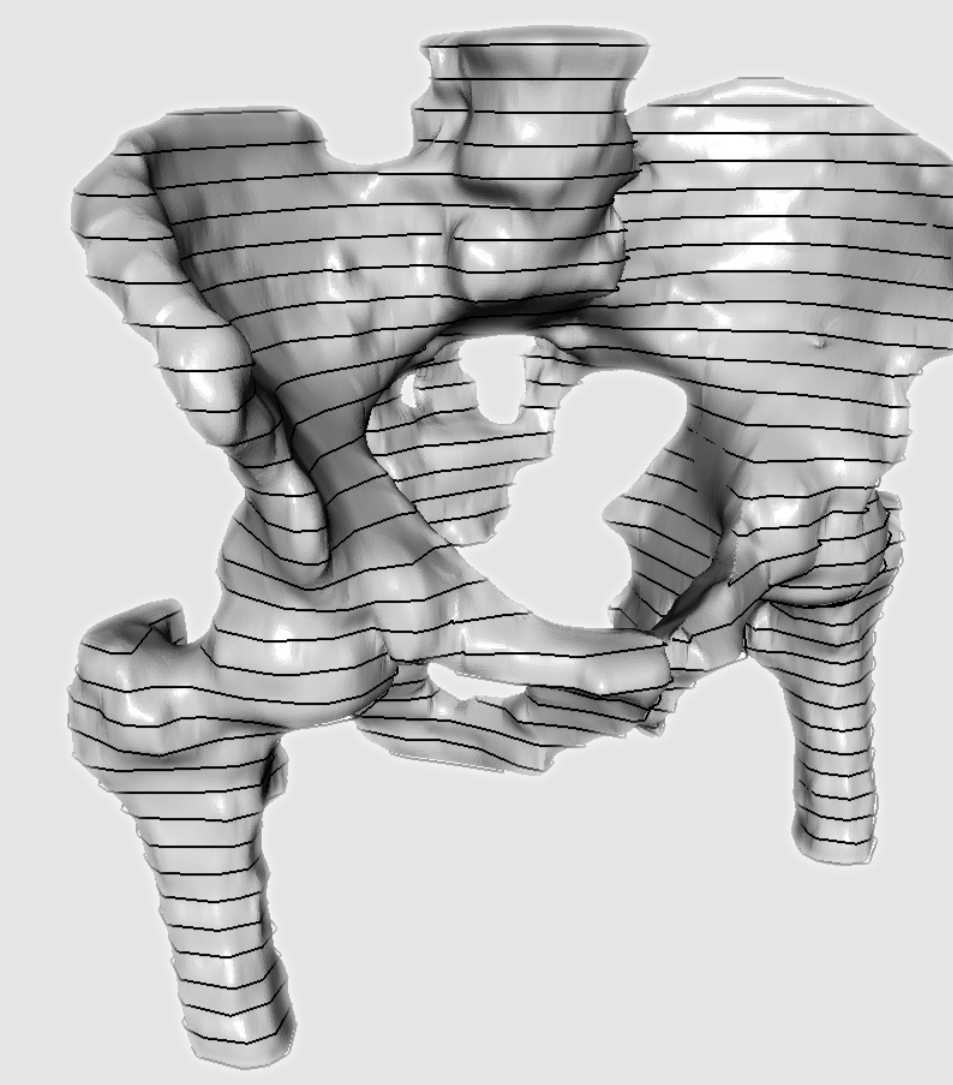


# Surface Reconstruction from Sparse Contours using Implicit Curve Fitting and Distance Field Interpolation



