# 3D Geometry Modeling summary

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Artificial Intelligence & Information Analysis Lab

# 3D Geometry Modeling

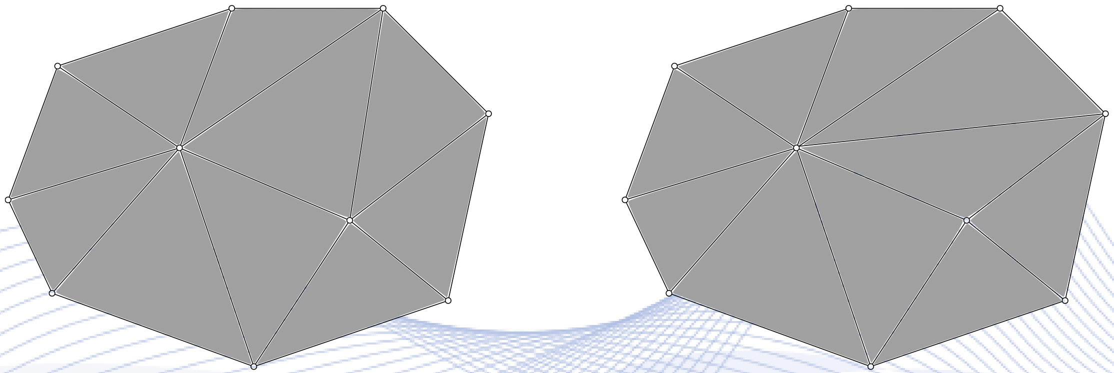
- **3D Point Cloud to Mesh Triangulation**
- 2D Contour Cross Sections to Mesh Triangulation
- Volumetric Image to Mesh Triangulation
- 3D Mesh to Volumetric Image Transformation
- 2D Contour Cross Sections to Volumetric Image Transformation

# 3D Point Cloud to Mesh Triangulation

- The development of optical measurement technology and 3-D imaging has been rapid in recent years.
- **Fields:** medical, engineering, VR, machine vision, etc.
- **Point cloud data:** A special information format containing 3-D spatial data.
- **Surface reconstruction:** Process of converting point-clouds to polygon or triangle mesh to get a 3D surface.

# Triangulation

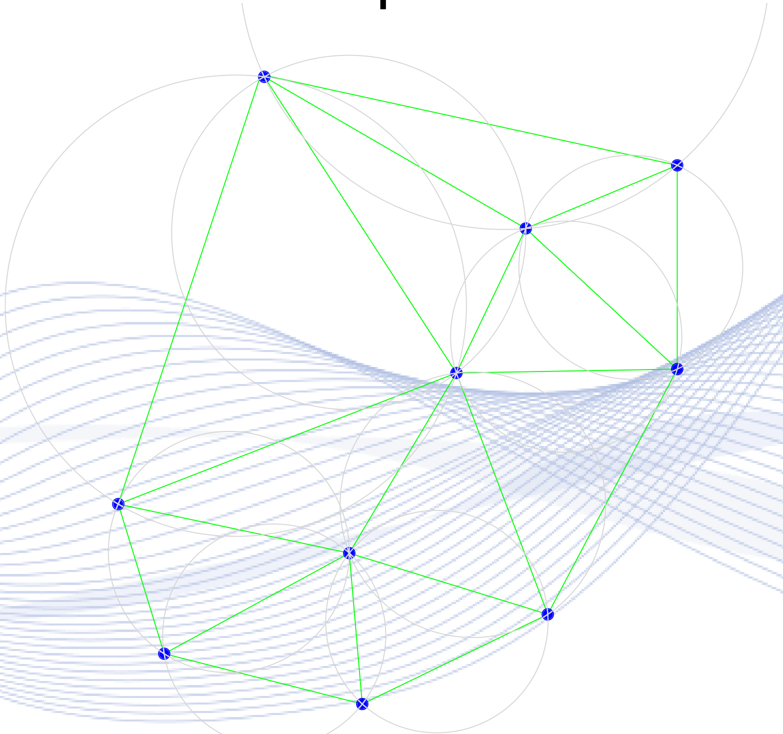
A triangulation of a set of points $\mathbf{P}$ in the Euclidean space $\mathbb{R}^d$ is a simplicial complex that covers the convex hull of $\mathbf{P}$, and whose vertices belong to $\mathbf{P}$.



