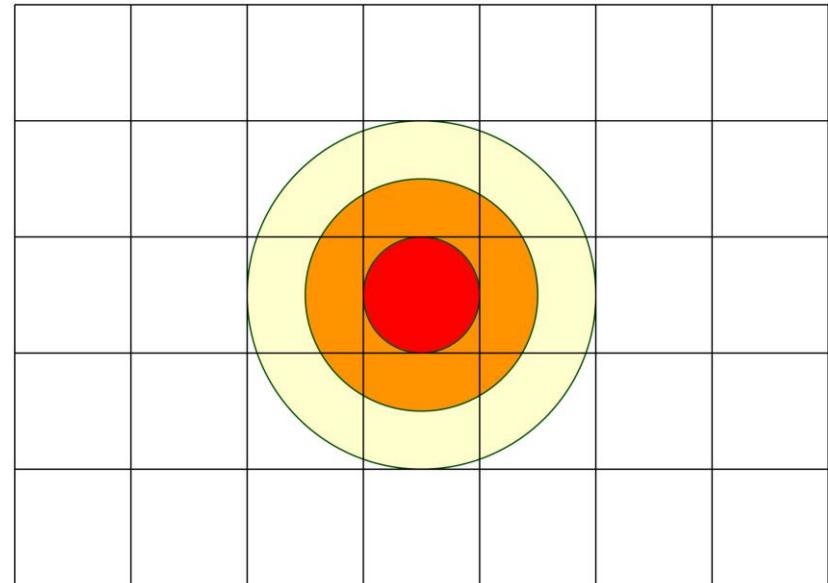
β is measured by detecting the position of the imaged diffusion spot.

CCD Sensors and Laser

β is measured by detecting the position of the imaged diffusion spot.

Laser light follows the Gaussian intensity distribution.

$$I_d = A e^{-0.5 \left[\frac{x - \bar{x}}{\sigma_x} \right]^2}$$

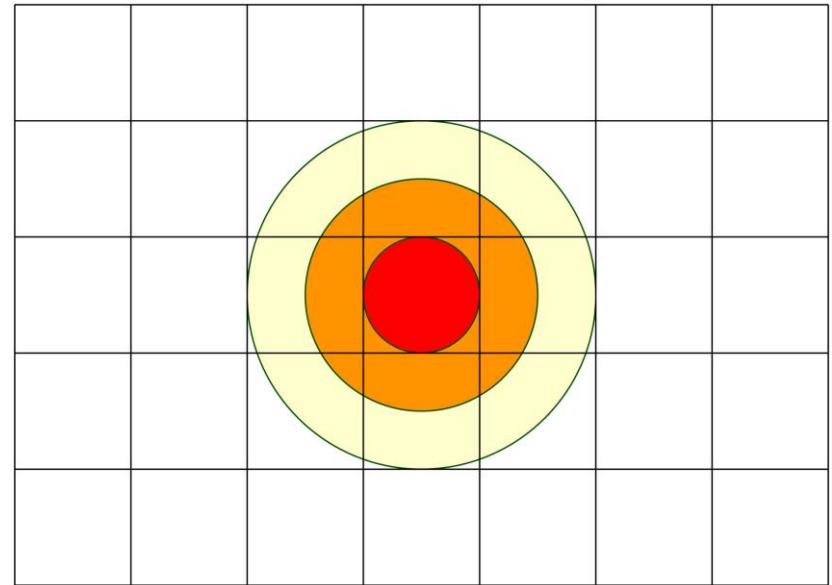


CCD Sensors and Laser

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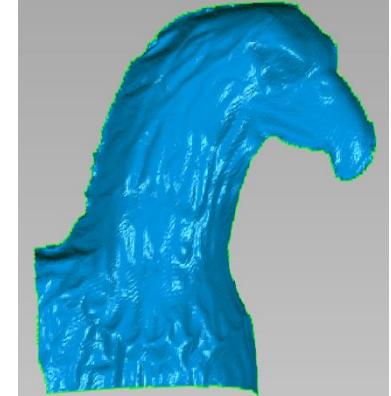
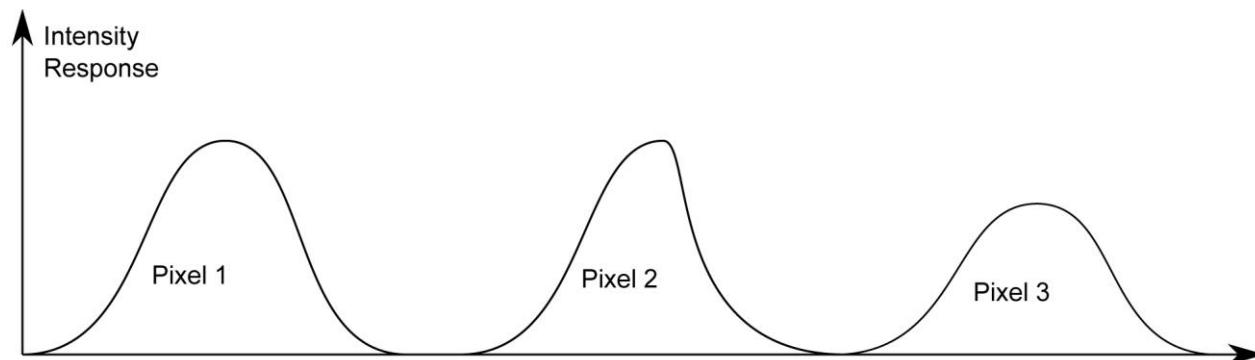
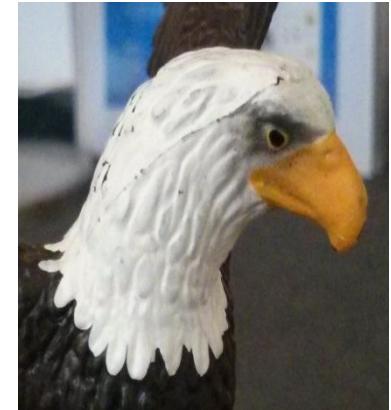
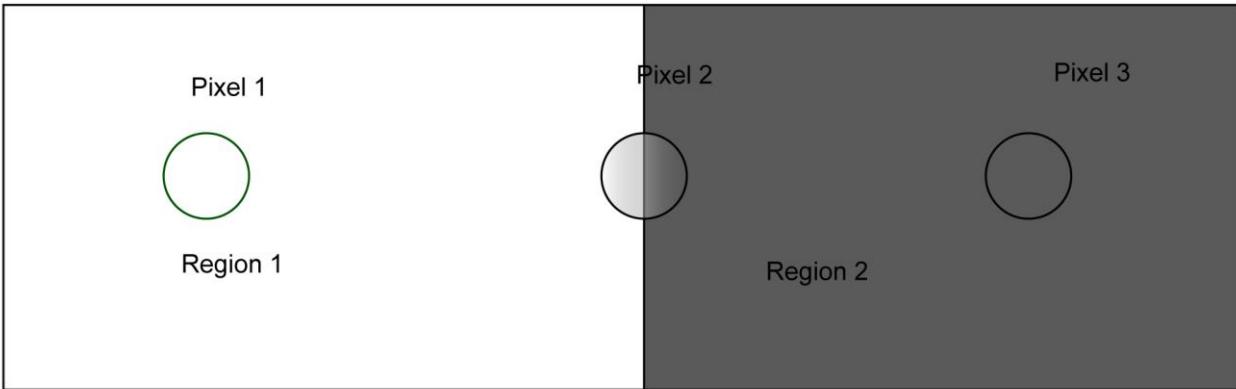
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If surface has non-uniform reflectance characteristics?

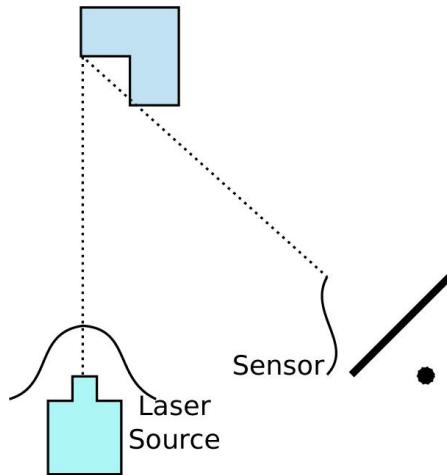
Reflectance Error



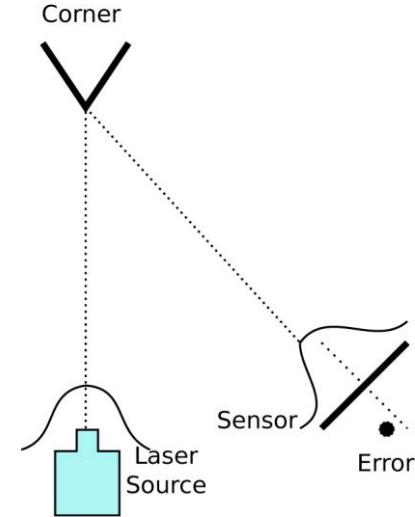
Due to different reflectance, position of the center of the gravity may not give the proper result.