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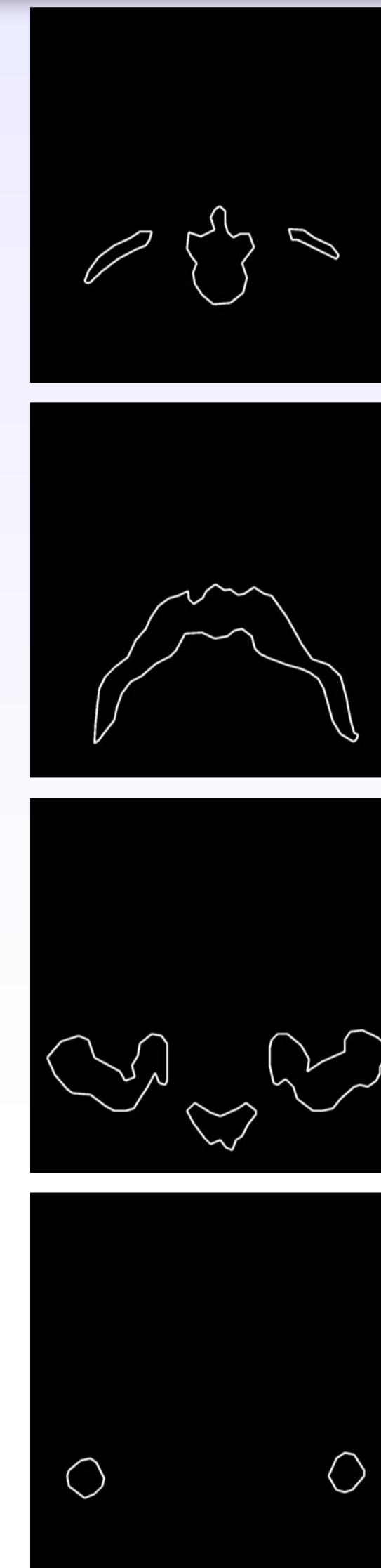
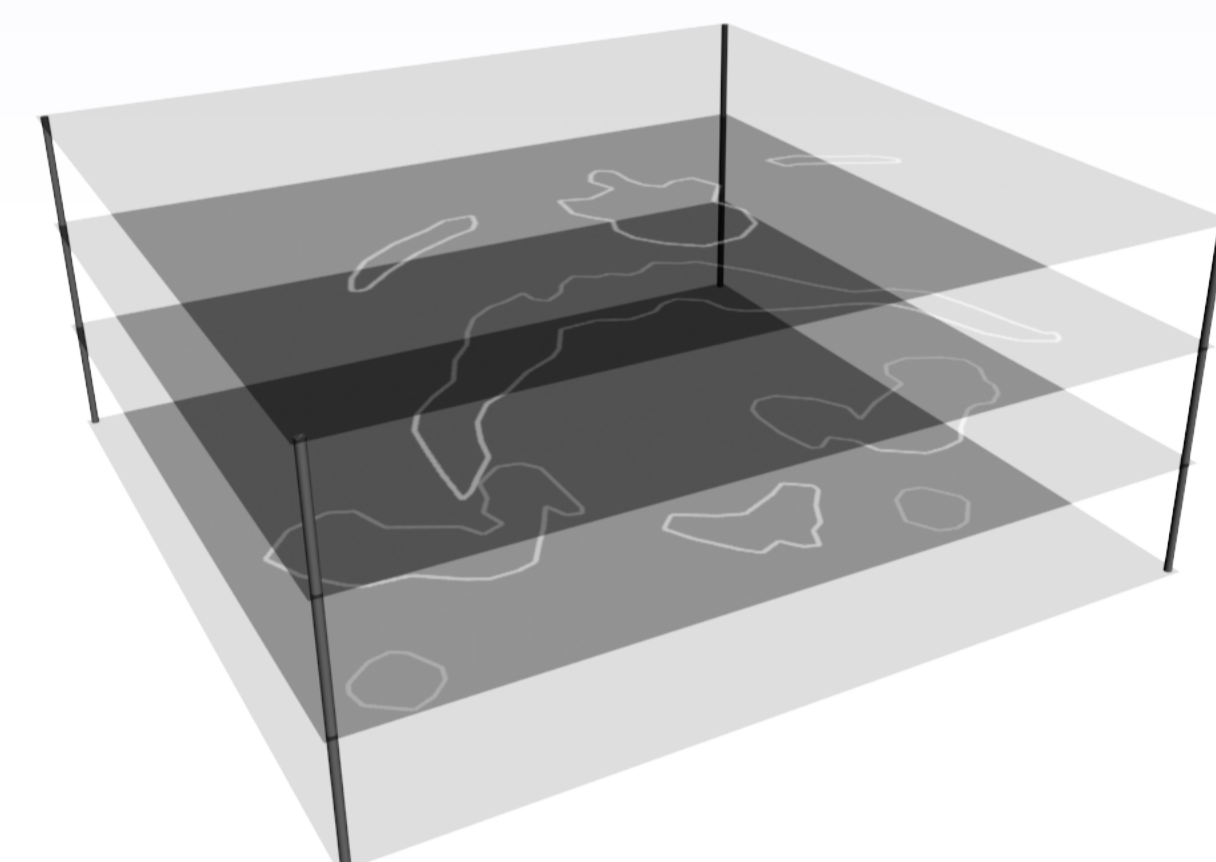
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## Introduction

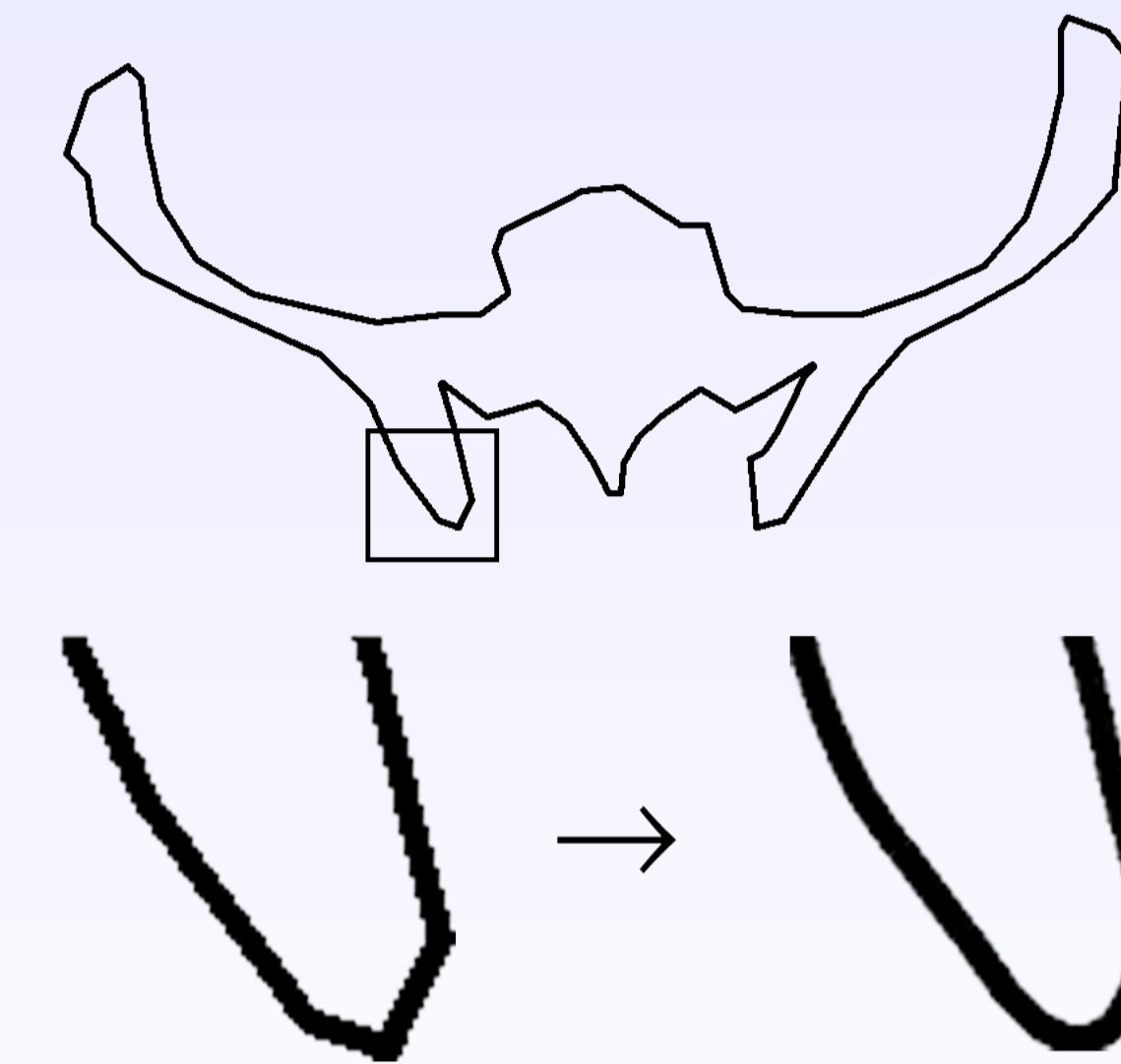
- Scientists and doctors scan all types of specimens
- Specific structures within the resulting 3D datasets need to be isolated and viewed for analysis
- Segmentation process may produce contours around structures in each slice of the dataset
- Goal: Given a sparse set of parallel contours, generate a smooth 3D surface that interpolates the contours
- General approach involves creating a volume dataset by interpolating 2D filtered distance fields
- The zero iso-surface in the computed volume provides the desired result.
- Our approach includes several stages
  - Contour smoothing with MPU implicit curves
  - Euclidean distance field calculation
  - Distance field filtering to remove discontinuities
  - Inter-slice monotonicity-constrained spline interpolation
  - Mesh extraction

## Input Data

- Binary images extracted from MRI scans, CT scans, and manual delineation
- Segmentation requires human-in-the-loop involvement, resulting in undesired noise
- Each structure must be isolated for processing, and signed to indicate inside/outside
- In-plane resolution can range from 100x100 to 1000x1000, with out-of-plane resolutions of 10:1 or more
- 2D data can be visualized as a volume by stacking the contours vertically; our algorithm creates a 1:1 distance-based volume to fully visualize the data