Other Errors

Occulusion State



Corner

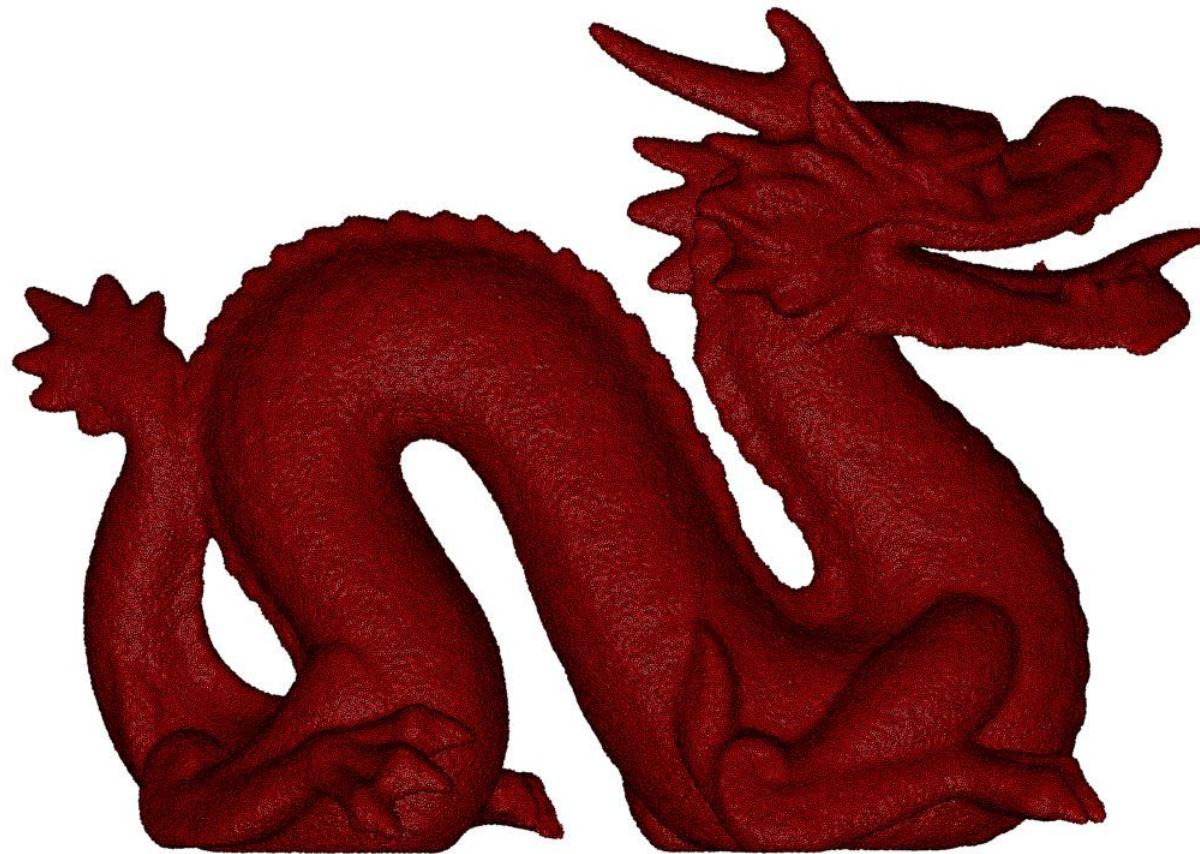


Data Acquisition – Points only



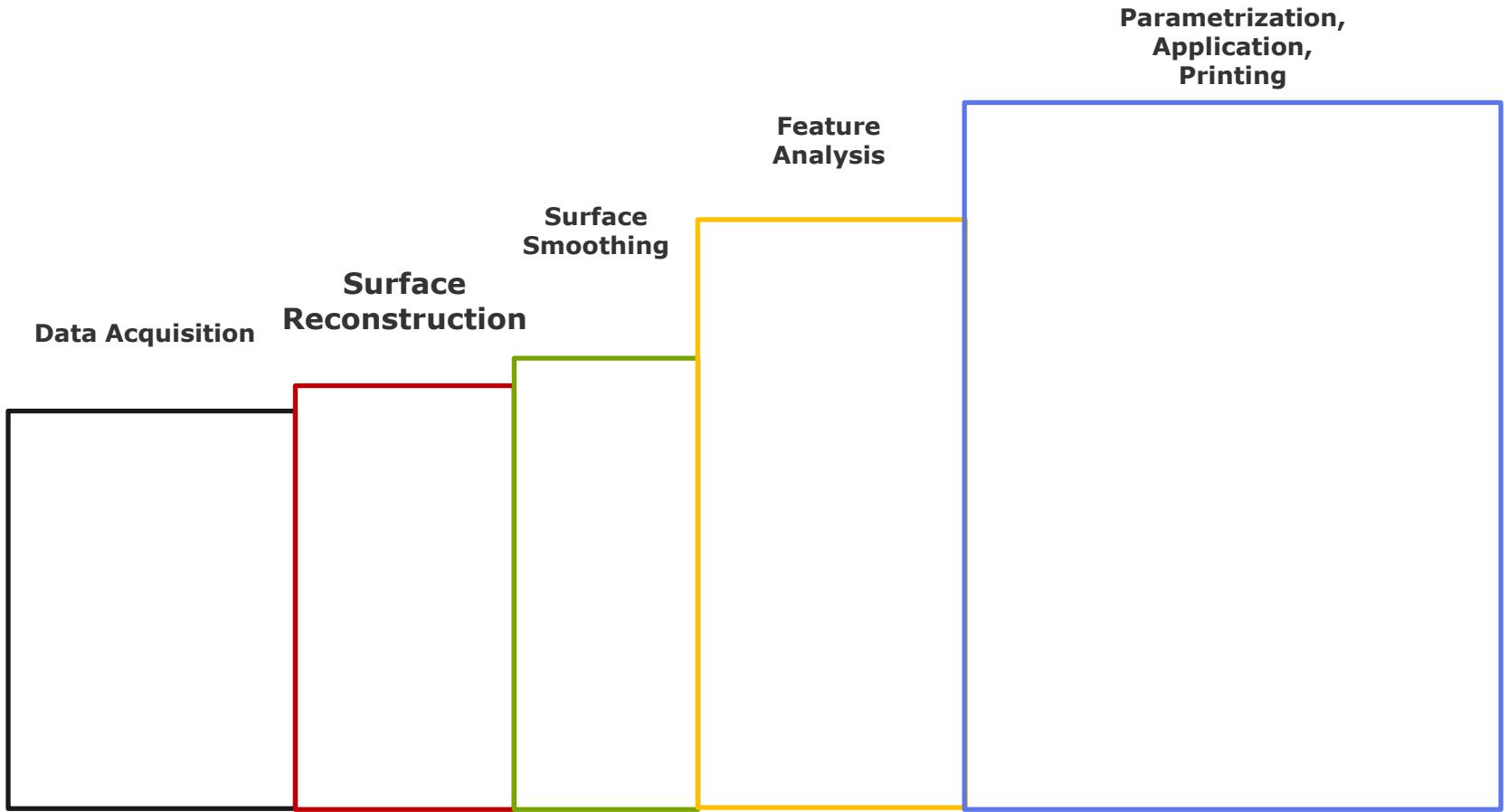


Data Acquisition – Points only





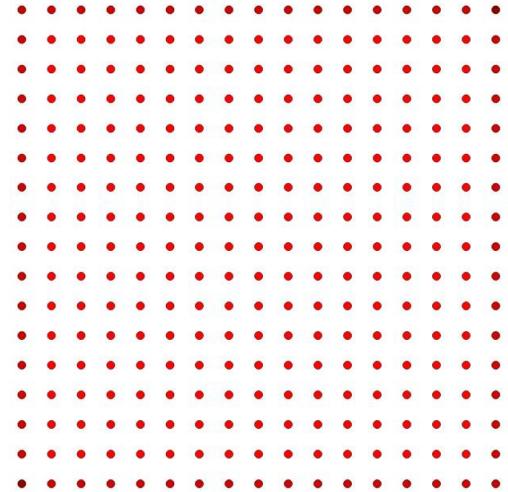
GPP - Stairs





Surface Reconstruction

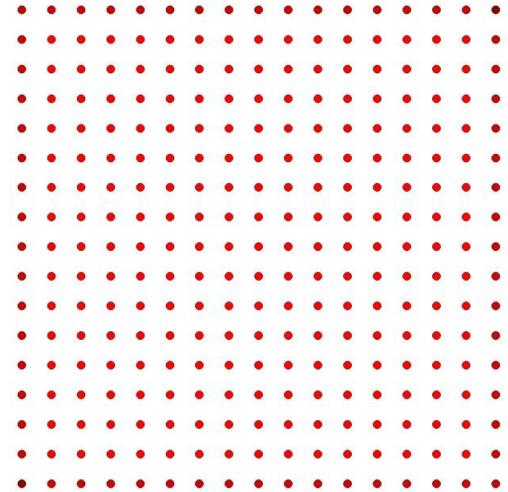
No connectivity, no surface



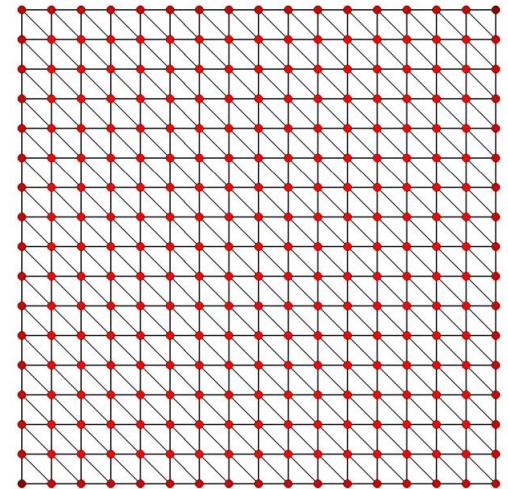


Surface Reconstruction

No connectivity, no surface

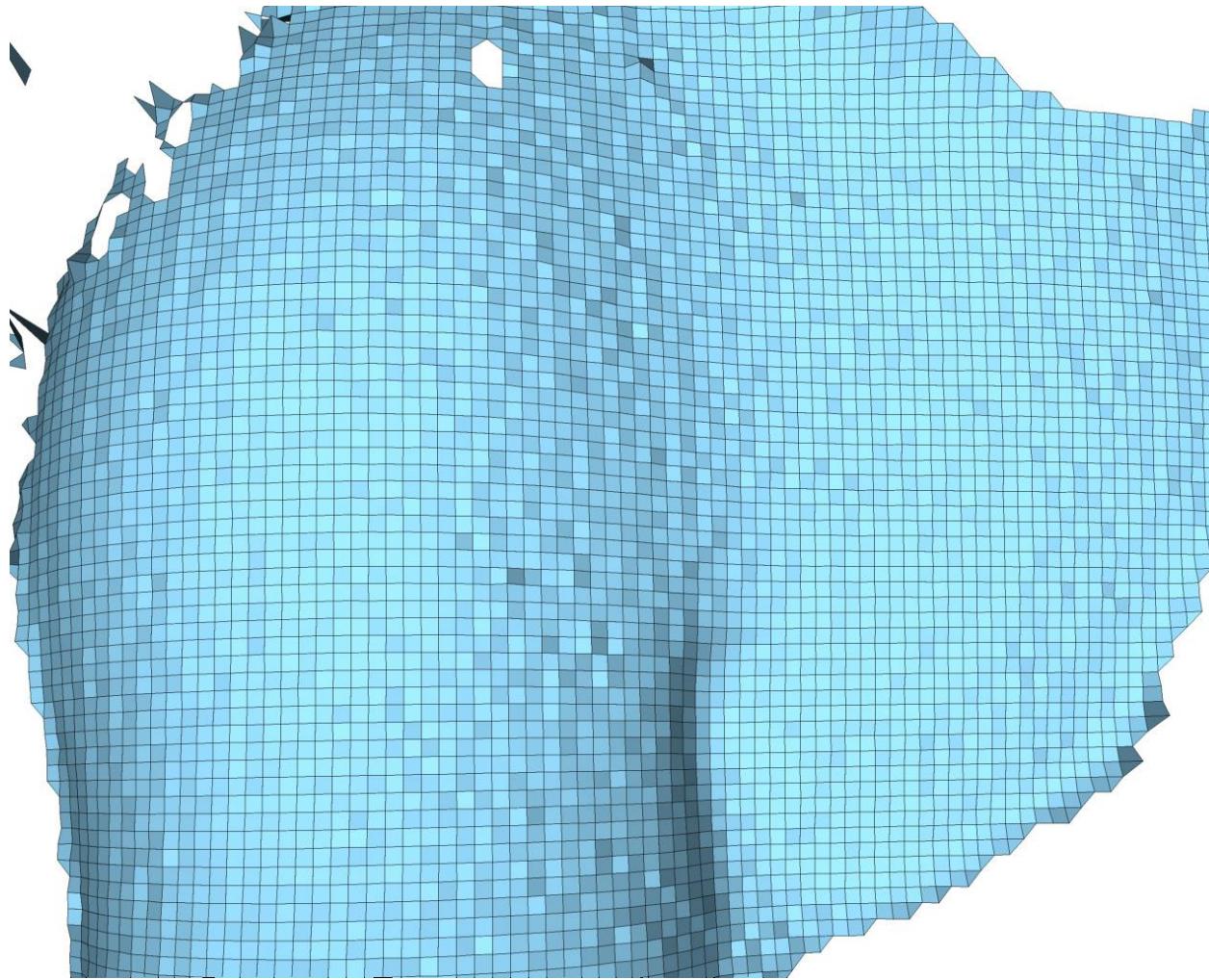


Simplest way





Surface





Data Acquisition – Regular Points

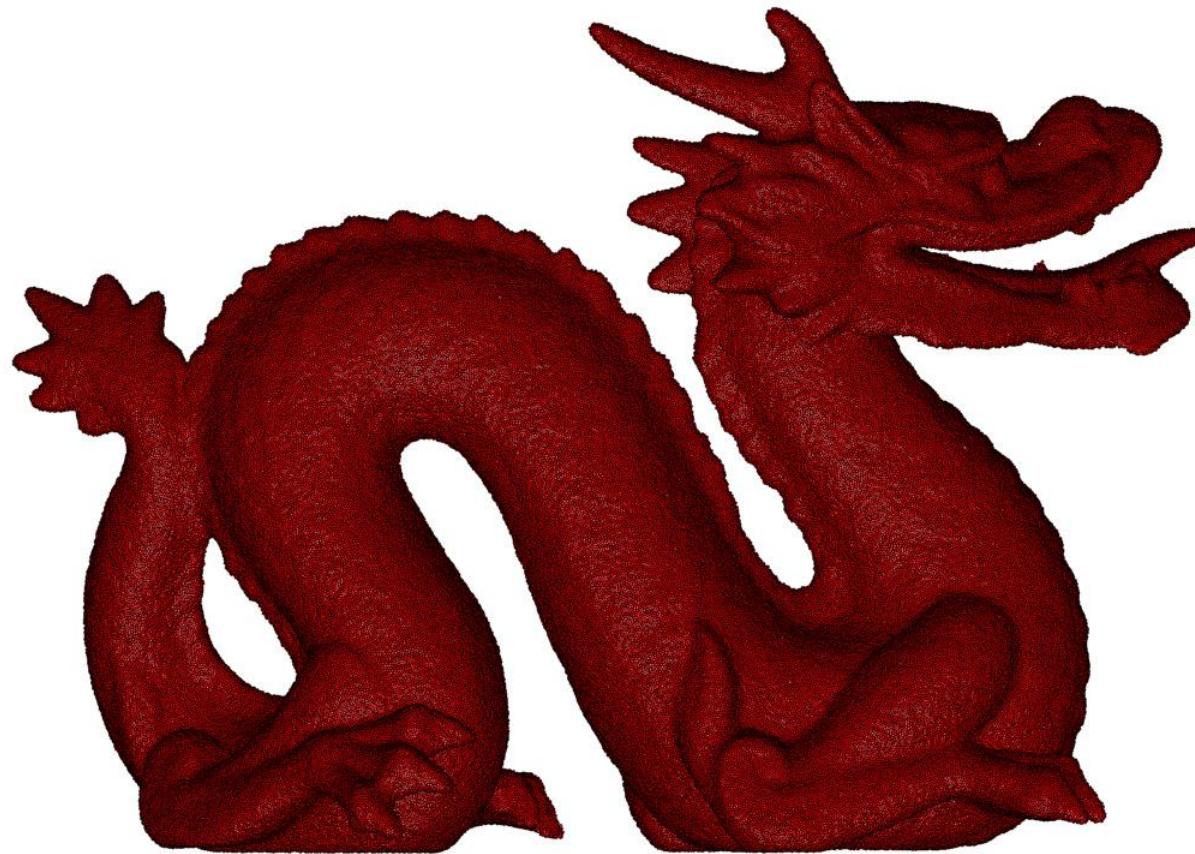


Triangulated Surface





Data Acquisition – Irregular Points





Surface Reconstruction

Irregular vertices.

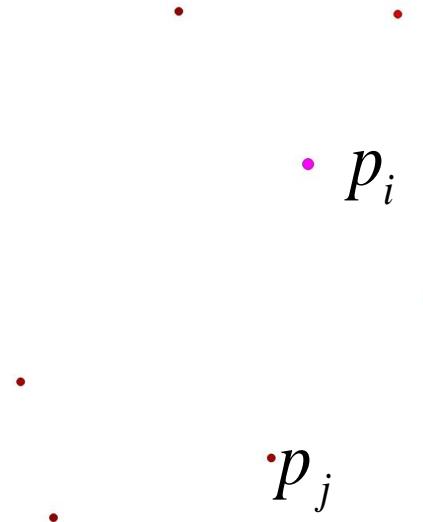




Surface Reconstruction

Irregular vertices

Apply K-nn algorithm.





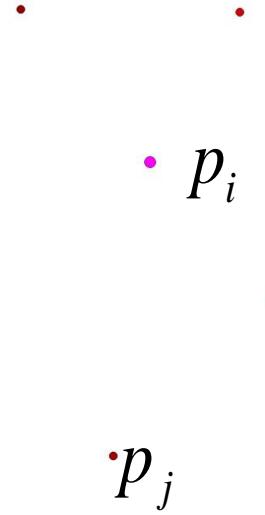
Surface Reconstruction

Irregular vertices

Apply K-nn algorithm.

Apply PCA.

$$C = \frac{1}{n} \sum_{j=0}^{n-1} (p_j - p_i)^T (p_j - p_i)$$





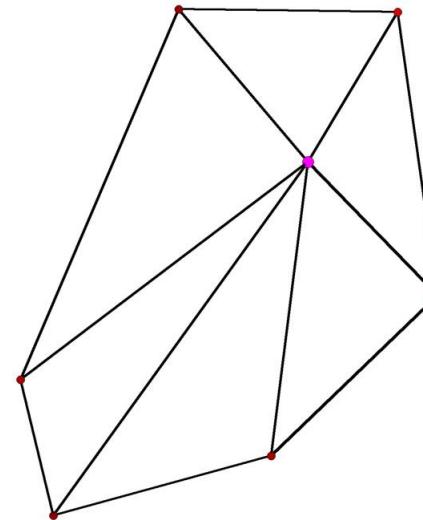
Surface Reconstruction

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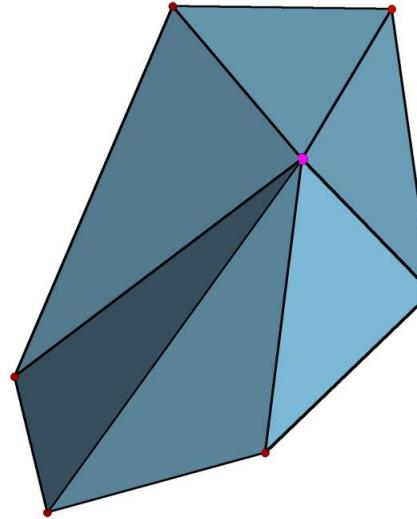
Surface Reconstruction

Irregular vertices

Apply K-nn algorithm.

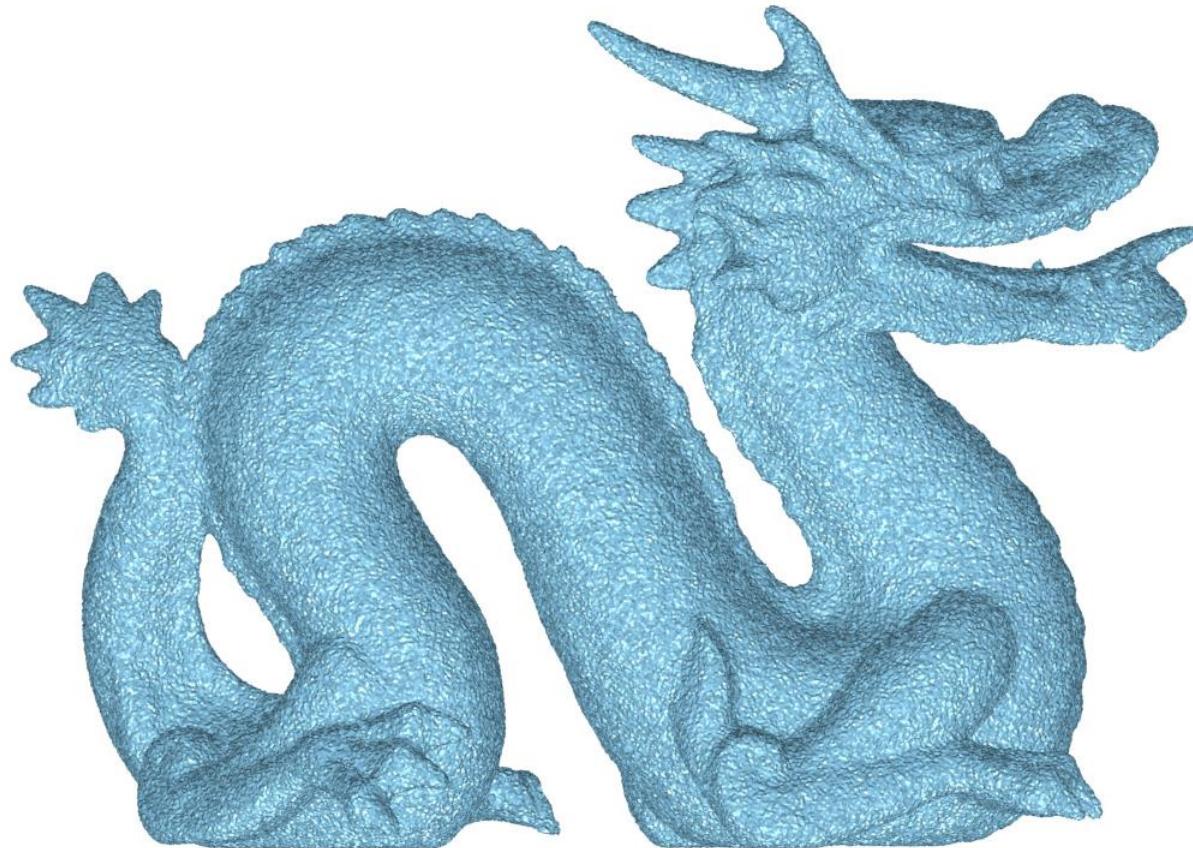
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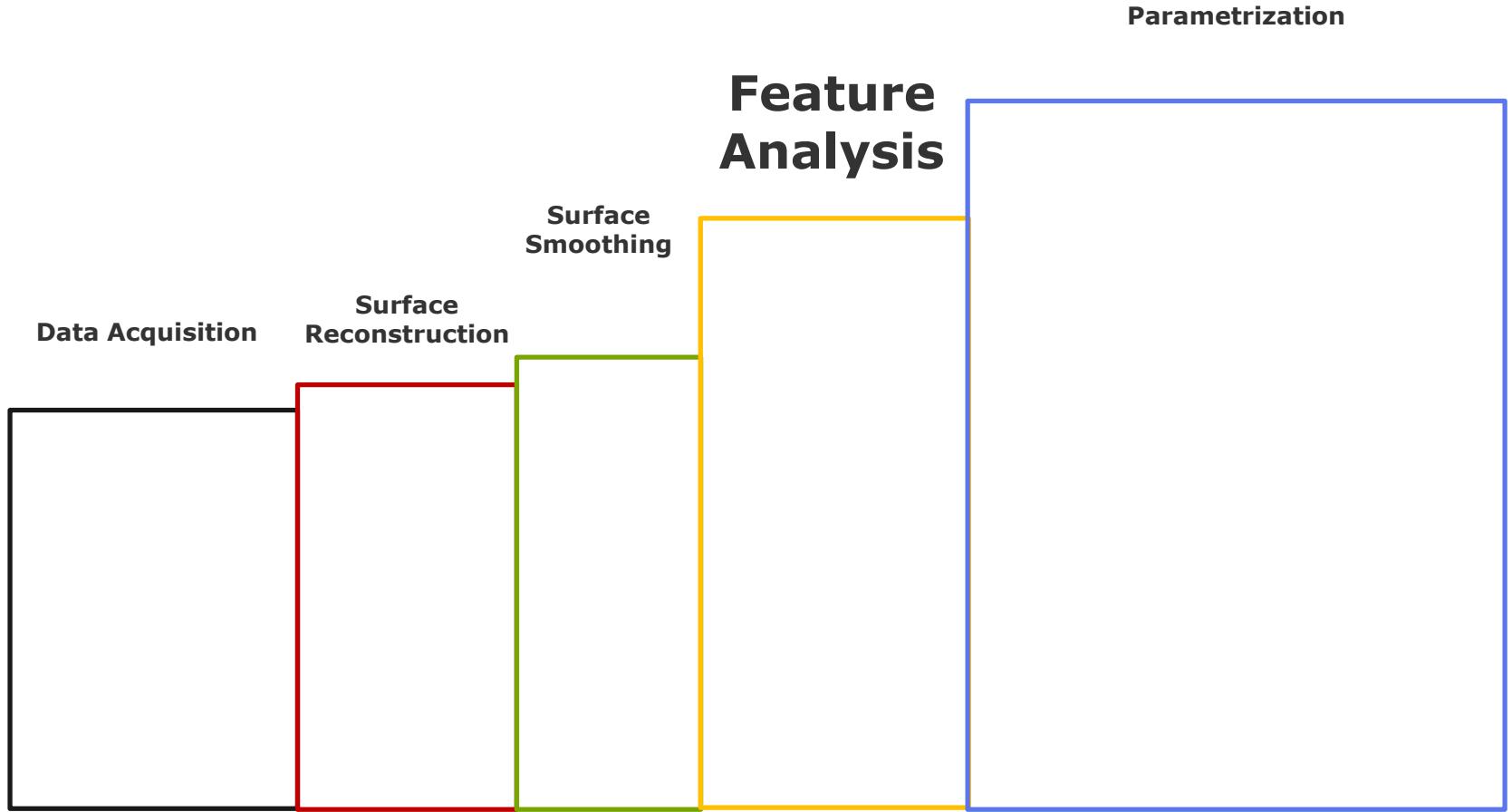




Triangulated Surface



Feature Analysis



Feature Analysis – Shape operator and Curvature

- Shape operator is a linear operator to compute the surface bending.

Definition: Let M subset \mathbb{R}^3 be a regular surface and let N be a surface normal to M defined in a neighborhood of a point p in M . For a tangent vector v_p to M at p we put .

$$S(v_p) = -D_v N$$

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$$S(v_p) = -D_v N$$

Principle curvatures are eigenvalues of the Shape operator:

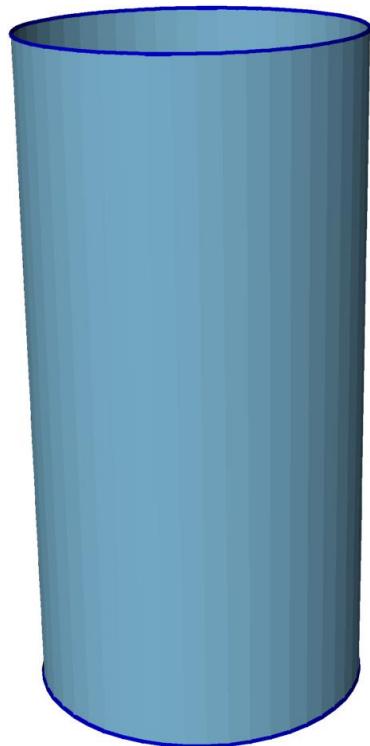
K_1 - Maximum Principle curvature

K_2 - Minimum Principle curvature



Curvature

Cylinder



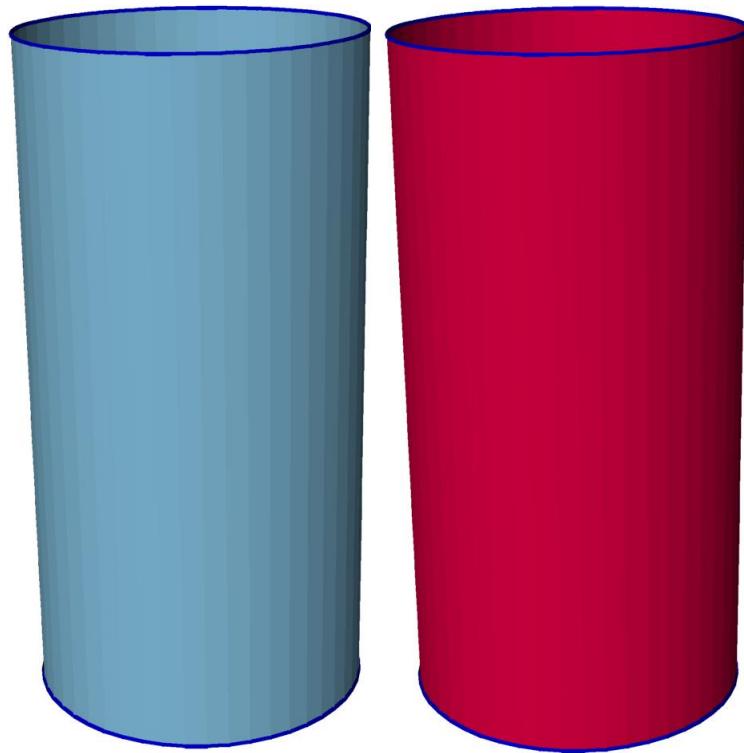


Curvature

Cylinder

Maximum
Principle
curvature

$$K_1$$



Curvature

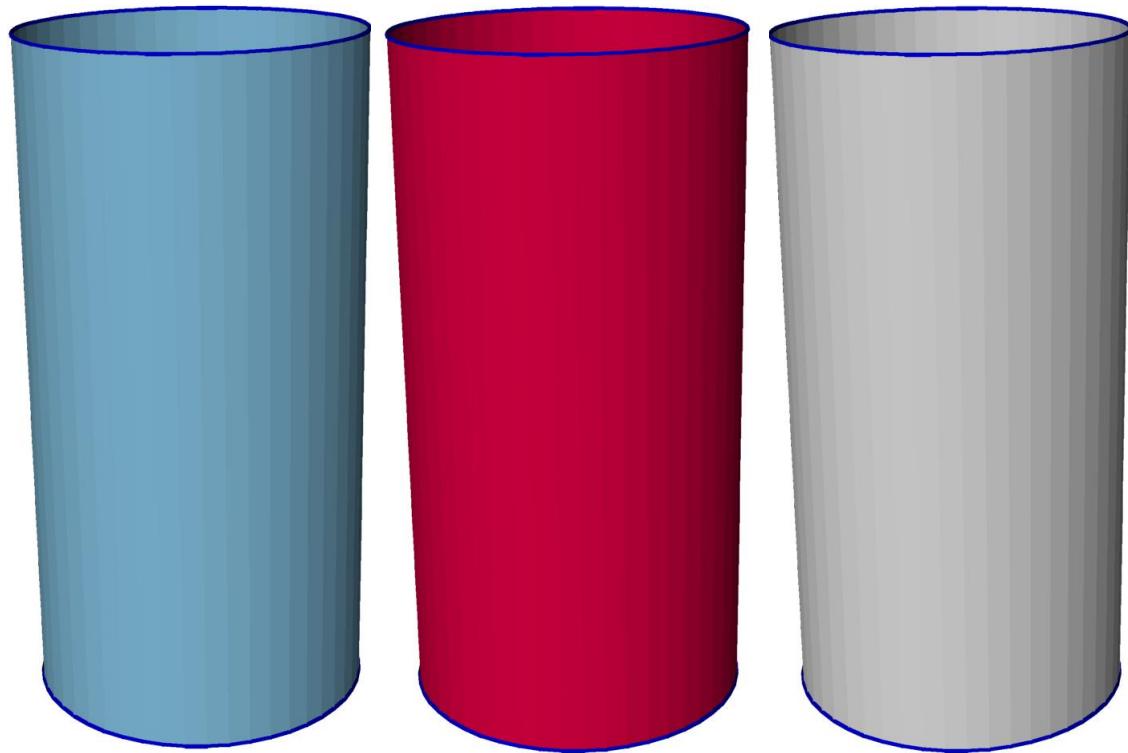
Cylinder

Maximum
Principle
curvature

$$\kappa_1$$

Minimum
Principle
curvature

$$\kappa_2$$



Curvature

Cylinder

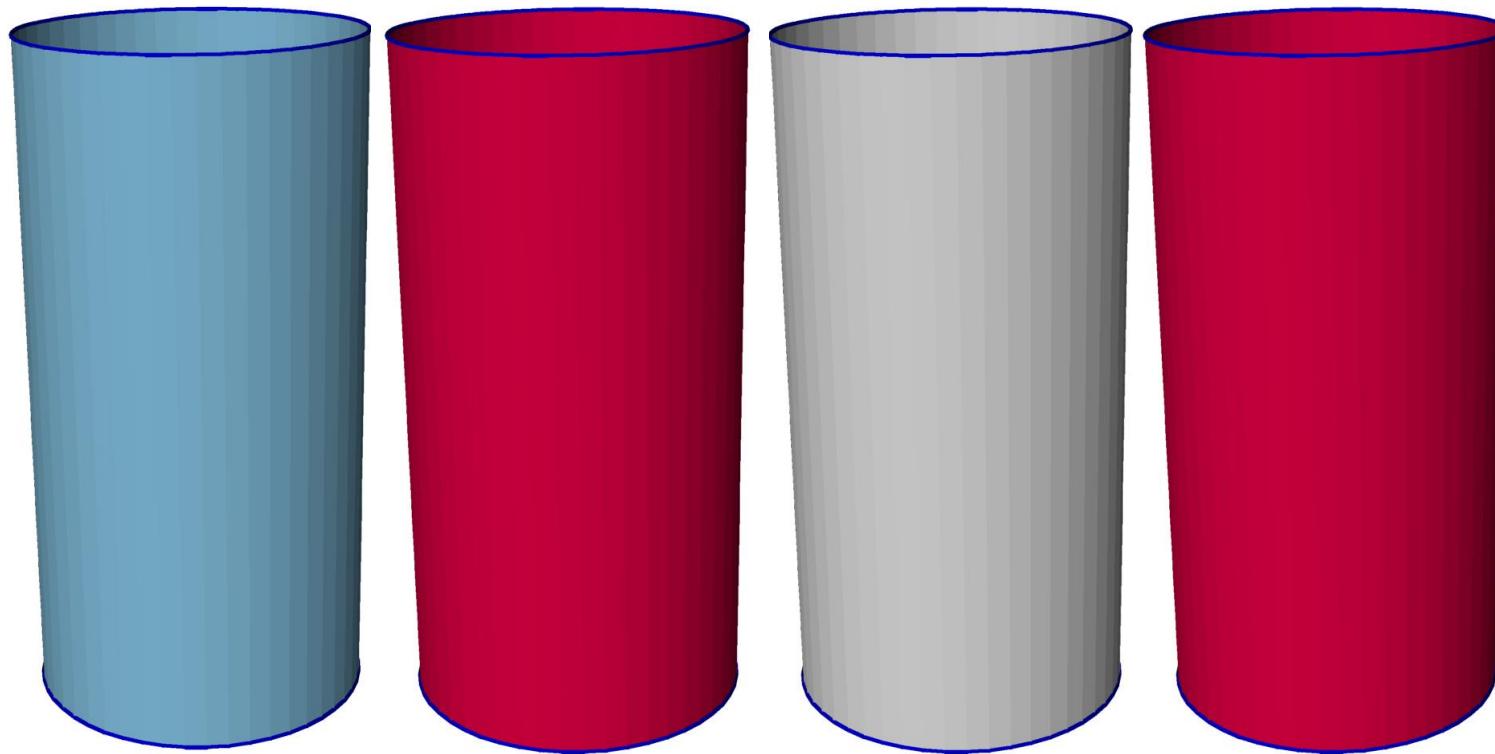
Maximum
Principle
curvature

$$\kappa_1$$

Minimum
Principle
curvature

$$\kappa_2$$

$$H = \frac{\kappa_1 + \kappa_2}{2}$$



Curvature

Cylinder

Maximum
Principle
curvature

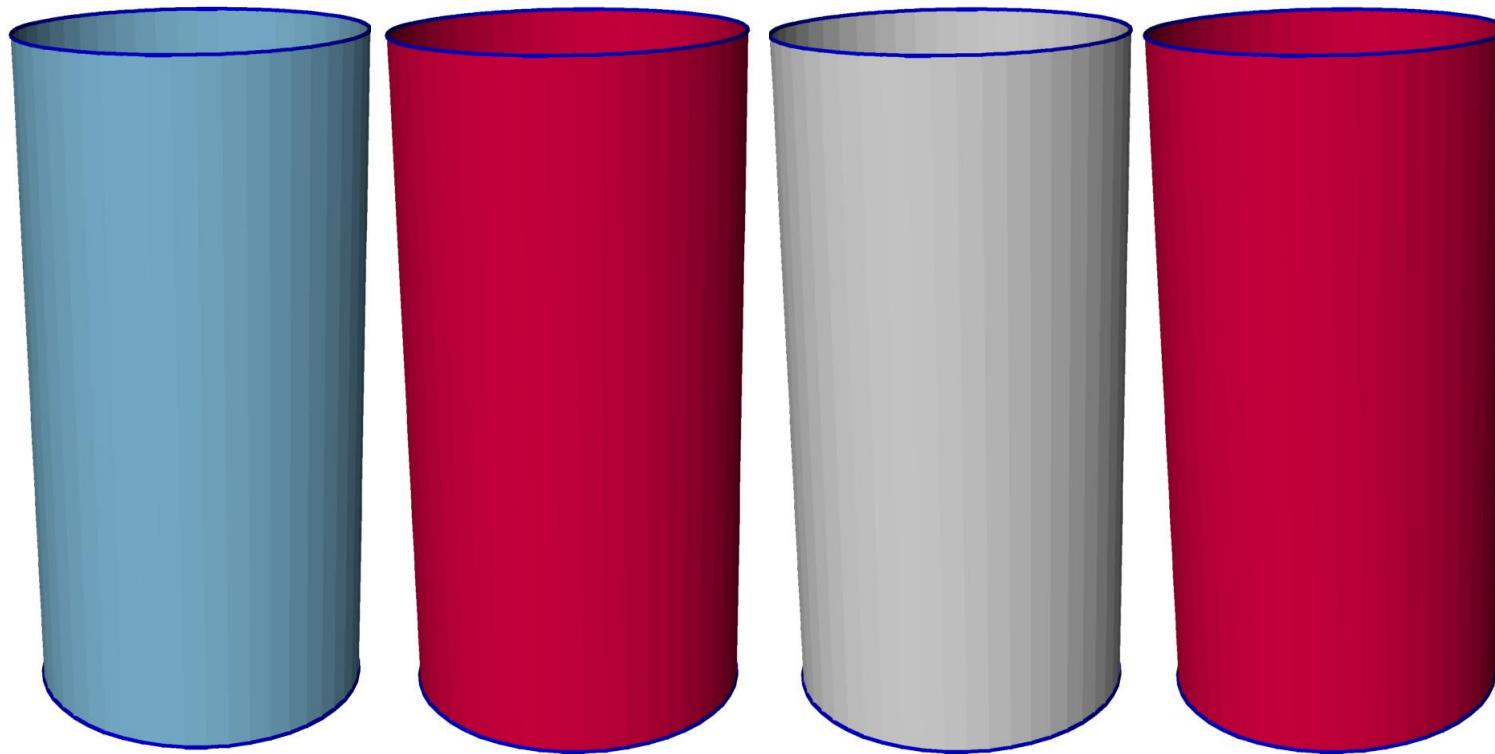
$$\kappa_1$$

Minimum
Principle
curvature

$$\kappa_2$$

Mean
curvature

$$H = \frac{\kappa_1 + \kappa_2}{2}$$



Curvature

Cylinder

Maximum
Principle
curvature

$$\kappa_1$$

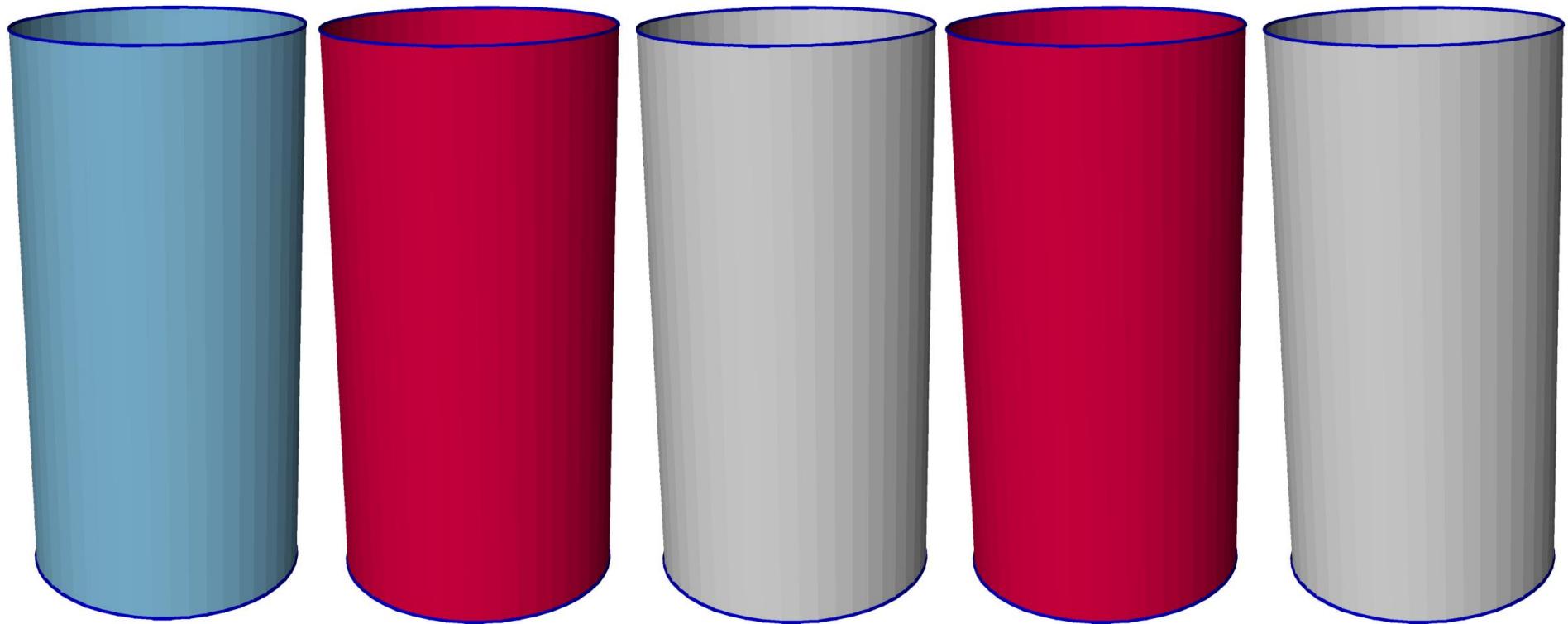
Minimum
Principle
curvature

$$\kappa_2$$

Mean
curvature

$$H = \frac{\kappa_1 + \kappa_2}{2}$$

$$K = \kappa_1 \cdot \kappa_2$$

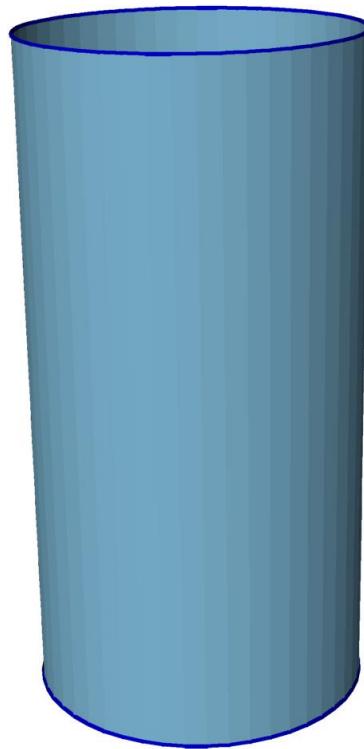


Curvature

Cylinder

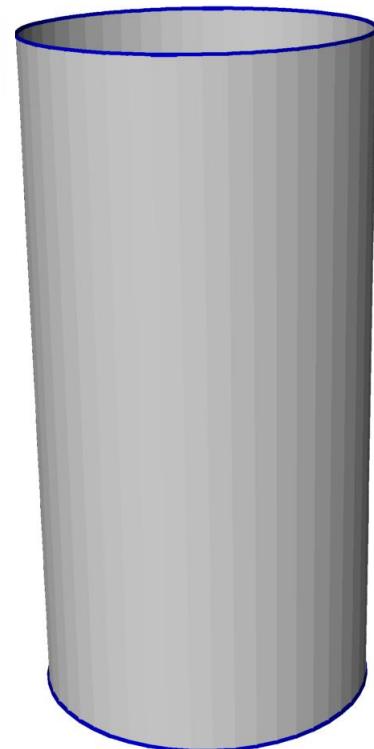
Maximum
Principle
curvature

$$\kappa_1$$



Minimum
Principle
curvature

$$\kappa_2$$



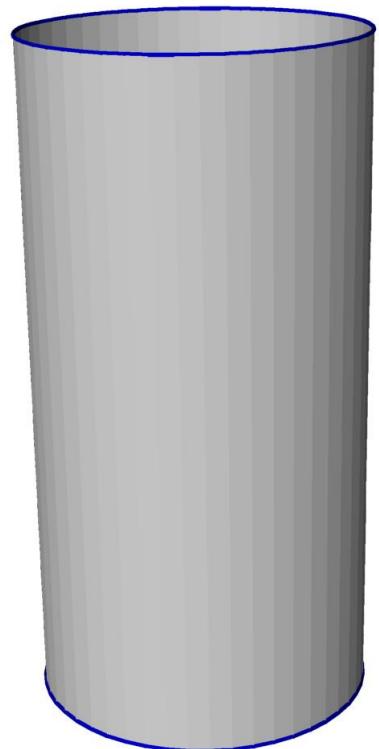
Mean
curvature

$$H = \frac{\kappa_1 + \kappa_2}{2}$$

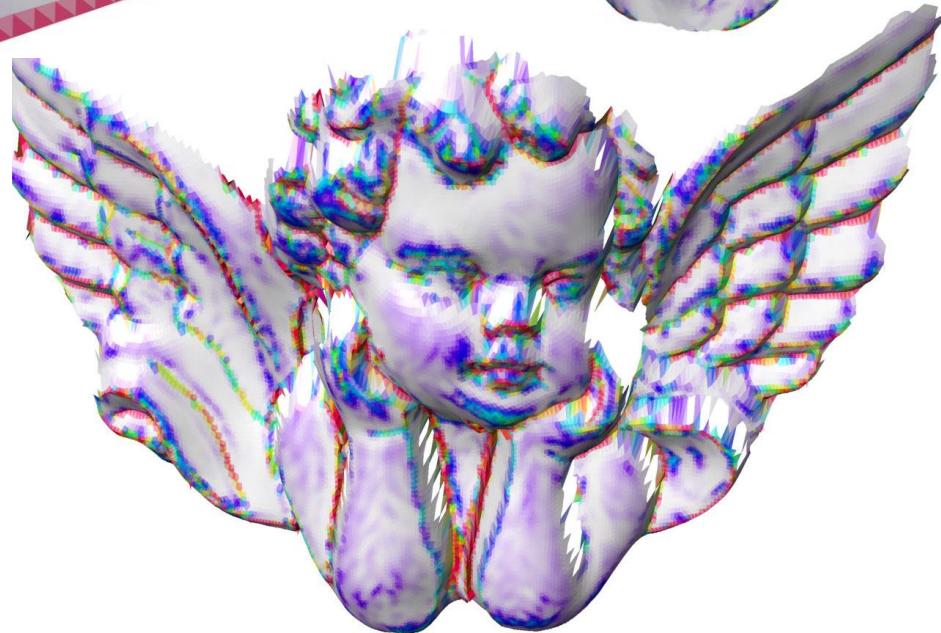
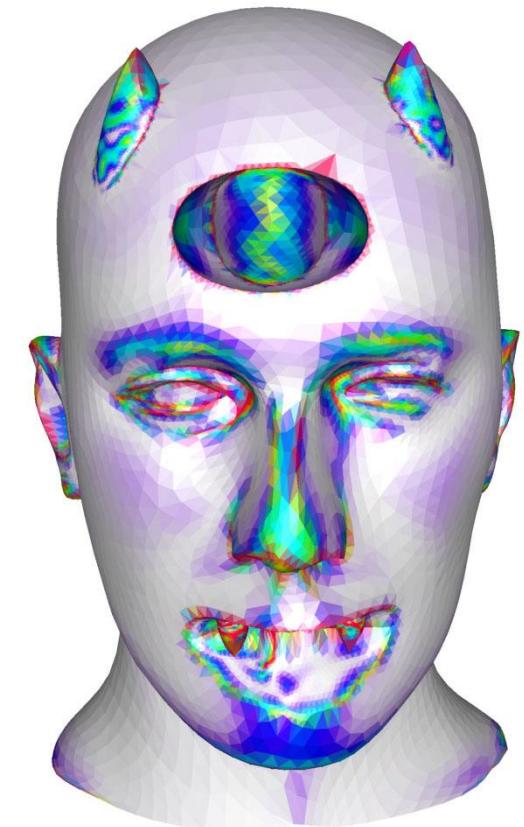
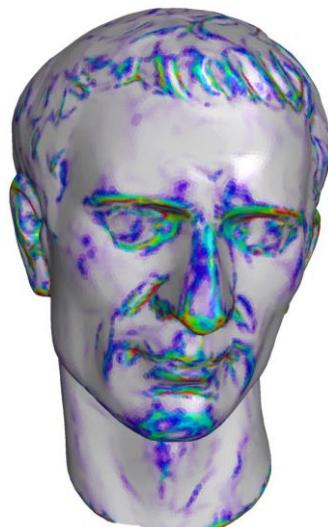
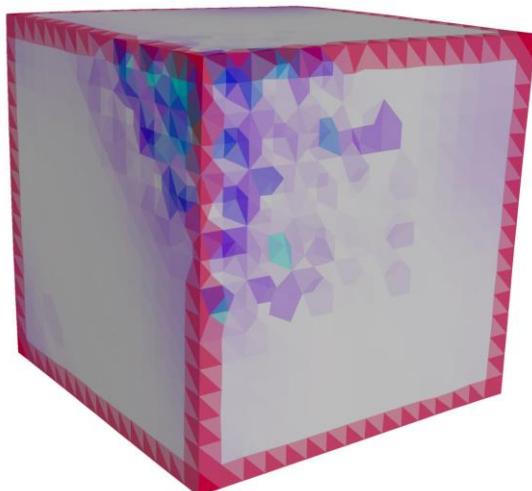