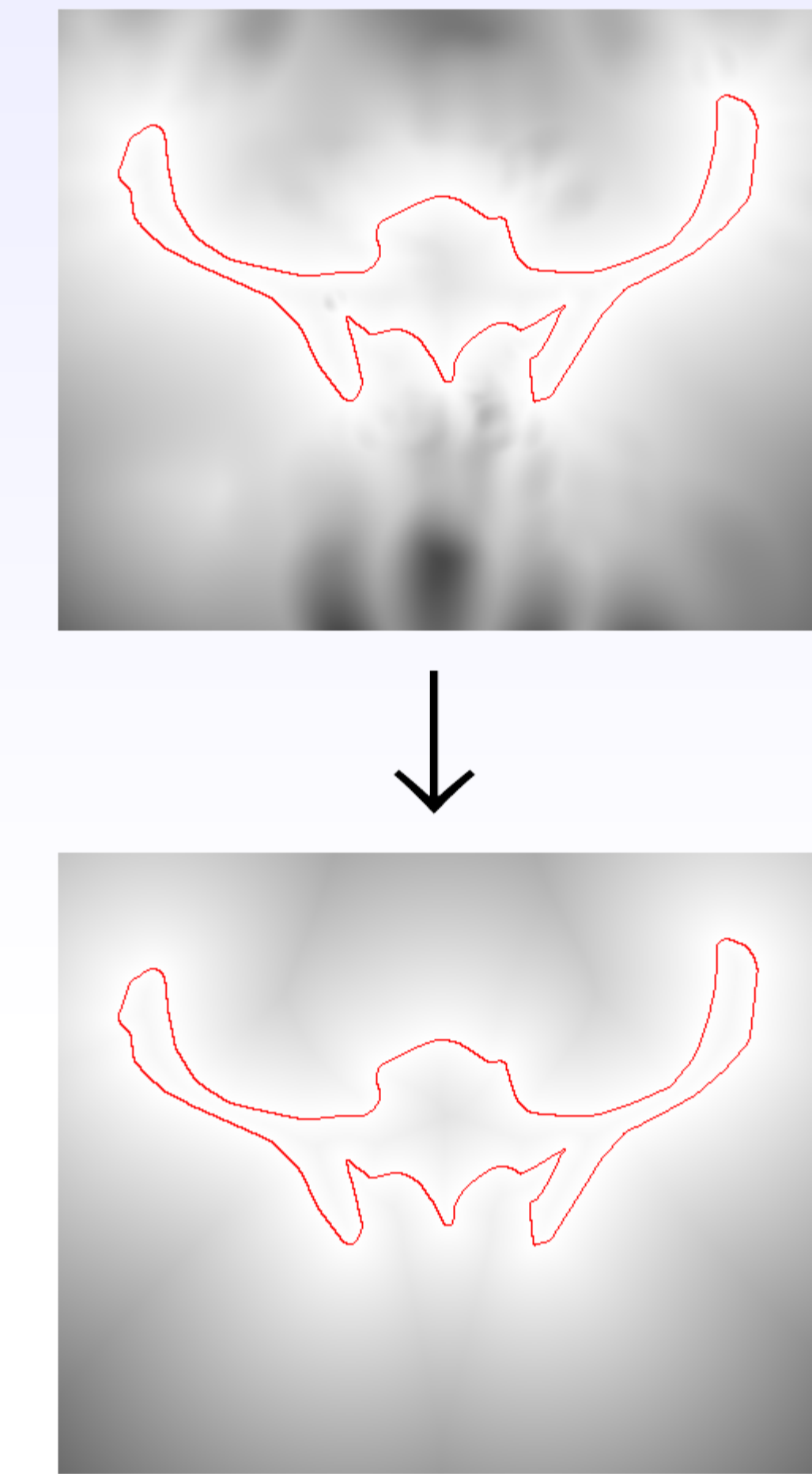
## Contour Smoothing



- Pelvis data set is vector-based, as evident in the above figure (top and bottom-left)
- Just as vector data sets contain discontinuities, raster human-traced histologic data also contains noise based on hand movements and shifting between slices
- MPU Implicit curve fitting is an ideal way to reduce noise; it generates smooth results, and is guaranteed to be within a certain error tolerance
- MPU Implicits can approximate 2D or 3D data; we use it in a 2D mode to process each slice, and use spline interpolation to create the full 3D volume