Gauss
curvature

$$K = \kappa_1 \cdot \kappa_2$$

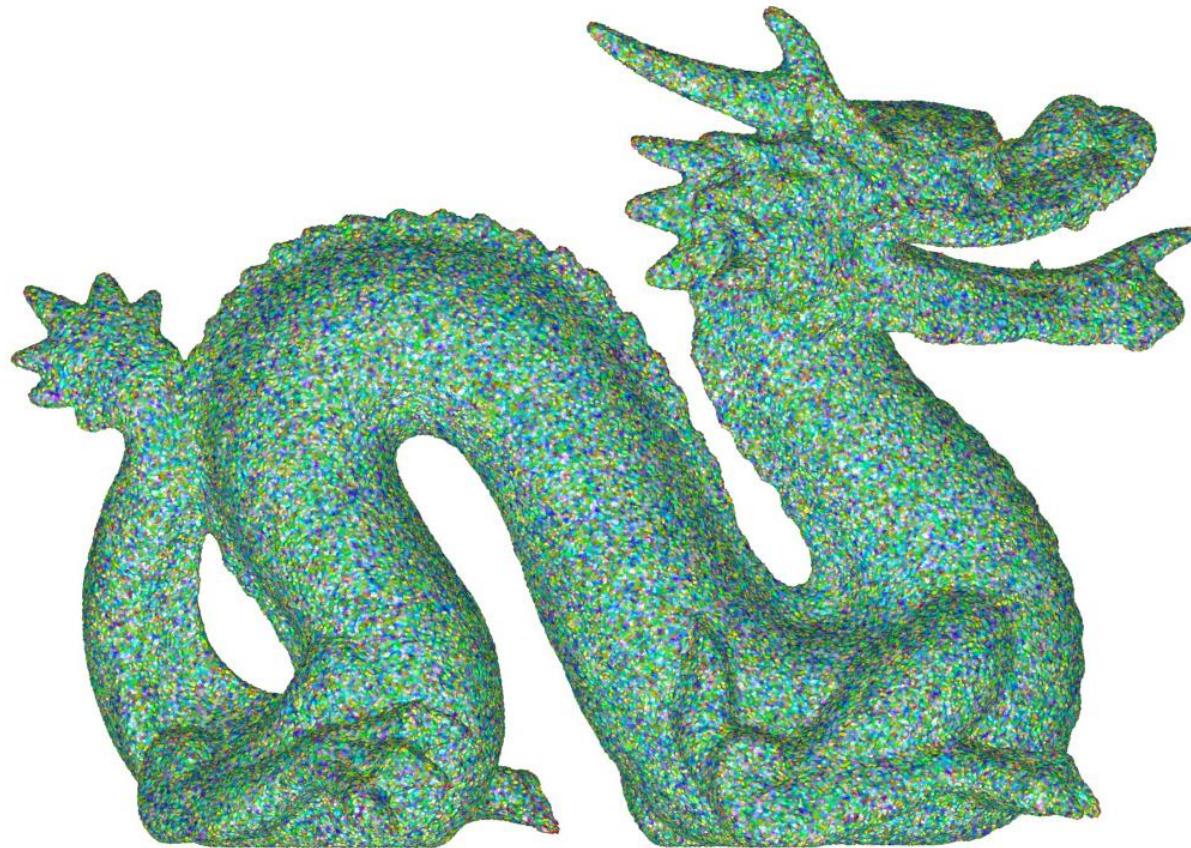


Mean Curvature – More example



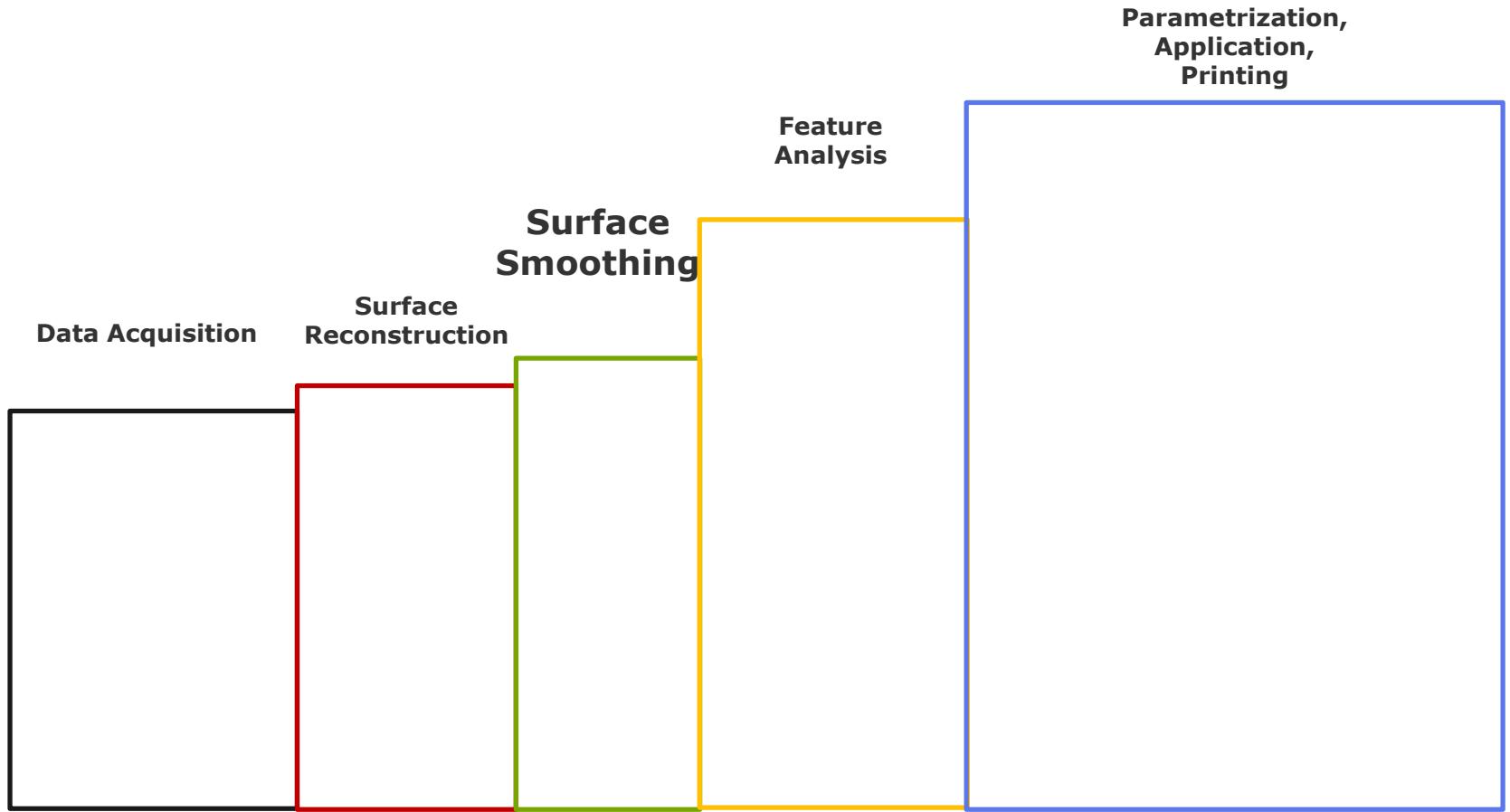


Mean Curvature – More example





GPP - Stairs





Smoothing/Denoising

Bending energy on a surface:

- Willmore Energy:

$$\int_S H^2 dA$$



Smoothing/Denoising

Bending energy on a surface:

- Willmore Energy:

$$\int_S H^2 dA$$

- Thin plate/Anisotropic energy:

$$\int_S (\kappa_1^2 + \kappa_2^2) dA$$



Smoothing/Denoising

Bending energy on a surface:

- Willmore Energy:

$$\int_s H^2 dA$$

- Thin plate/Anisotropic energy:

$$\int_s (\kappa_1^2 + \kappa_2^2) dA$$

To remove the noise components, minimize the anisotropic energies

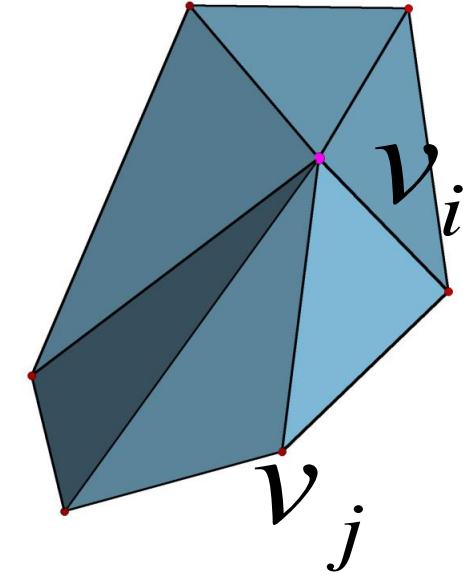
Smoothing/Denoising – Isotropic (Laplacian)

Laplace Beltrami Operator:

$$\Delta_s f = -2Hn$$

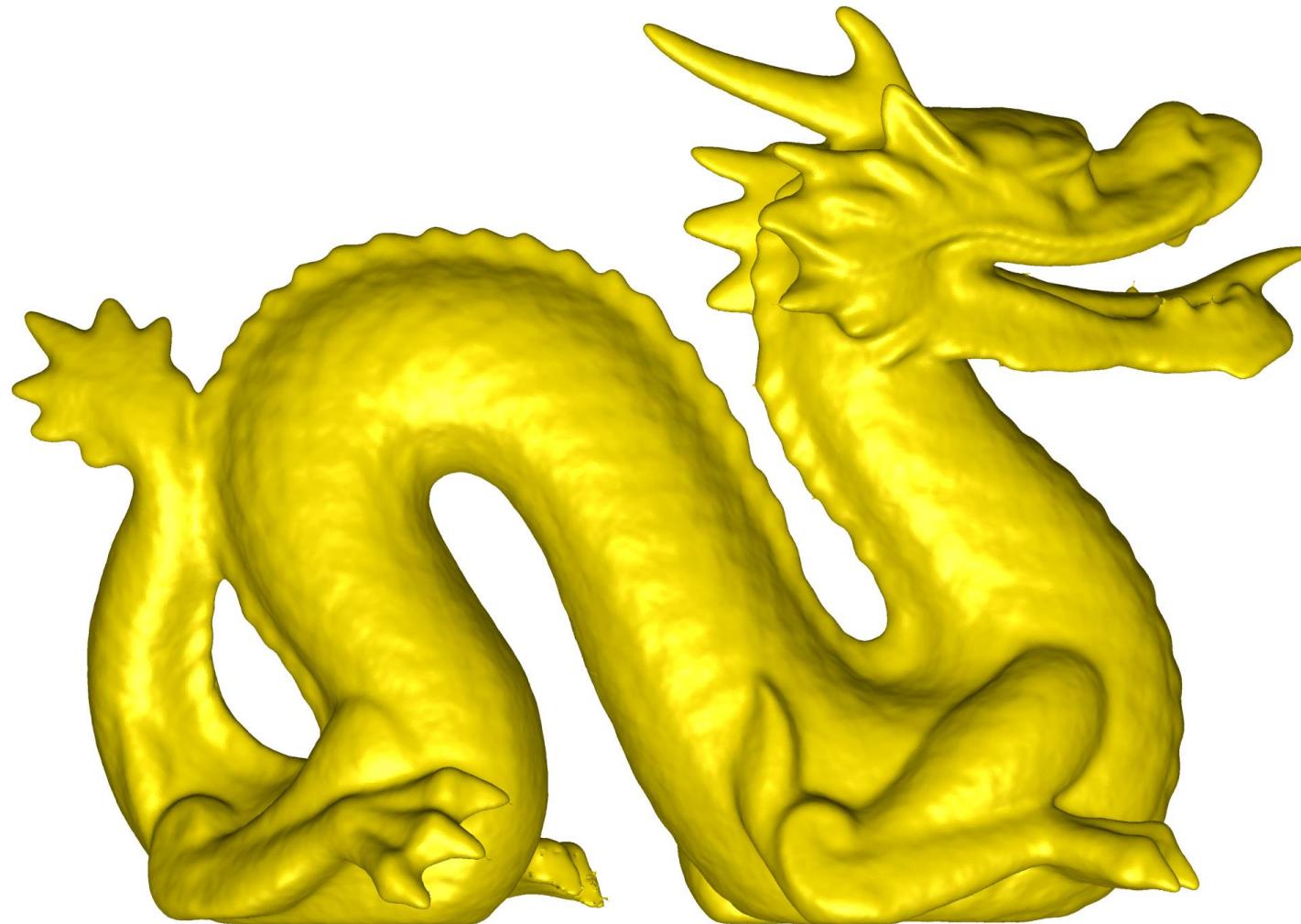
Uniform discretization of Laplace Beltrami operator:

$$L = \frac{1}{N_v} \sum_{j \in N_v} v_j - v_i$$

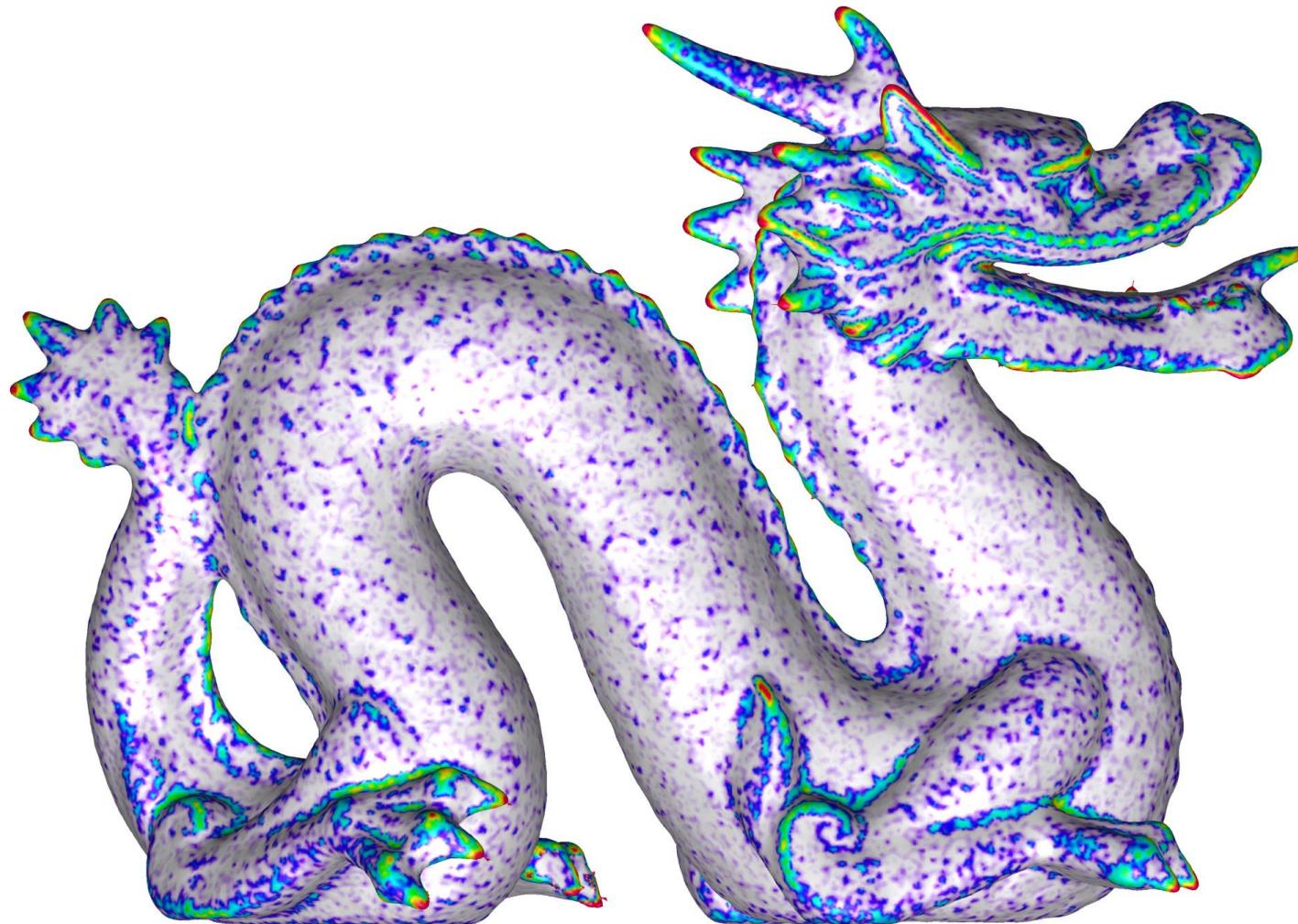


Weighted discretization of Laplace Beltrami operator: Cotangent Operator

Smoothing/Denoising – Isotropic (Laplacian)

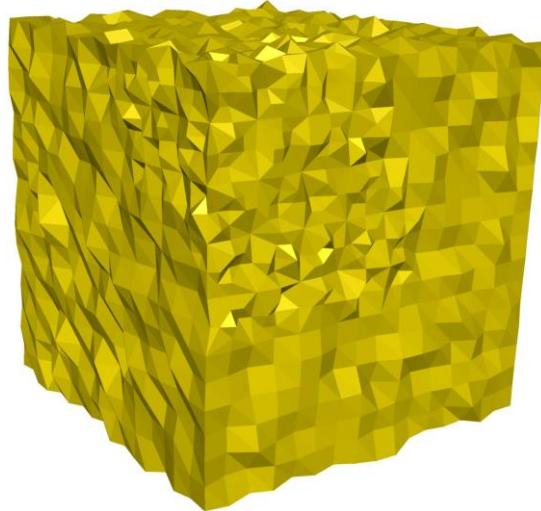


Smoothing/Denoising – Isotropic (Laplacian)



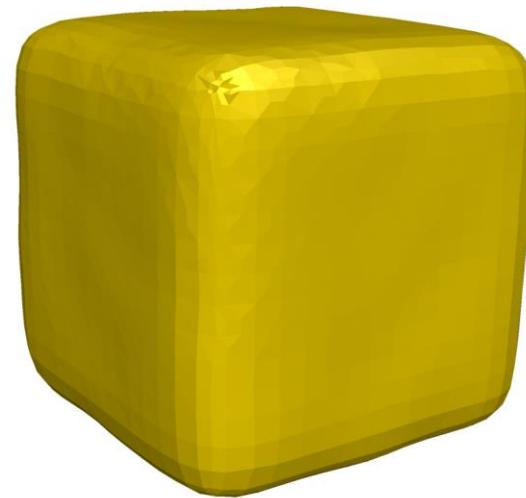
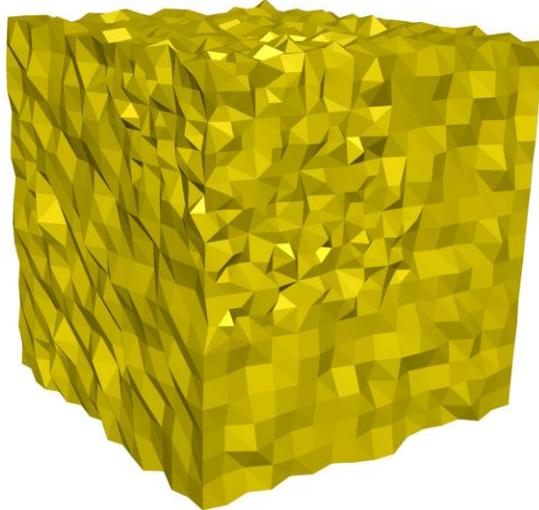


Isotropic (Laplacian) - Drawbacks



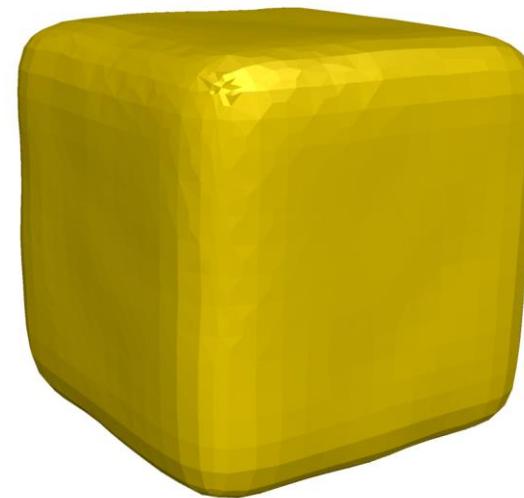
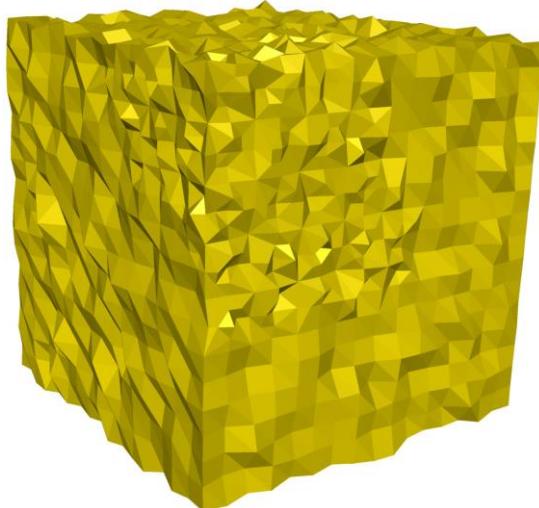


Isotropic (Laplacian) - Drawbacks

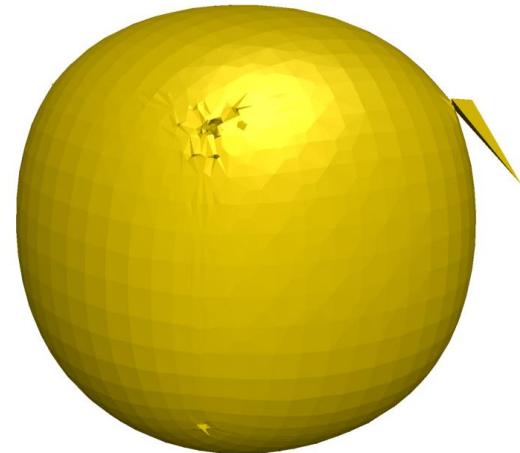


50 iterations

Isotropic (Laplacian) - Drawbacks

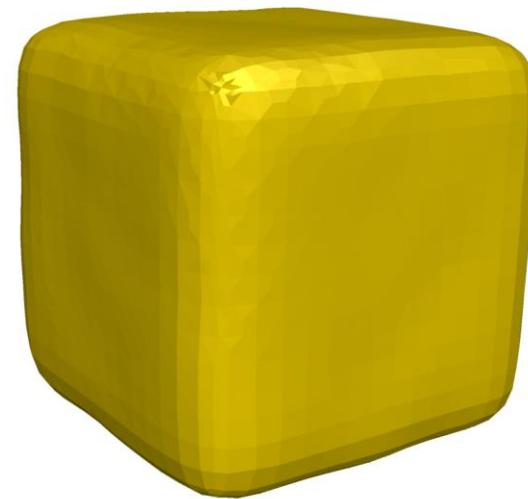
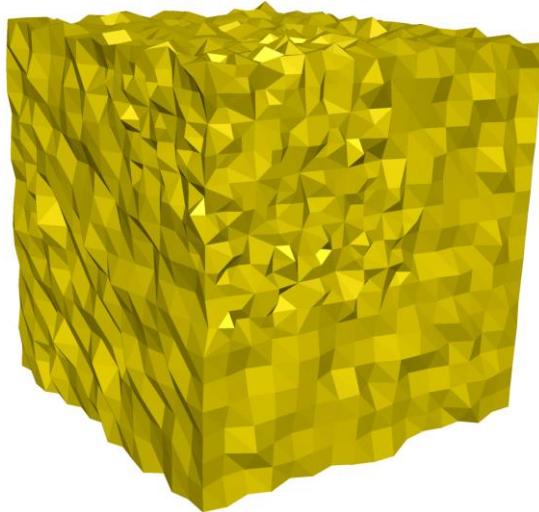


50 iterations

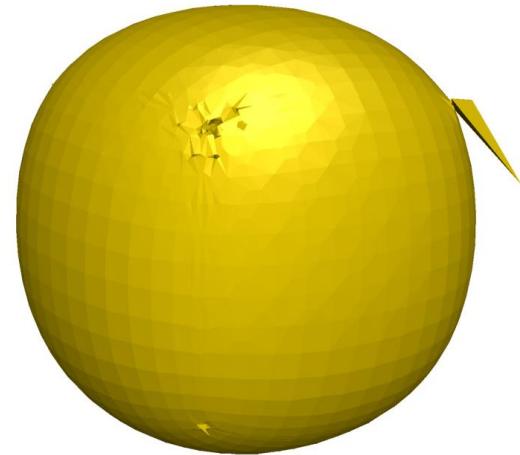


200 iterations

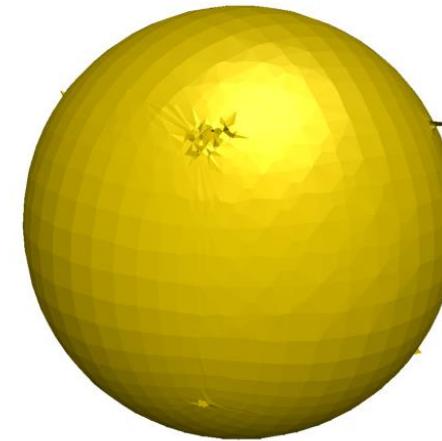
Isotropic (Laplacian) - Drawbacks



50 iterations



200 iterations



1000 iterations



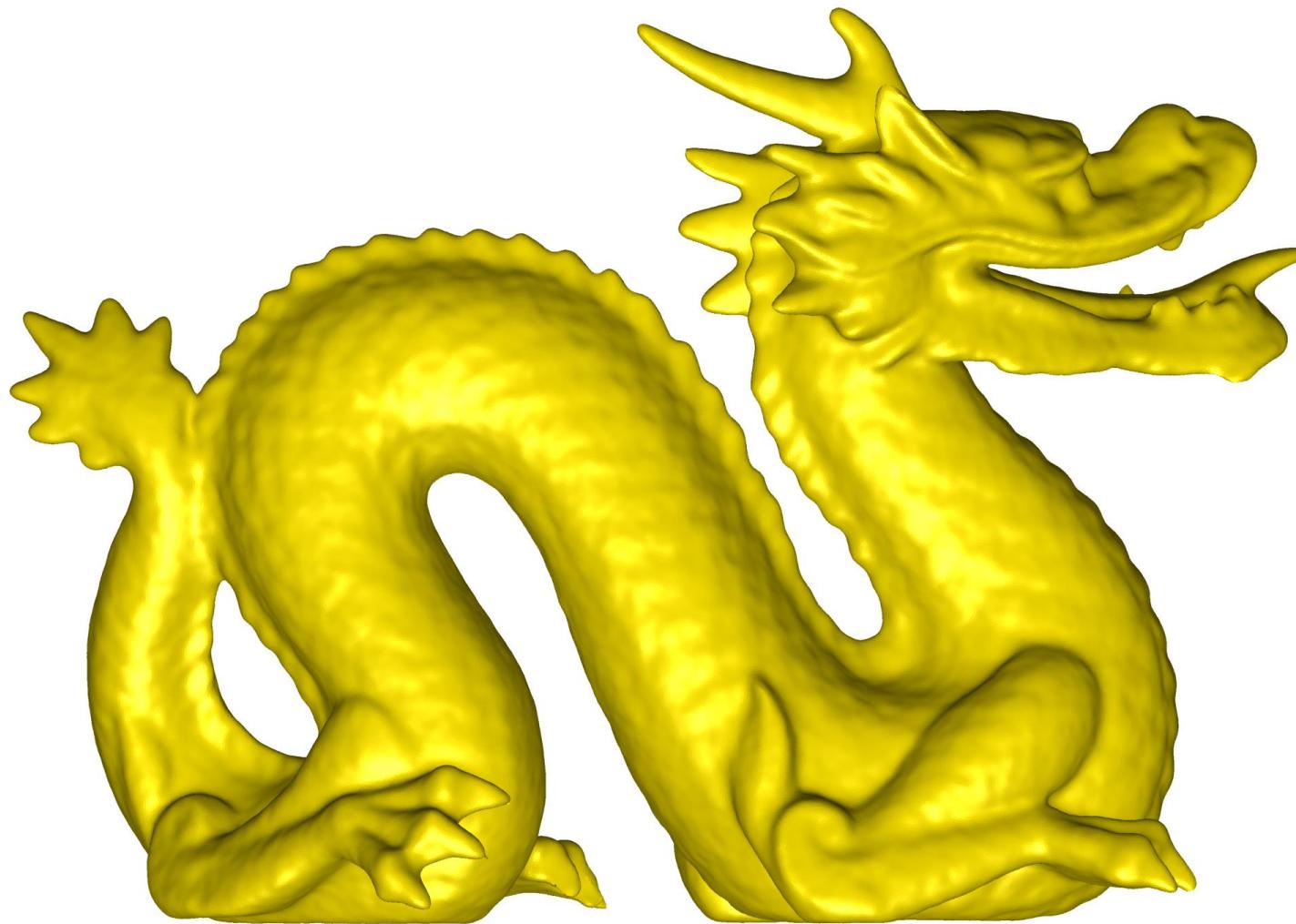
Smoothing/Denoising – Anisotropic

Feature Preserving smoothing:

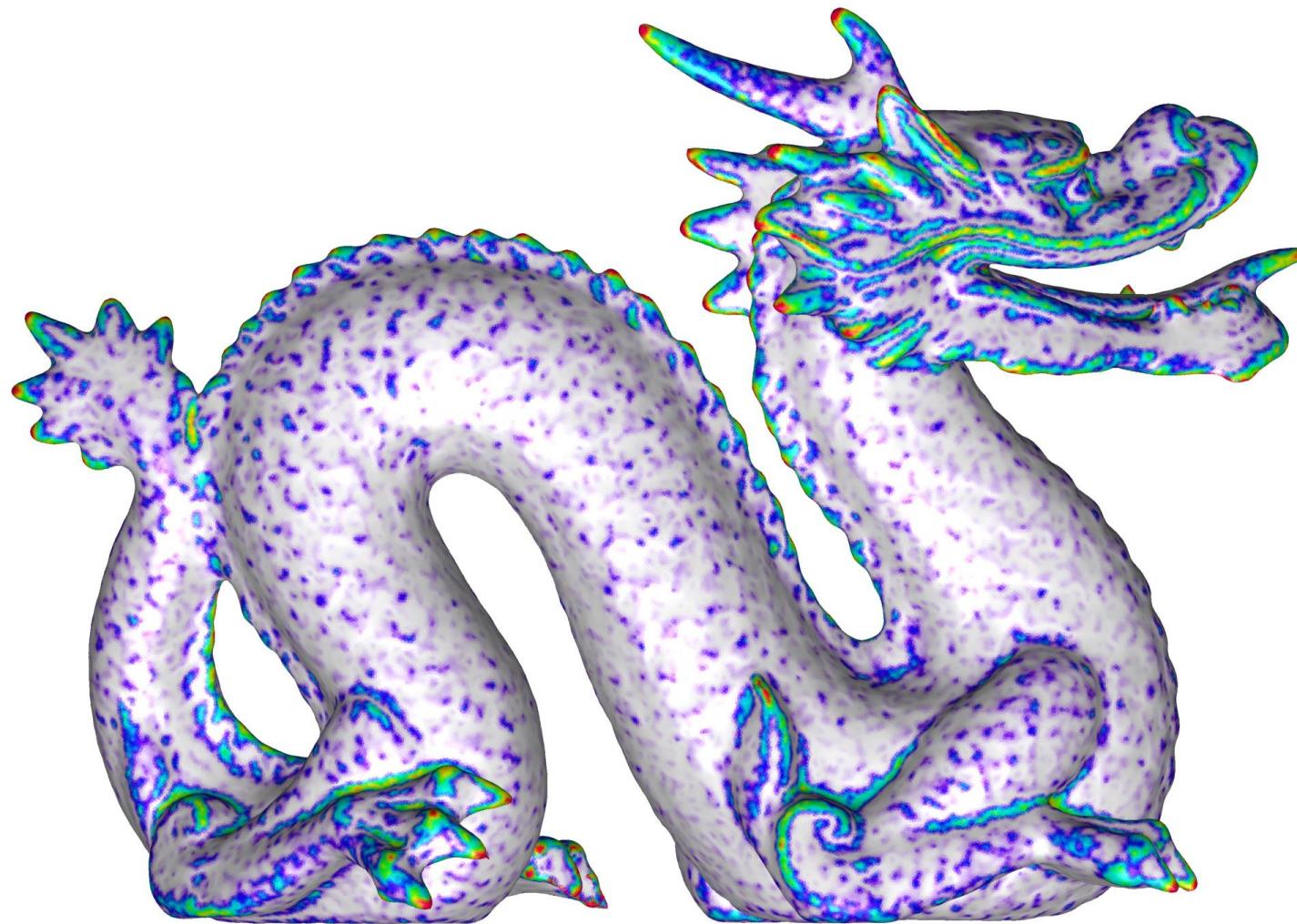
$$\vec{H}_A(x_i) = \frac{1}{2} \sum_{e=\{x_i, x_j\}} w(H_e) H_e \vec{N}_e \quad w_{\lambda,r}(a) = \begin{cases} 1 & |a| \leq \lambda \\ \frac{\lambda^2}{r(\lambda - |a|)^2 + \lambda^2} & \text{otherwise} \end{cases}$$

Based on anisotropic diffusion equation.

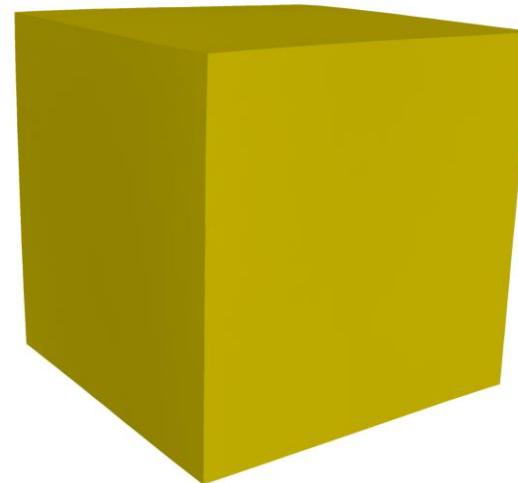
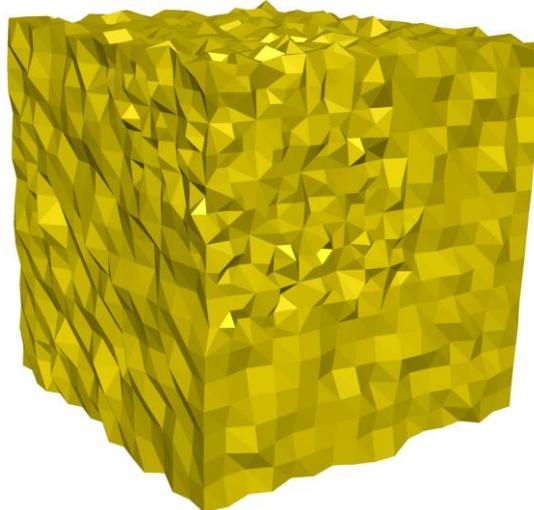
Smoothing/Denoising – Anisotropic