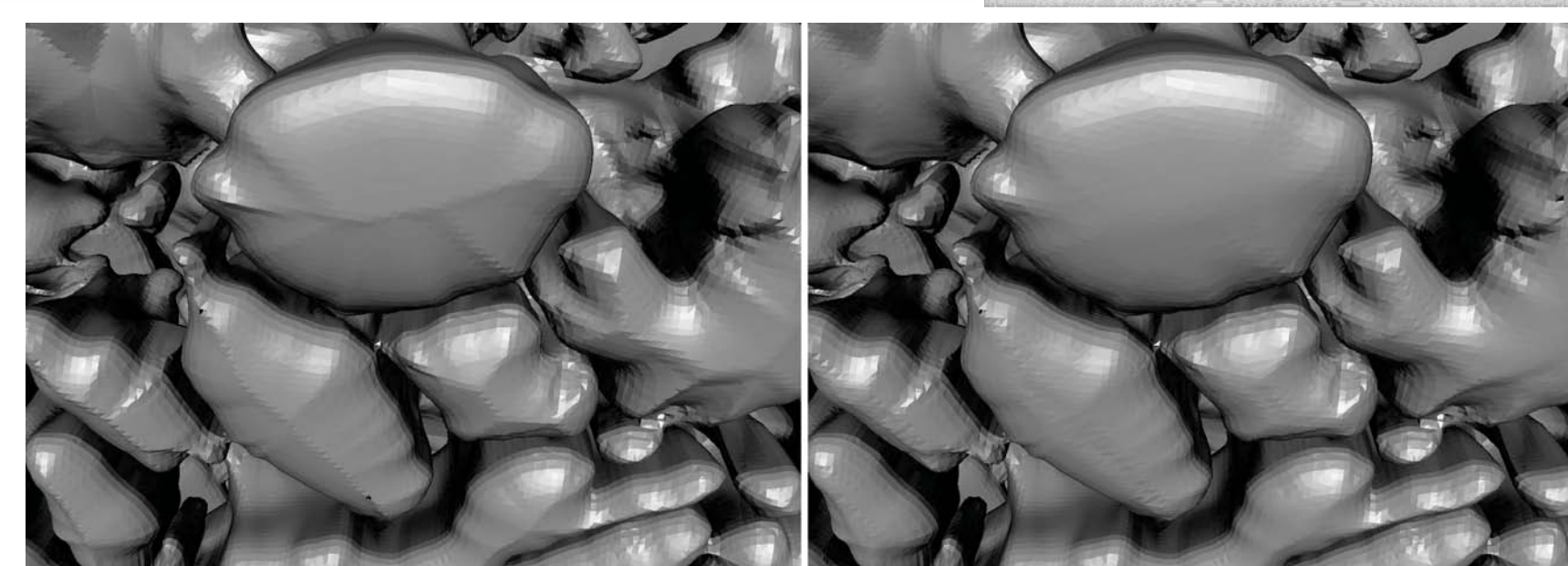
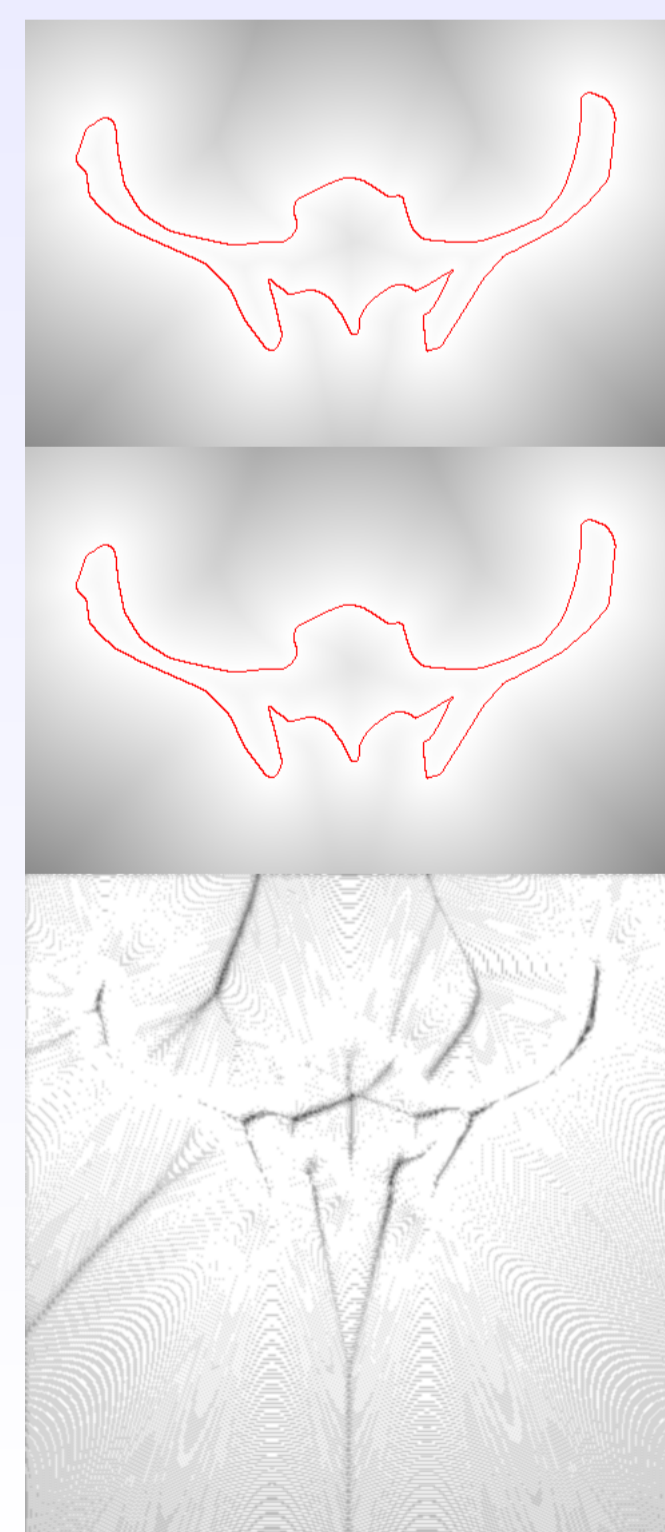
## Euclidean Field

- While MPU Implicits are very accurate in a narrow band near the zero level set (implicit curve) of the resulting field, they become erratic away from the narrow band
- The distance information in the narrow band can be extracted from the MPU field, and used to create a full Euclidean distance field
- A full Euclidean field is necessary because spline interpolation requires accurate data at each voxel
- Fitting a spline to each column of data taken from the inaccurate MPU fields would result in erroneous structures and undesirable artifacts



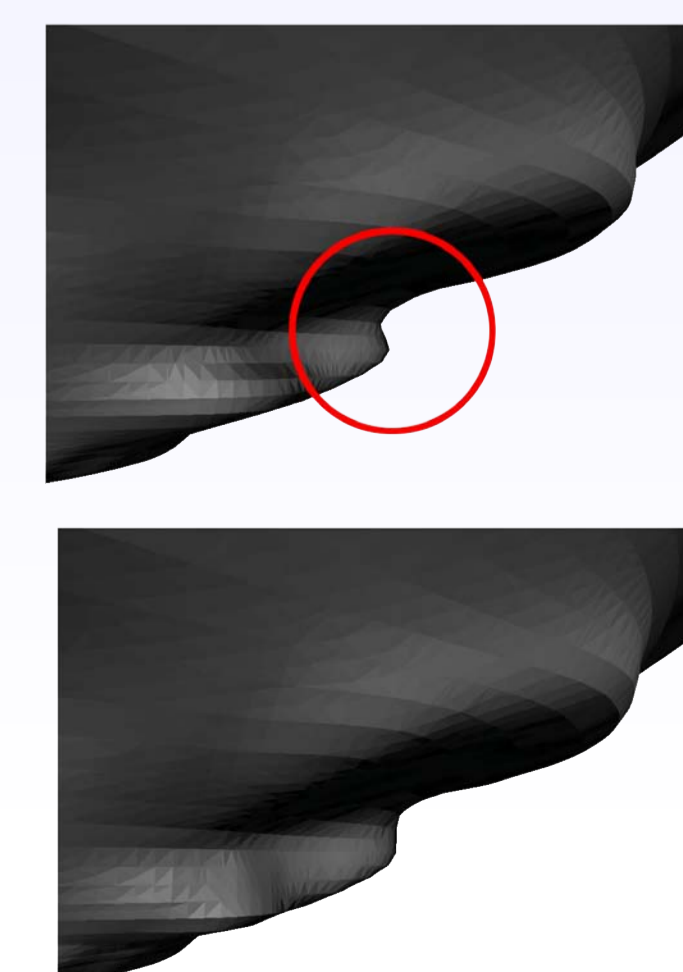
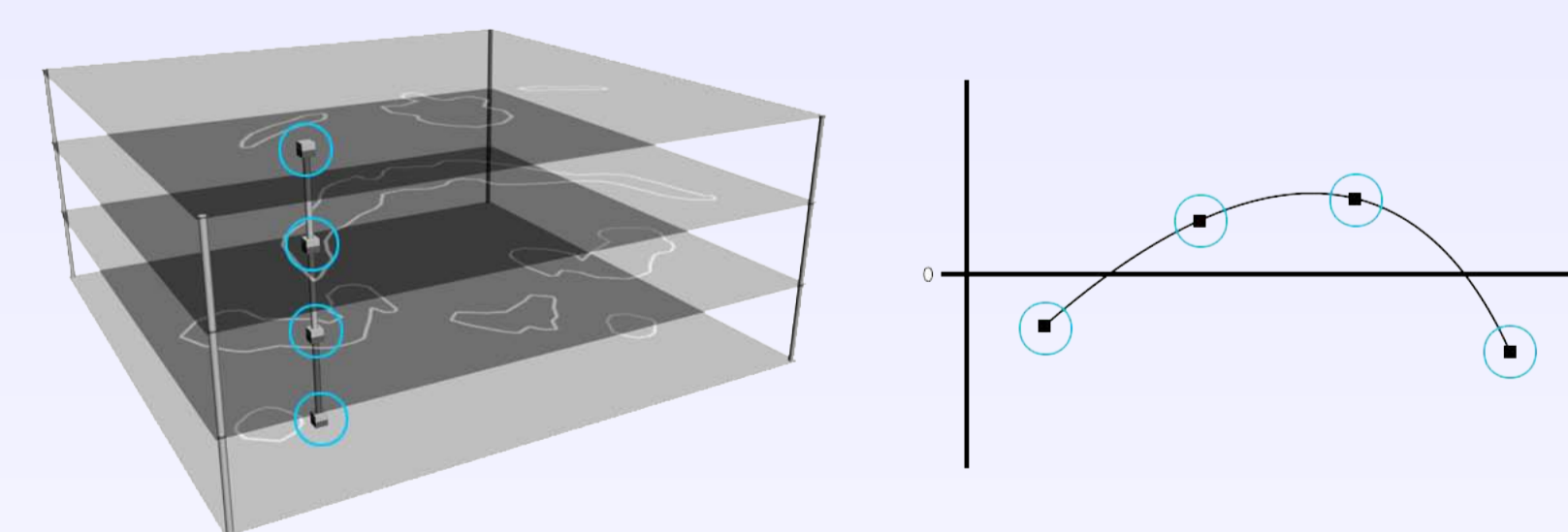
## Filtering