Smoothing/Denoising – Anisotropic



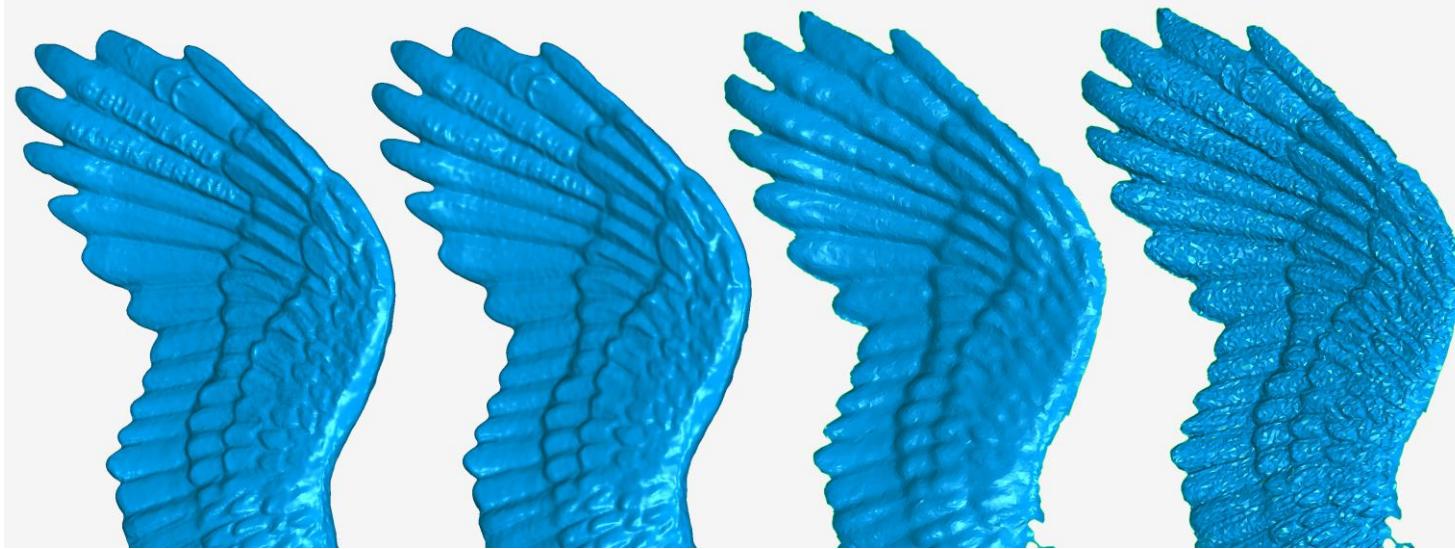
Anisotropic Smoothing – more examples



With Multiple scans and processing



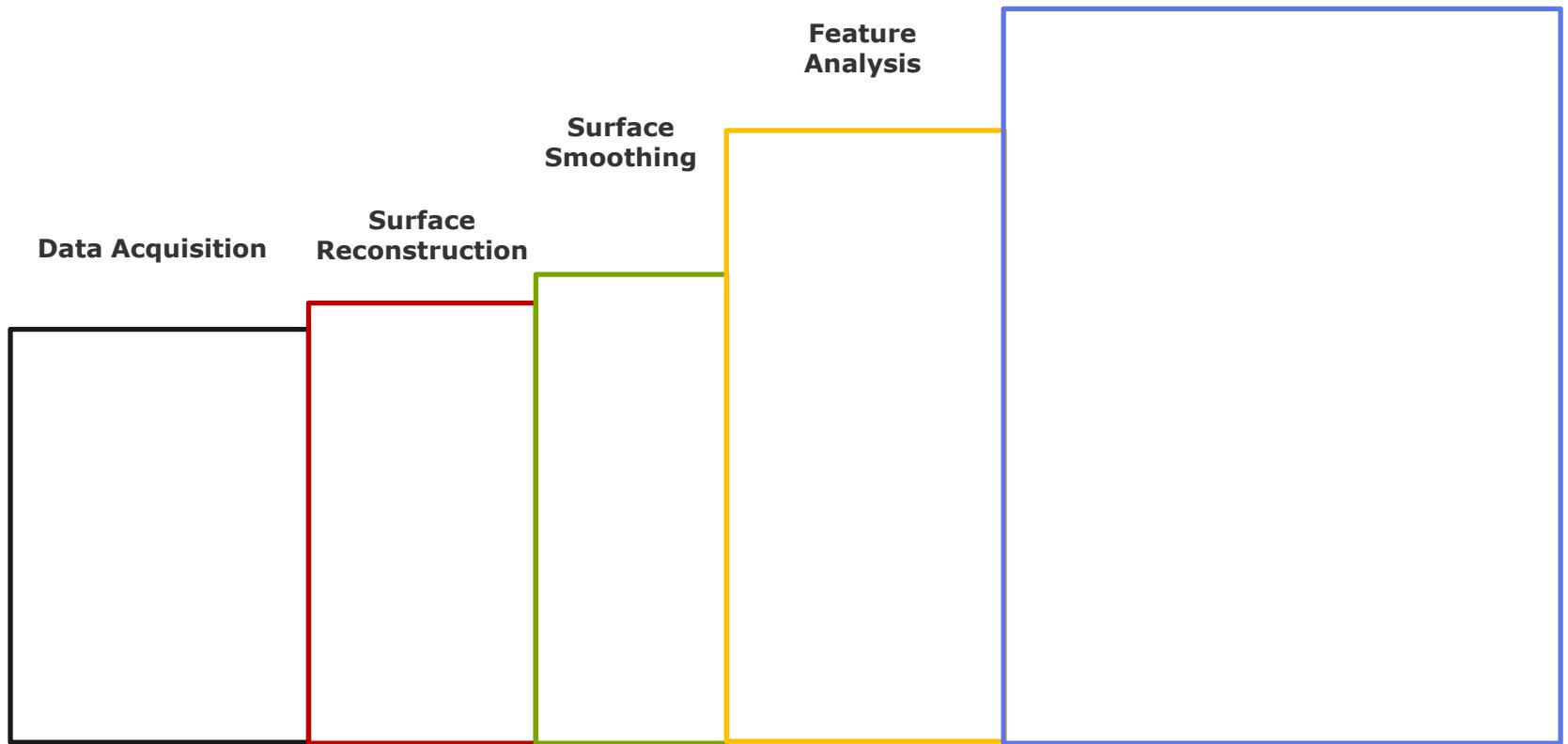
Results



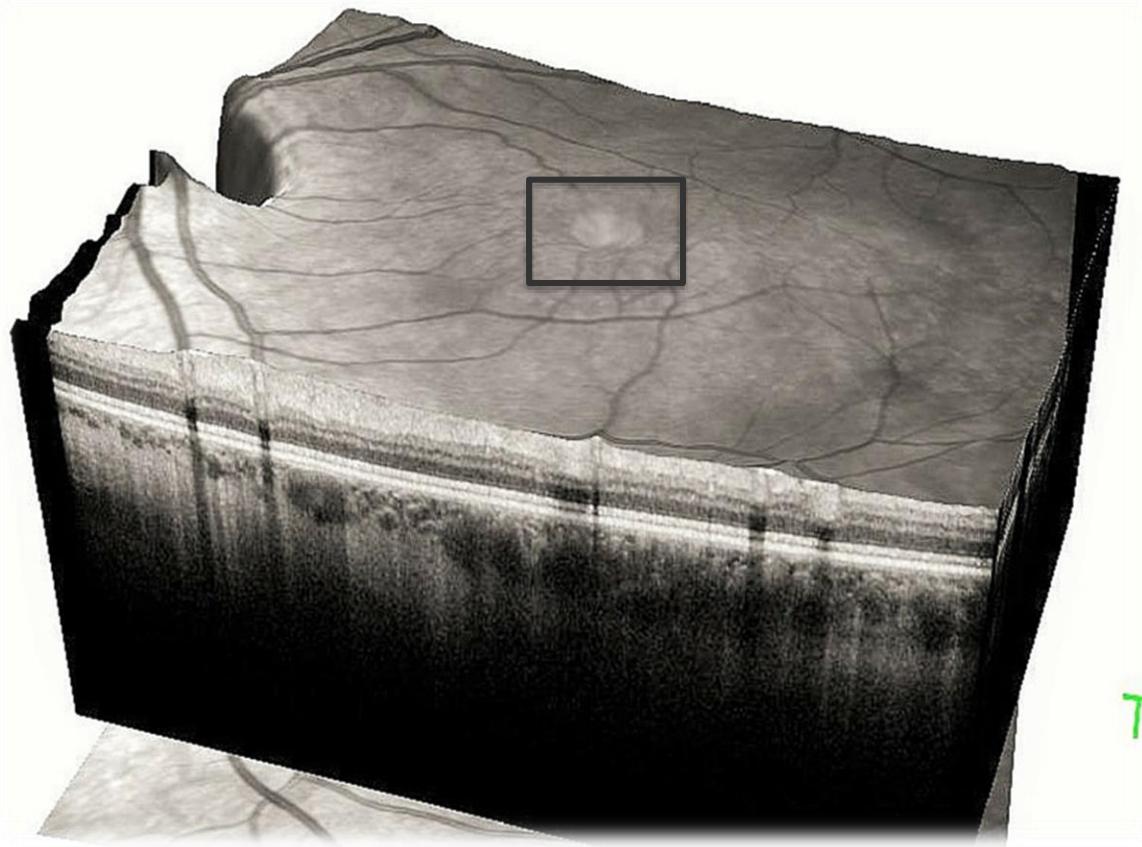


GPP - Stairs

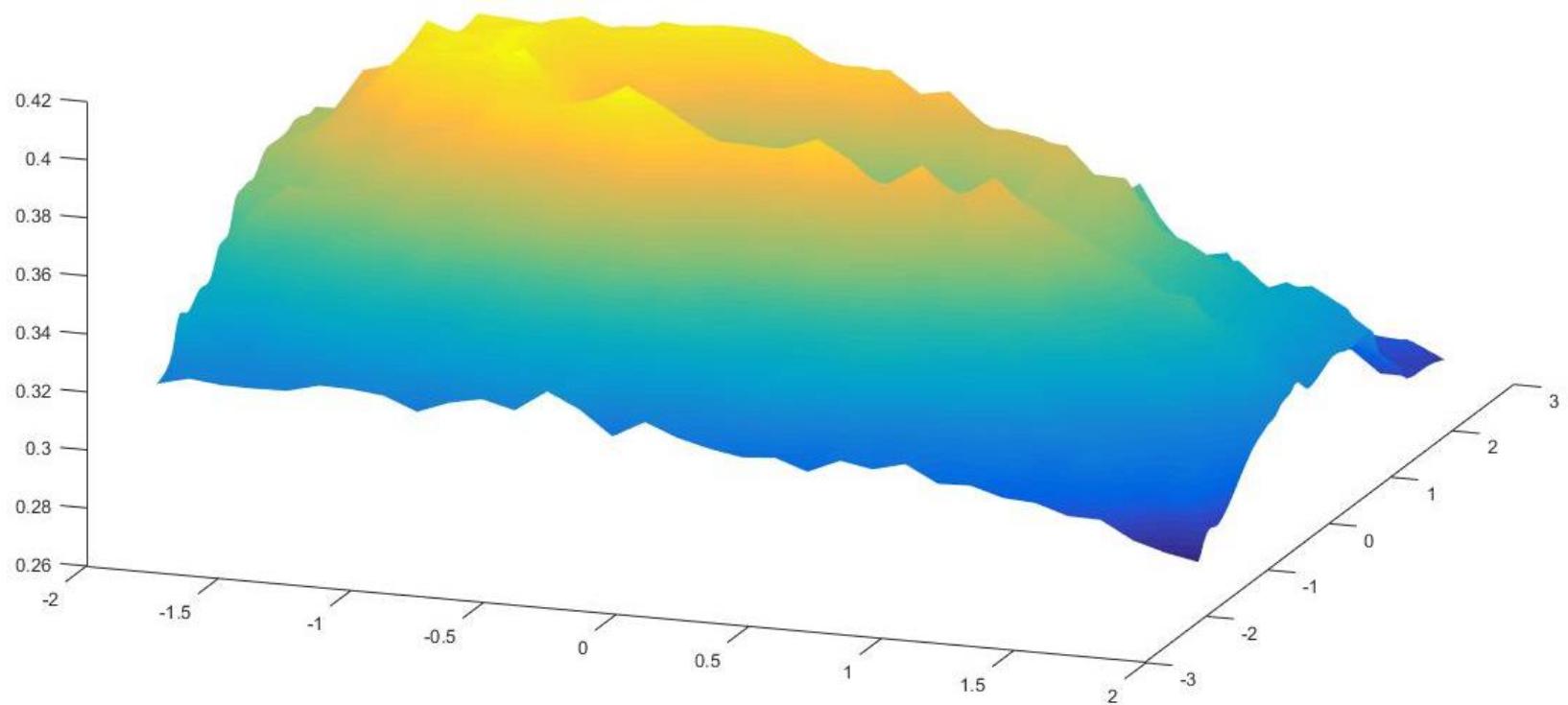
**Parametrization,
Application,
Printing**



Medical Application – 3D shape

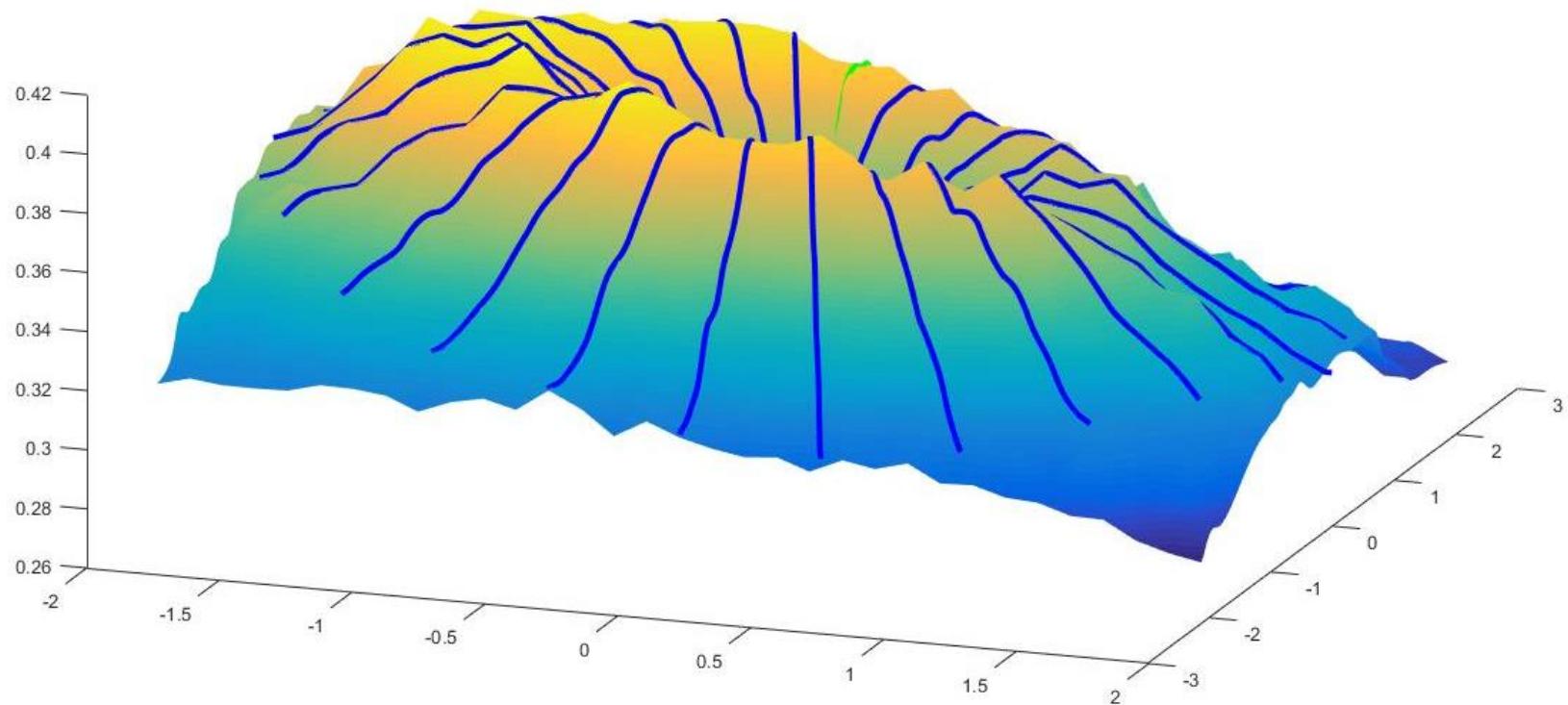


- **Resample volume scan to the radial scan using the polar coordinate transformation.**

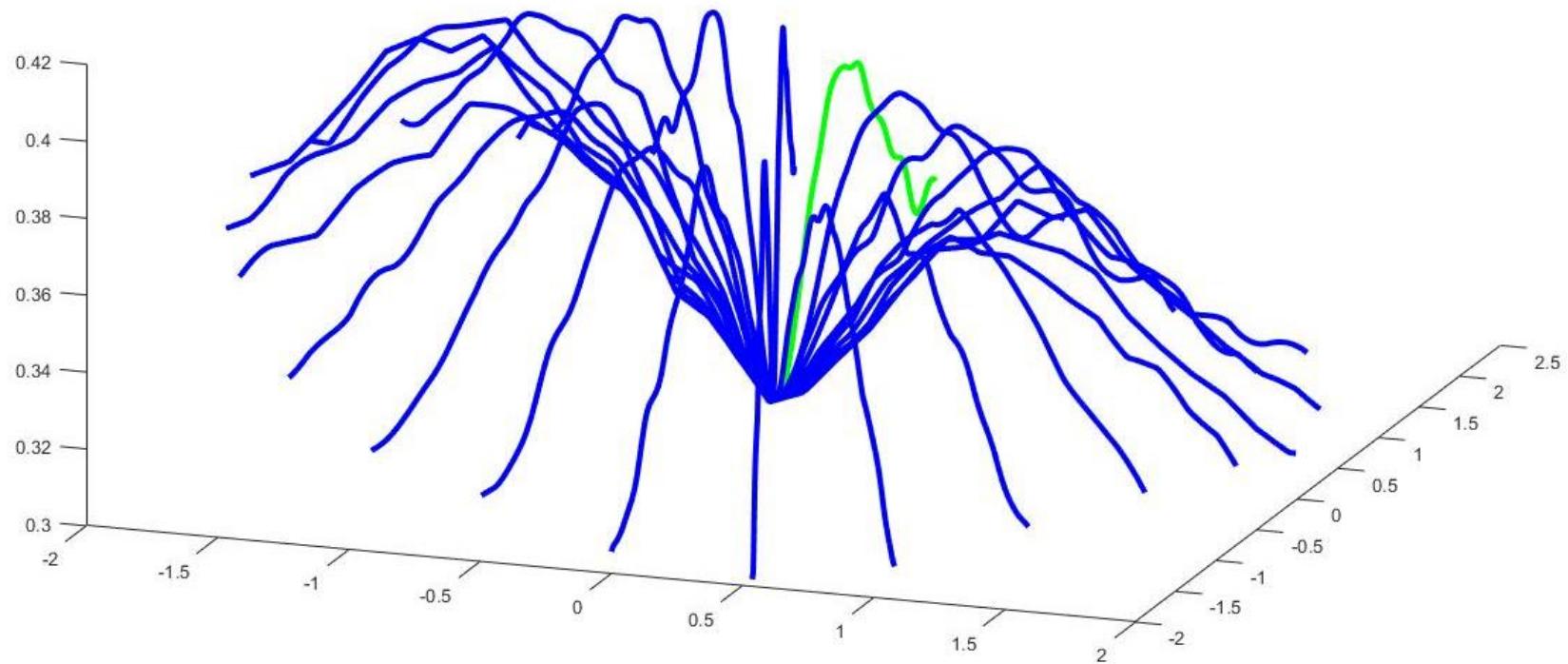


Radial Scans on Volume

- Using Bilinear interpolation.

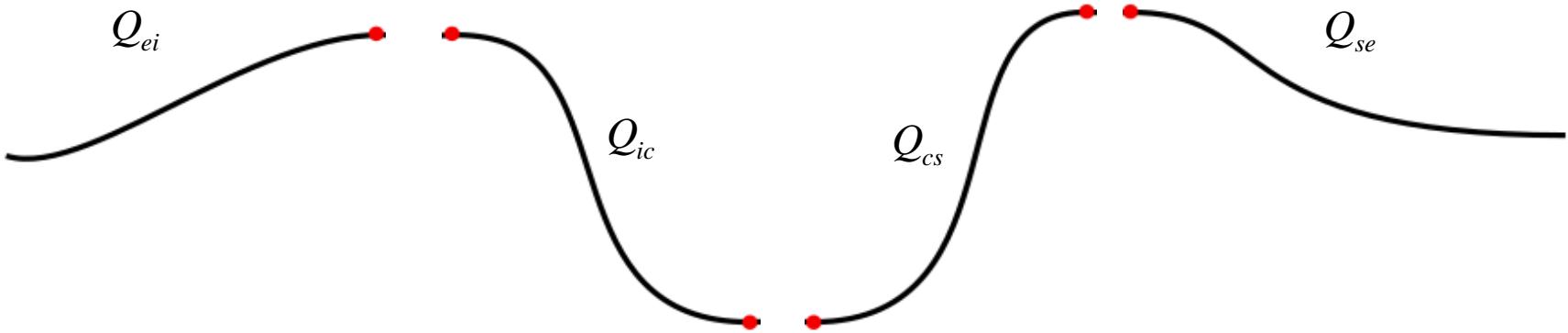


Radial Scans

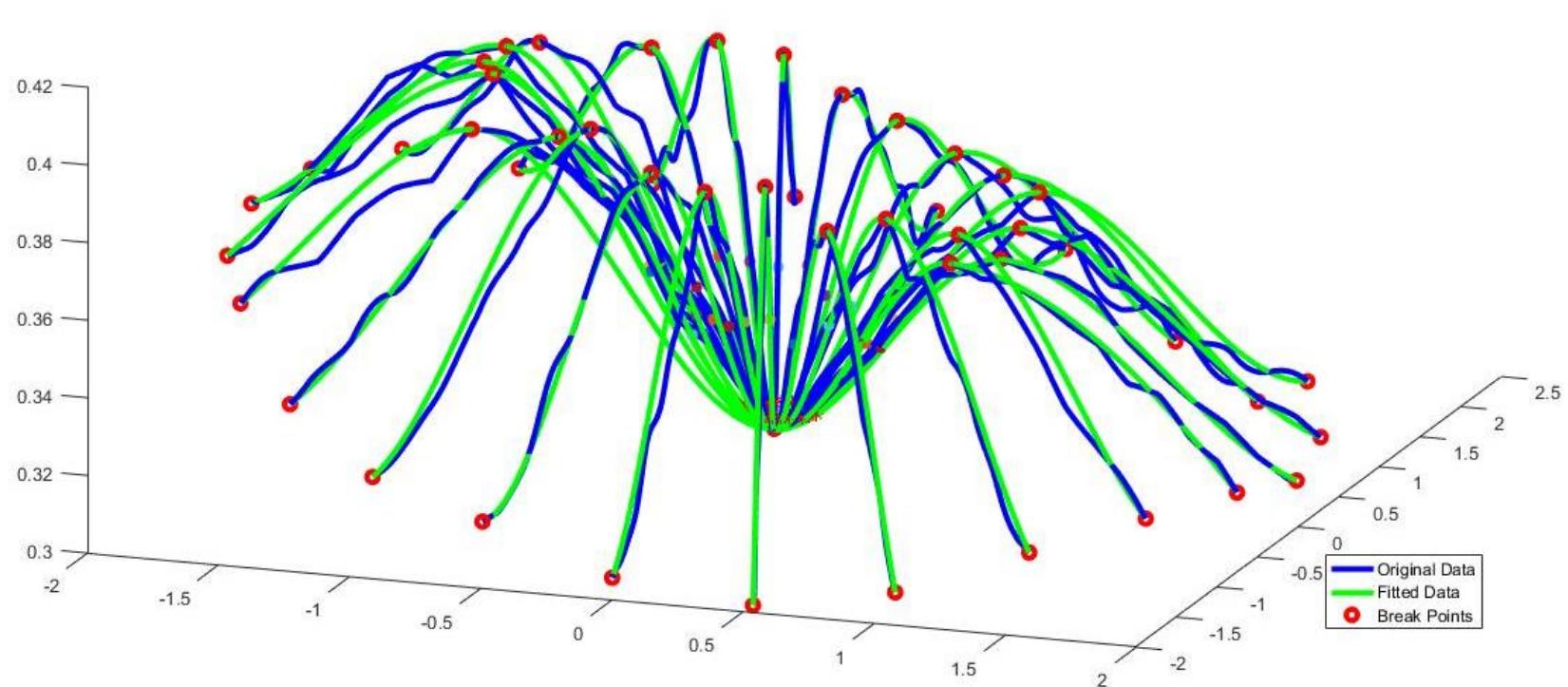


Cubic Bezier Fitting

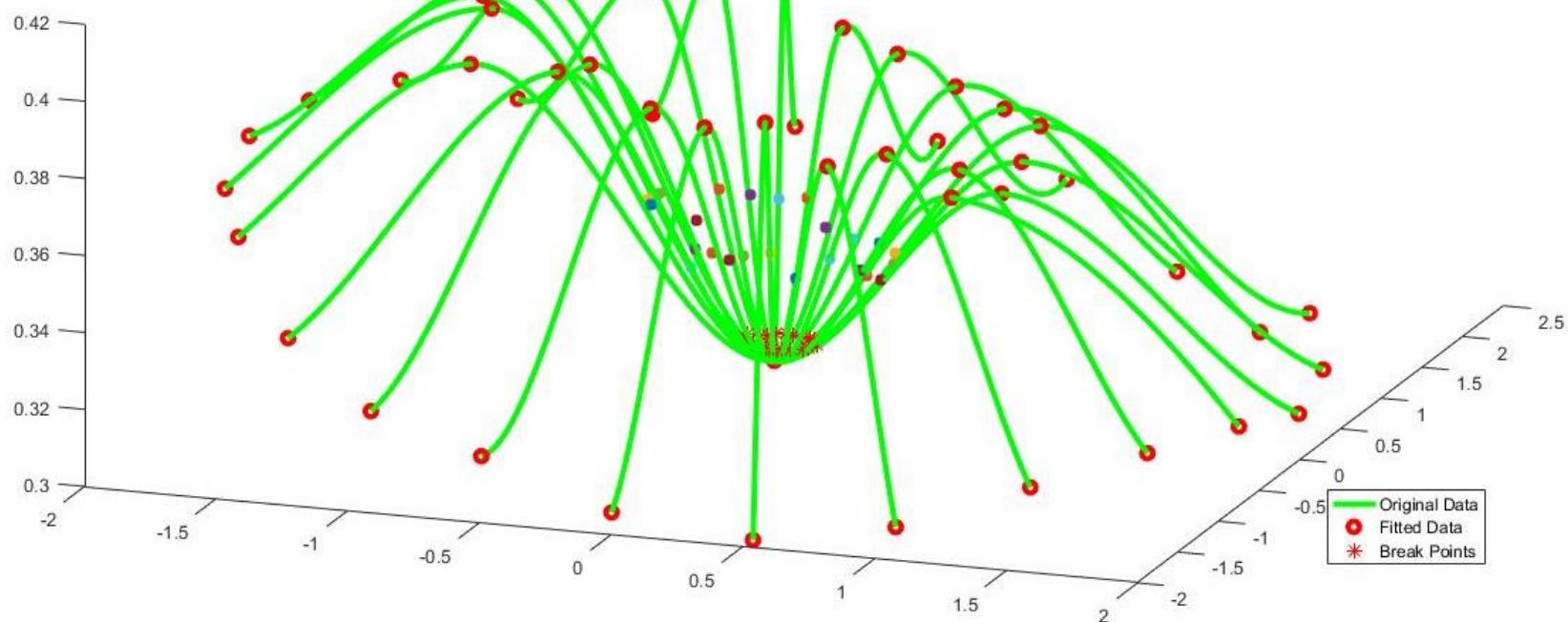
- Split whole scan in to 4 parts.
- Splitting points: rim points and foveal pit
- Each segment can be approximated by using the Bezier cubics.