- Medial axes are structures in a distance field that are equidistant to two or more points on the curve
- They produce derivative discontinuities in the field
- These discontinuities cause ridges and creases in the resulting mesh
- Two properties of filtering are desired: smooth the medial axis while leaving the zero level set (curve) intact
- Distance-dependent Gaussian filtering effectively blurs the data; the amount of filtering varies based on distance, with no filtering near the zero level set, to full filtering a safe distance away



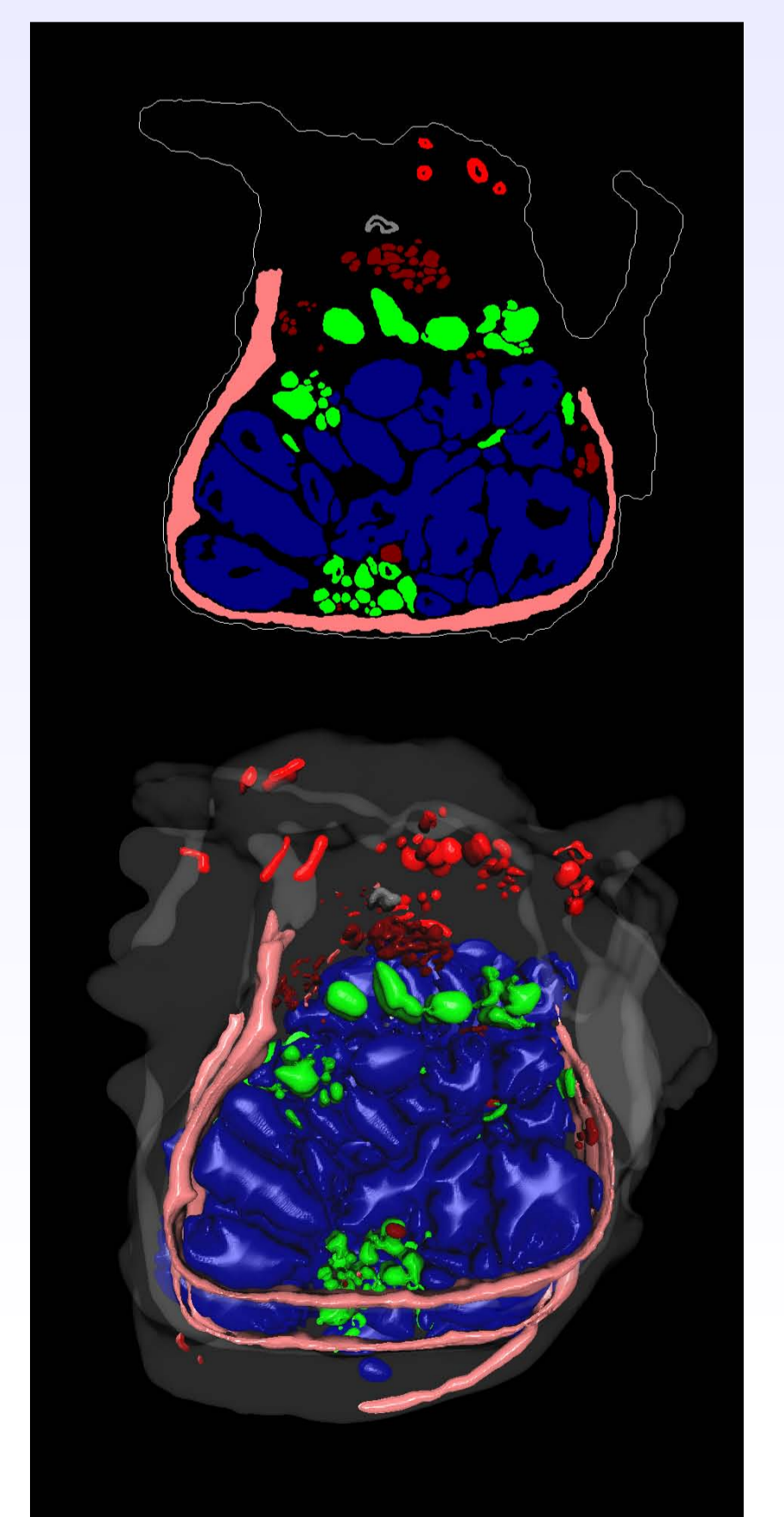
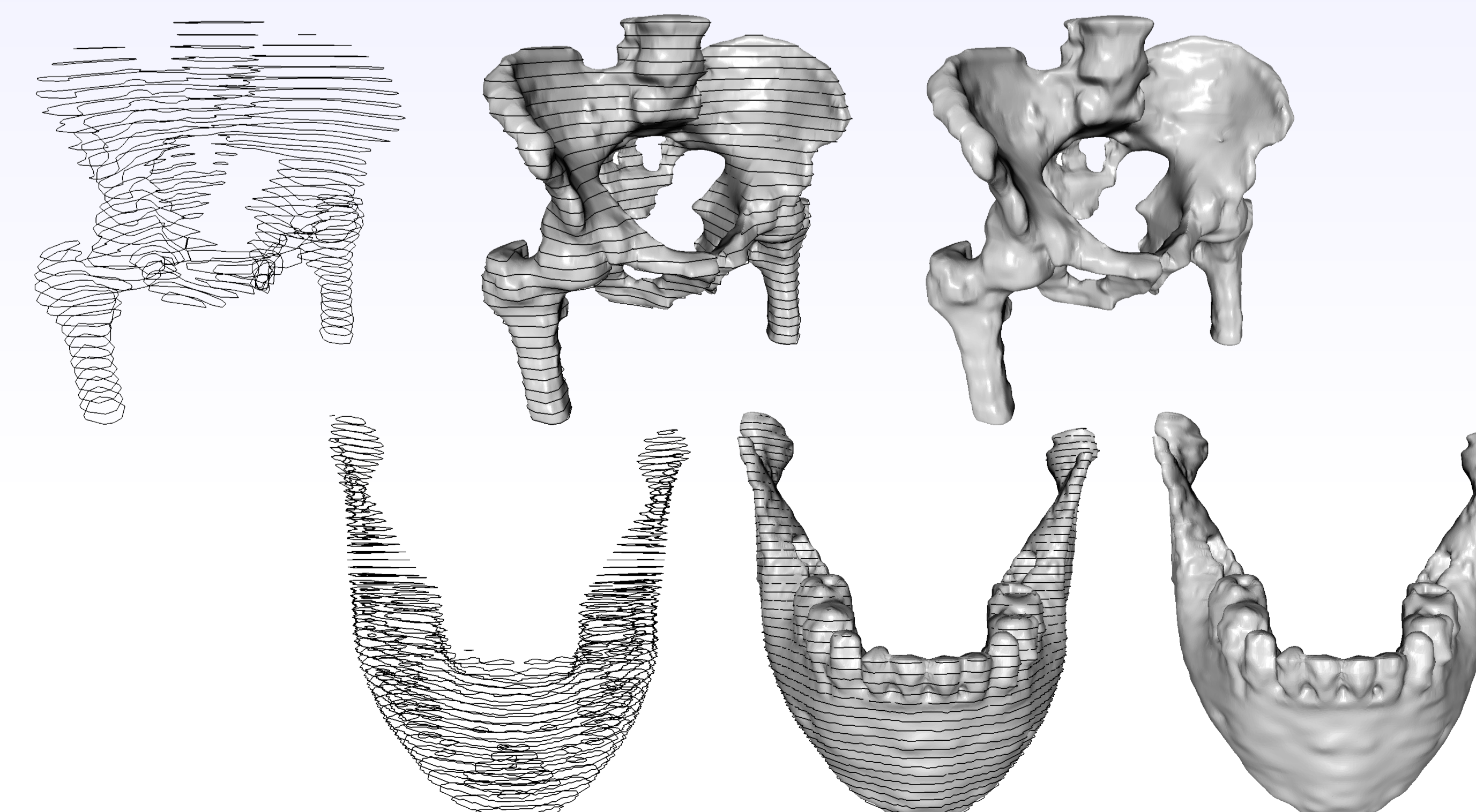
## Interpolation

- We create new, blending slices between input slices by interpolating stacked pixels with cubic splines
- Hermite splines were tried first; however they are not C2 continuous, and produced undesirable artifacts (lips and troughs) on the resulting surface due to overshoot in data ranges with a high rate of change
- Natural cubic splines provide C2 continuity, however do not address the overshoot problem
- Monotonicity-constraining natural cubic splines sacrifice C2 continuity in order to prevent overshoots; resulting in a more acceptable result



## Results

- After spline interpolation, the Marching Cubes algorithm is used to create a mesh that approximates the zero level set embedded in the computed volume
- Testing platform: dual 2.0 Ghz Apple G5 with 3GB RAM
- Pelvis: smoothed at 2000x2000, interpolated at 500x500x456, data ratio is 13:1; run time: 43 minutes
- Jawbone: smoothed at 500x500, interpolated at 500x500x393, data ratio is 8:1; run time: 11 minutes
- Tumor: smoothed at 978x967, interpolated at 489x483x101, data ratio is 10:1, run time: 26 minutes



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