Fitted Radial Scans

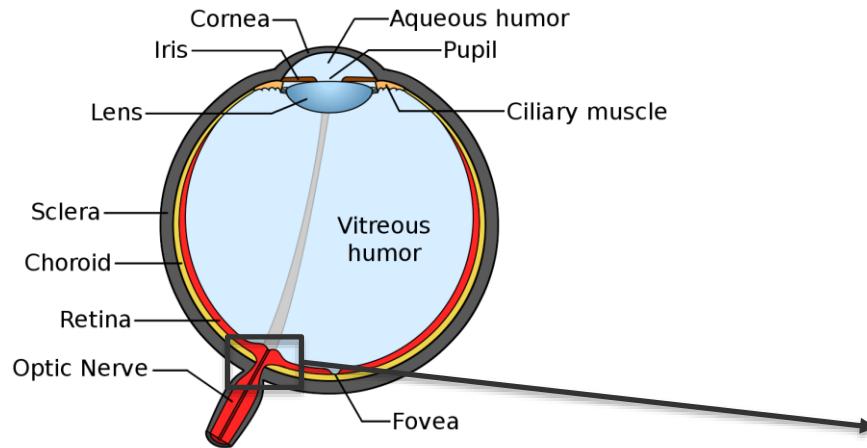


Fitted Radial Scans



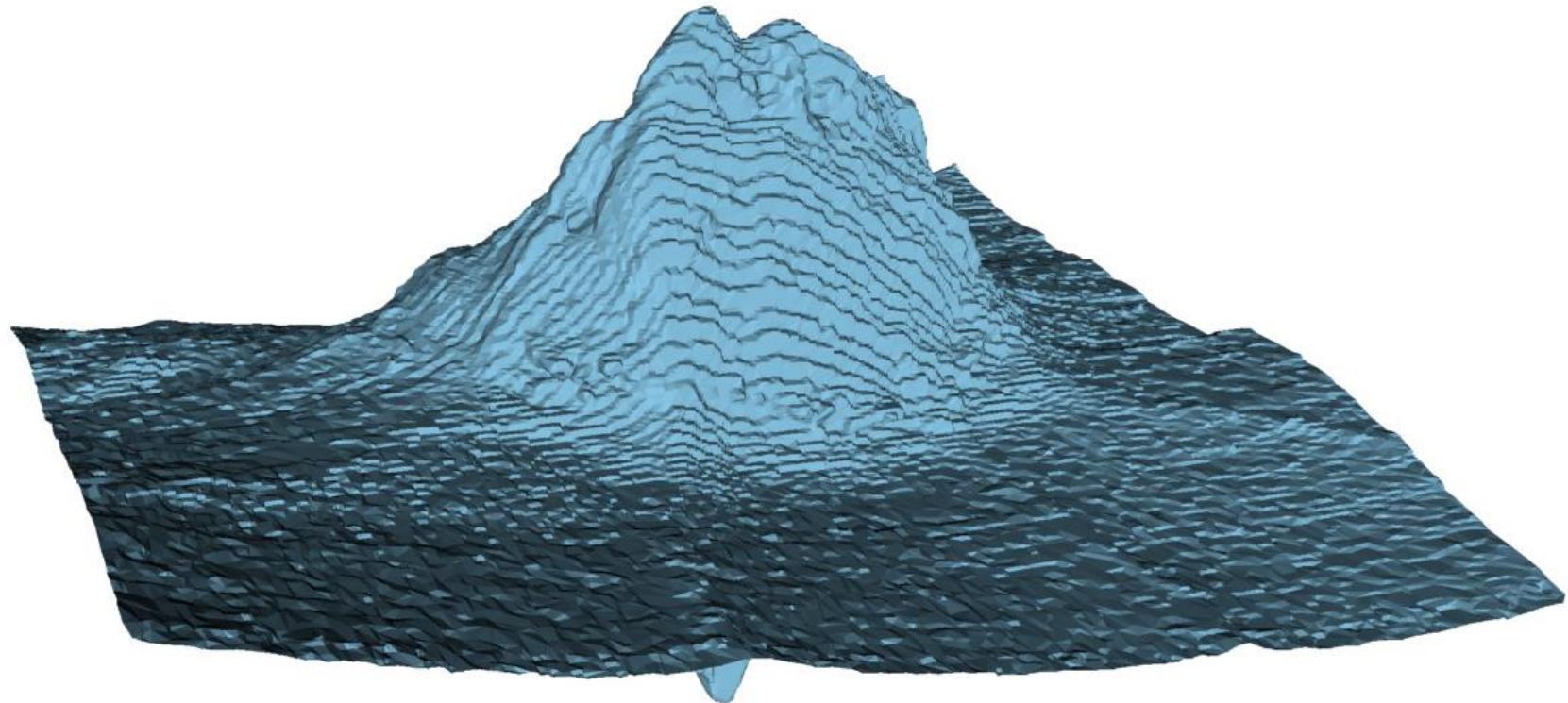


Optical Nerve Head Morphometry

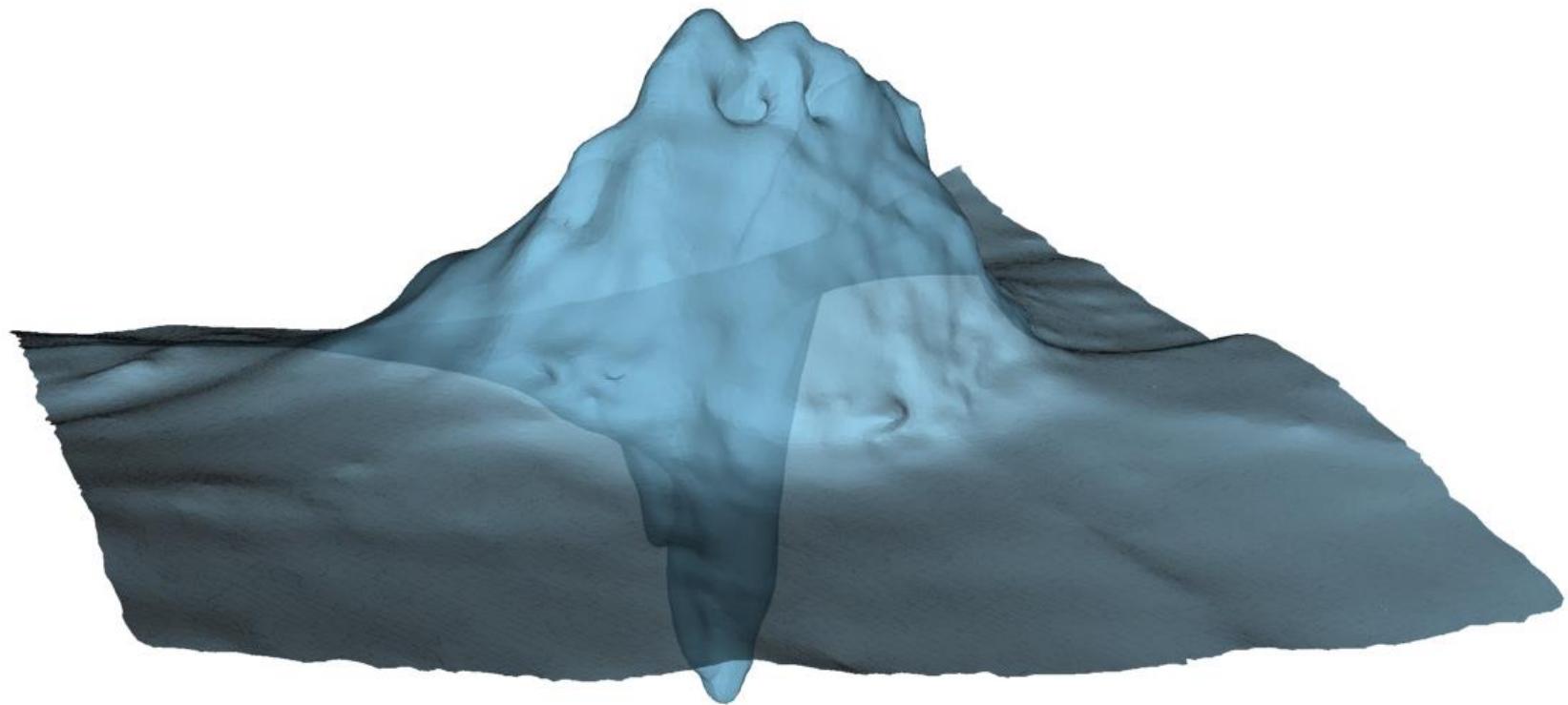




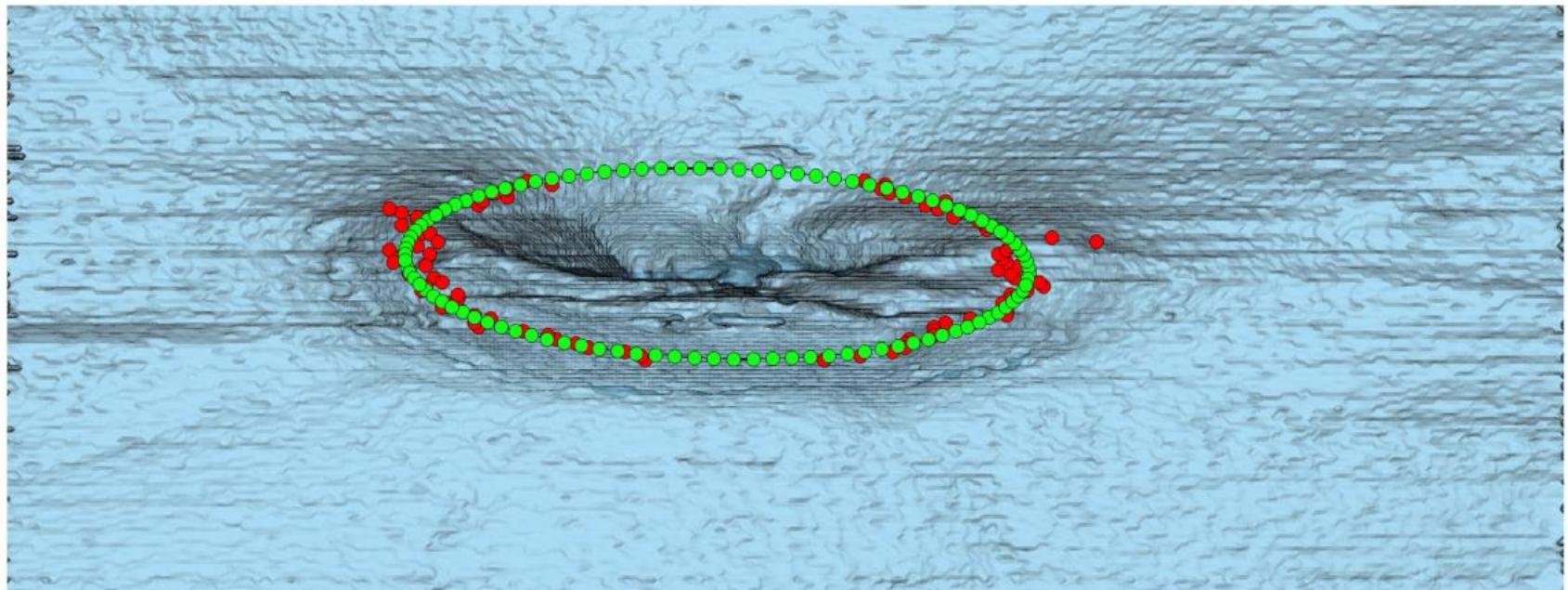
Surface reconstruction



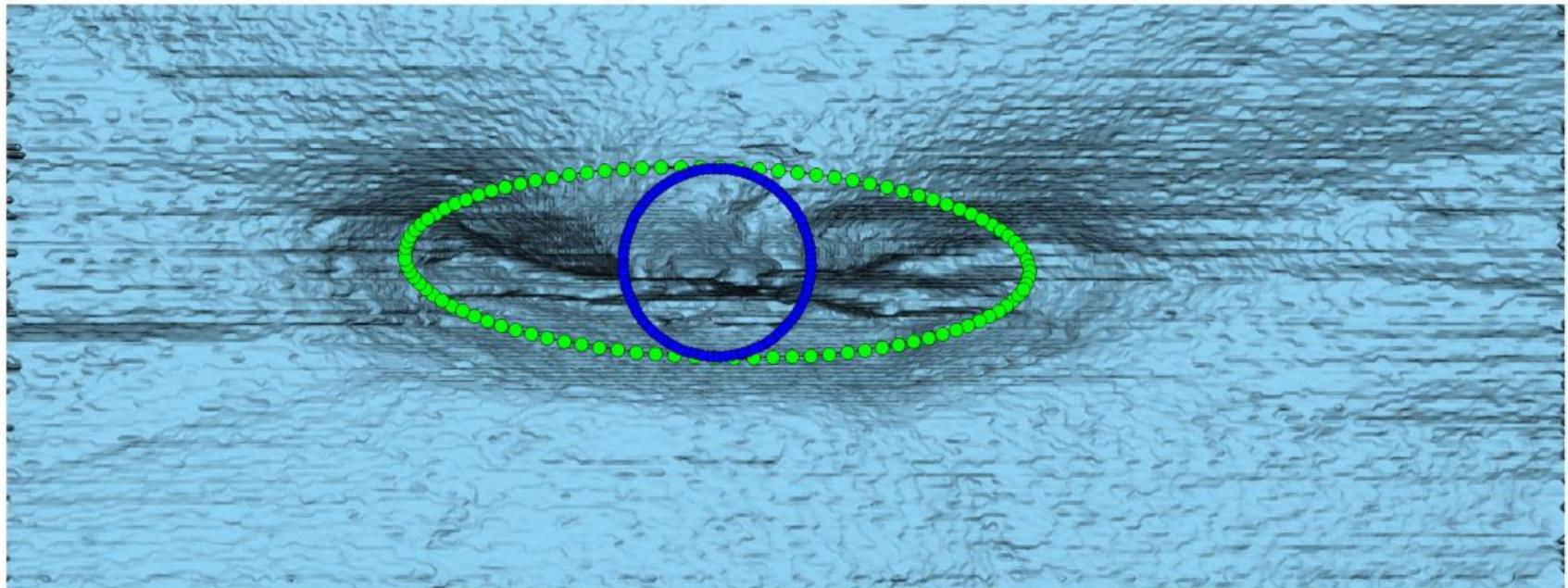
Outlier removal and Smoothing



Interior Region based on Landmarks

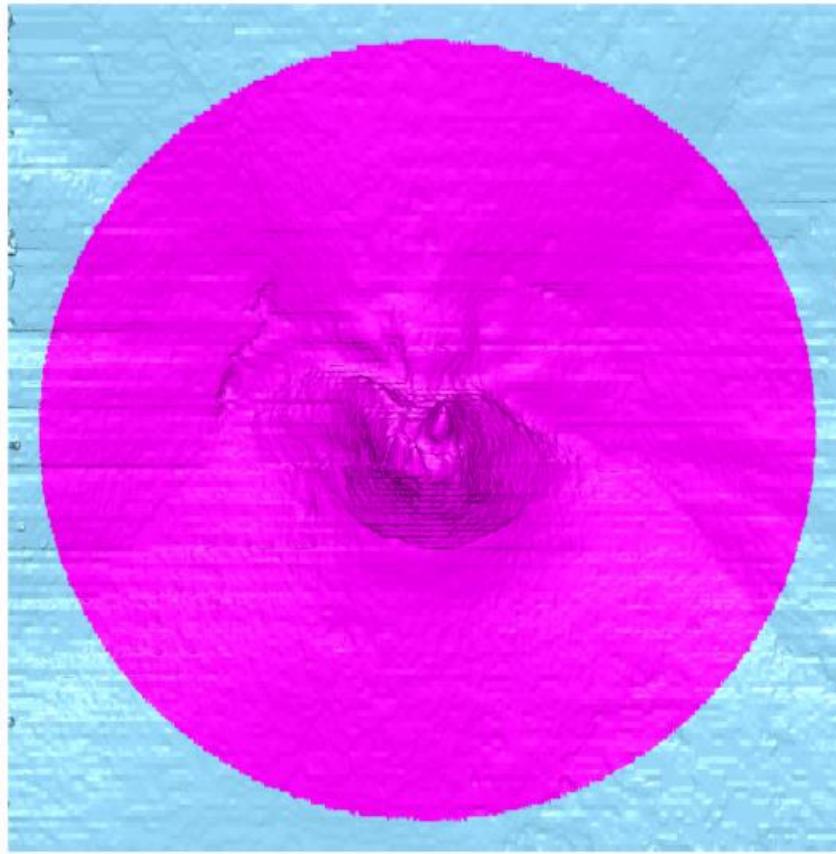


Interior Region based on Landmarks



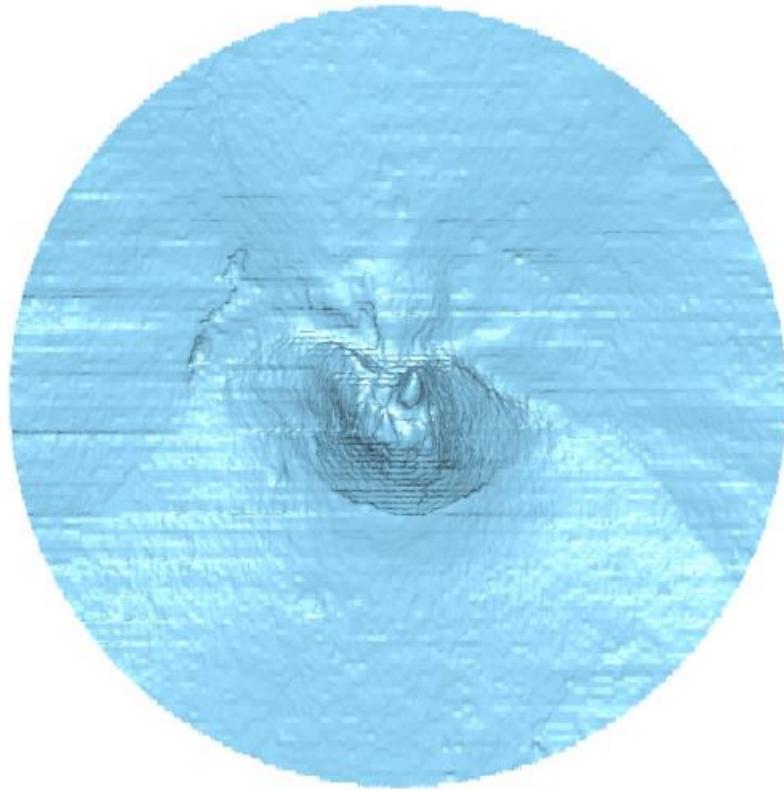


Annular shape ONH – User defined radius (2mm)



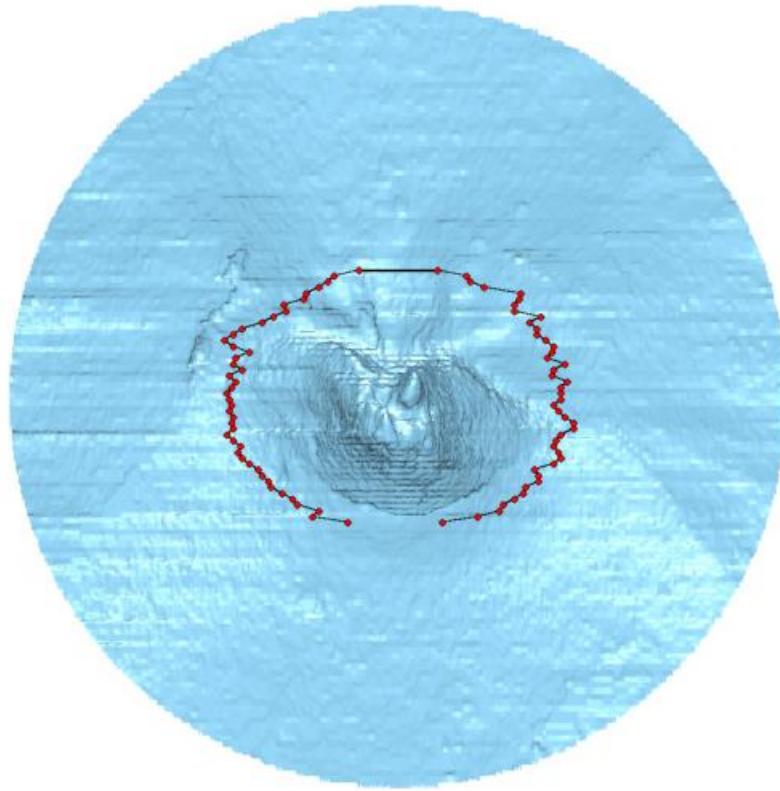


Annular shape ONH – User defined radius (2mm) - ROI



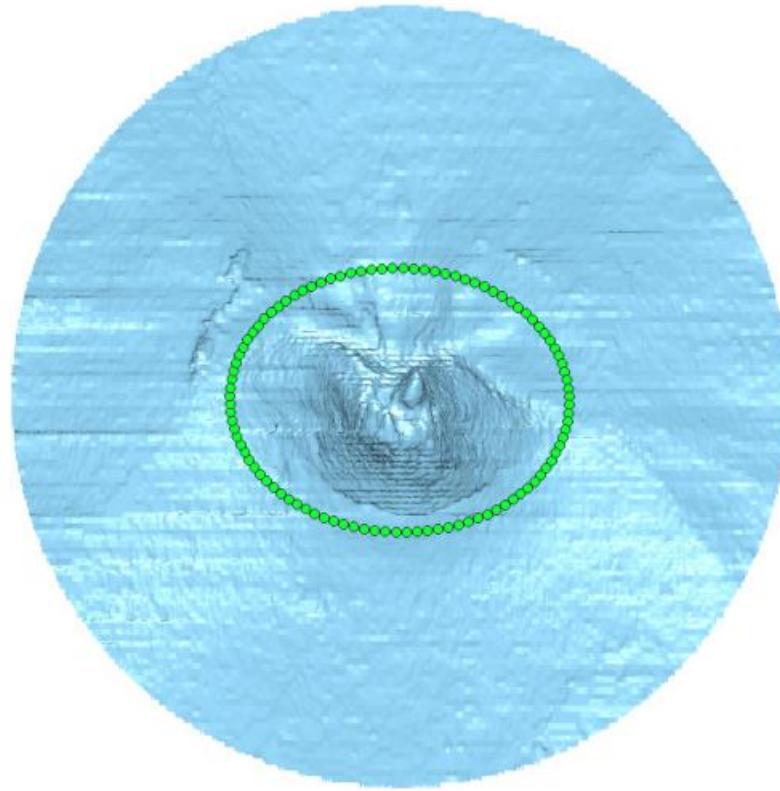


ROI - Landmarks



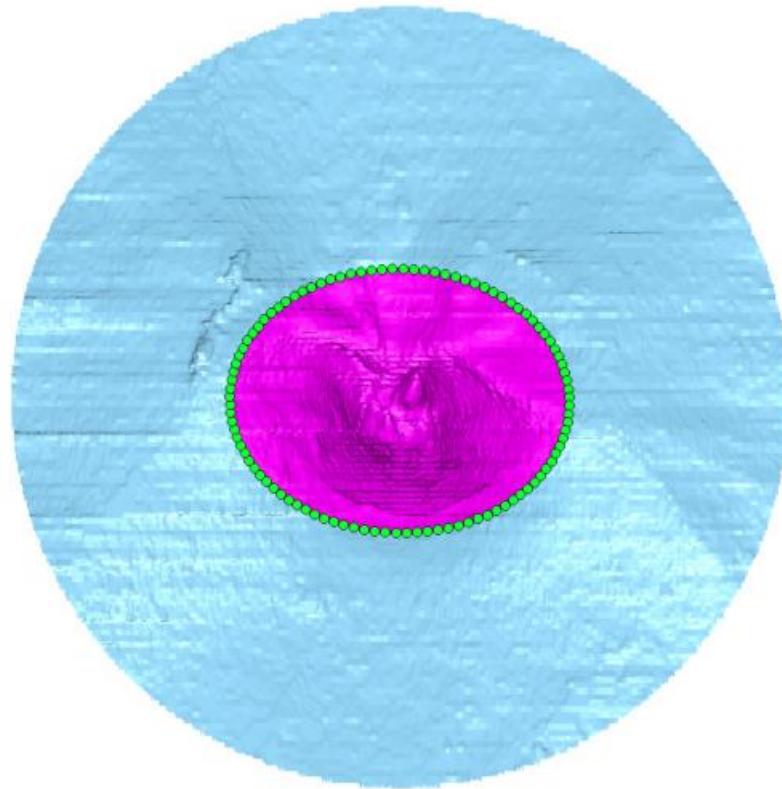


ROI - Ellipse Fitted Landmarks



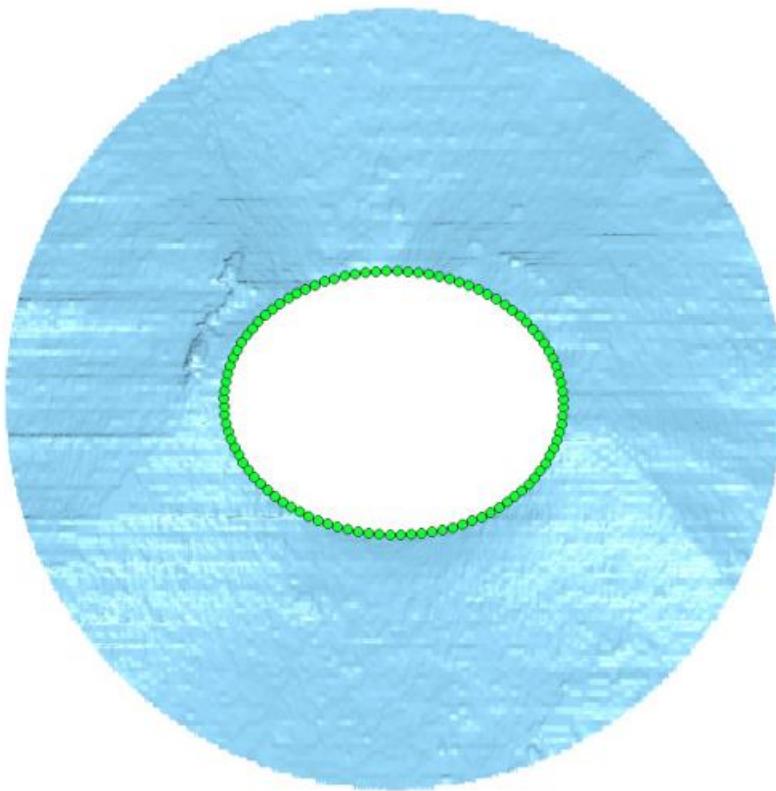


Interior region - Landmarks



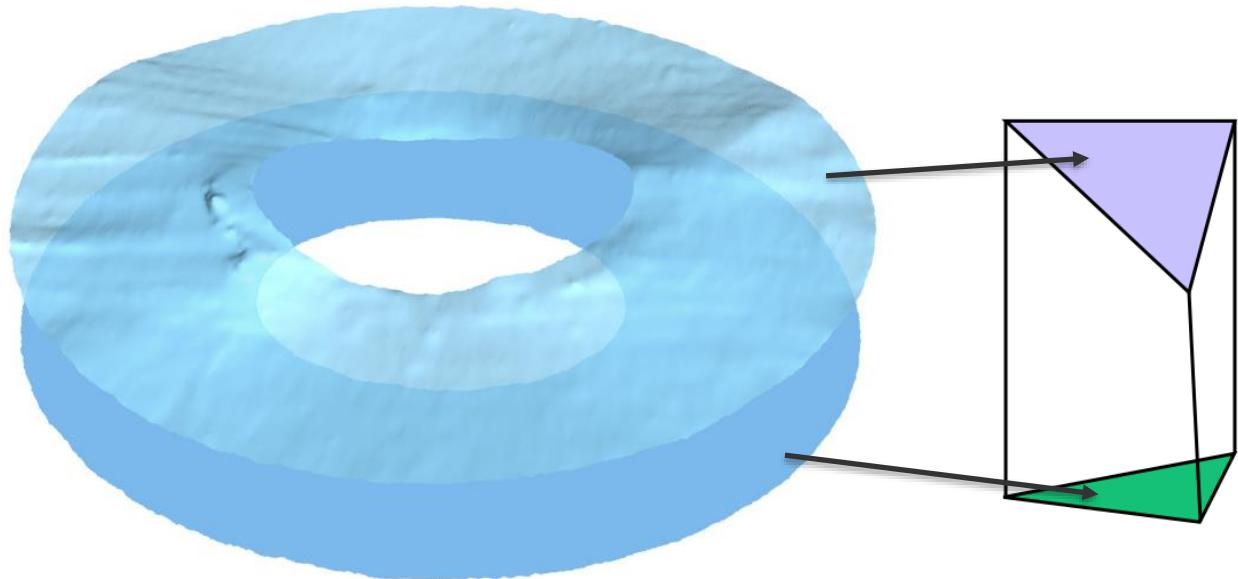


Annular Region ONH



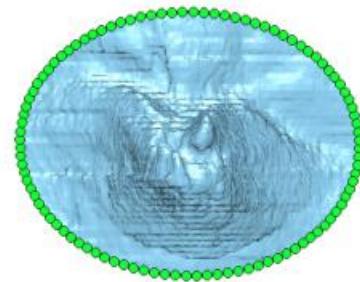


Annular Region ONH - Volume



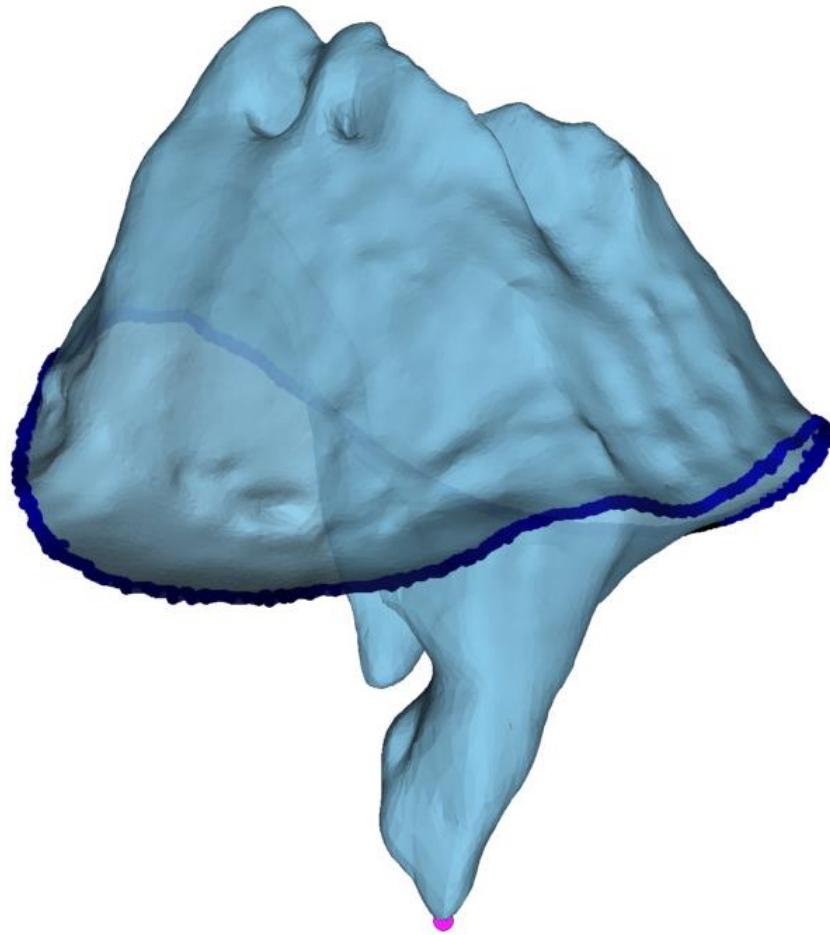


Interior Region ONH



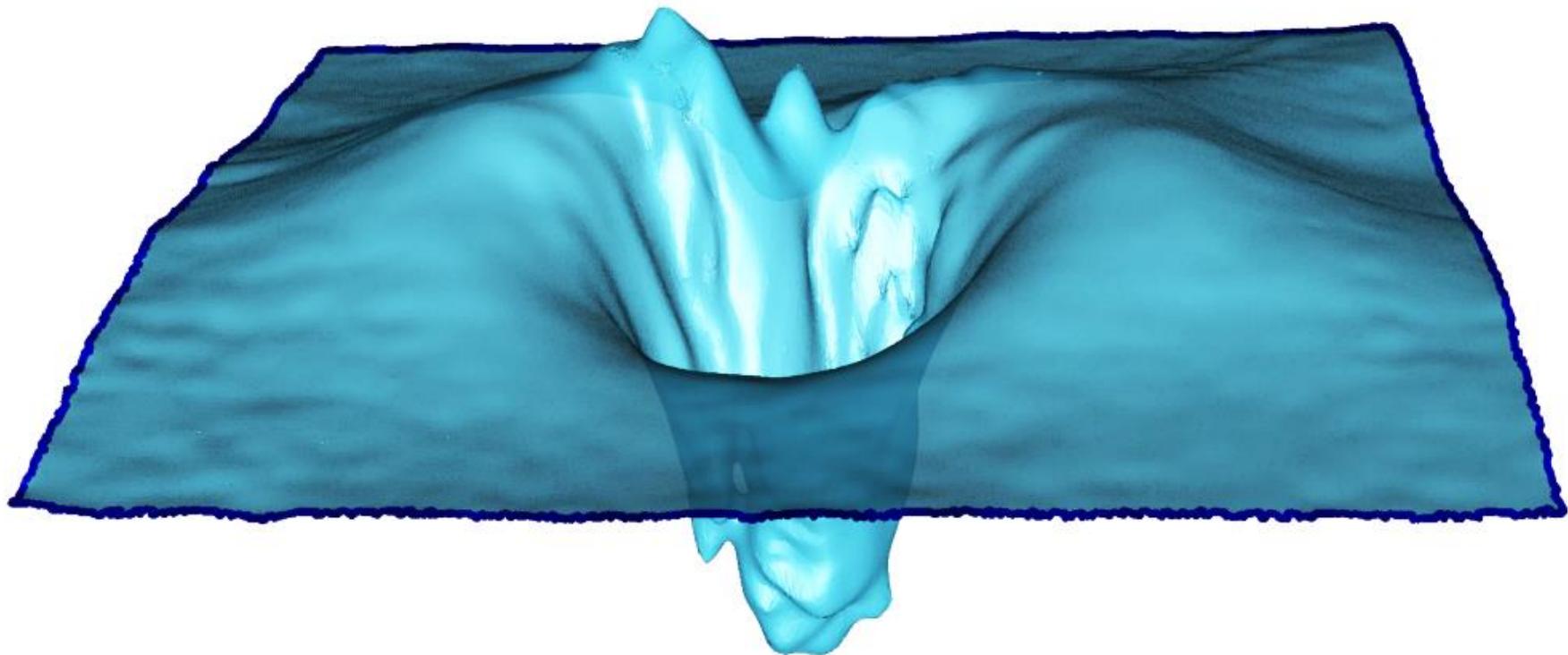


Interior Region ONH





Mean Shape of Healthy Right Eye



Thank You for your Attention