Two different triangulations of the same set of 10 points in the plane.

# Delaunay Triangulation

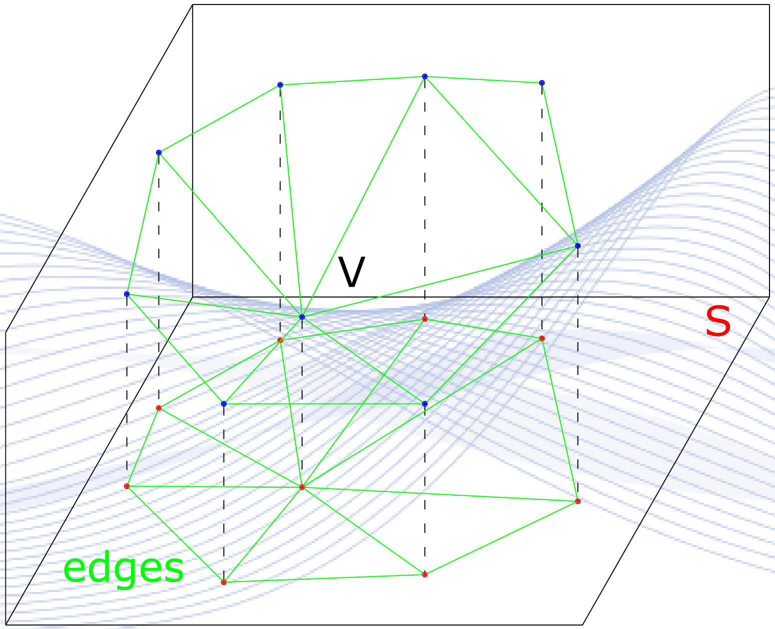
A Delaunay triangulation **T** of **P** is a triangulation of **P** such that the circum-circle of any triangle belonging to **T** does not contain points of **P** in its interior. The Delaunay triangulation of a set **P** of points is unique provided that no four or more points of **P** are co-circular.



Delaunay triangulation schematic.

# Greedy Projection Triangulation

**Step 4:** The connection relationship of the points is obtained through triangulation. The space triangulation of point $\mathbf{V}$ and its nearby points is formed.

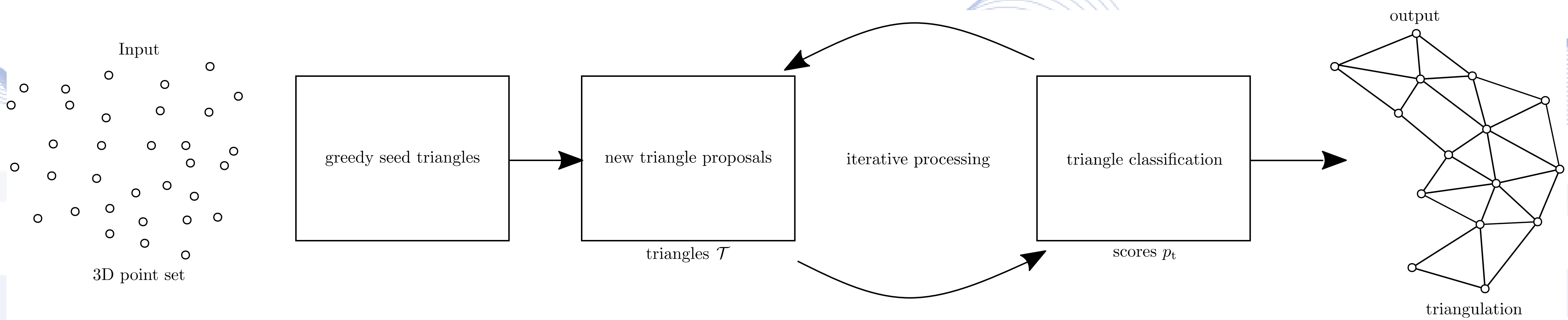



Greedy projection triangulation schematic – step 4.

# PointTriNet

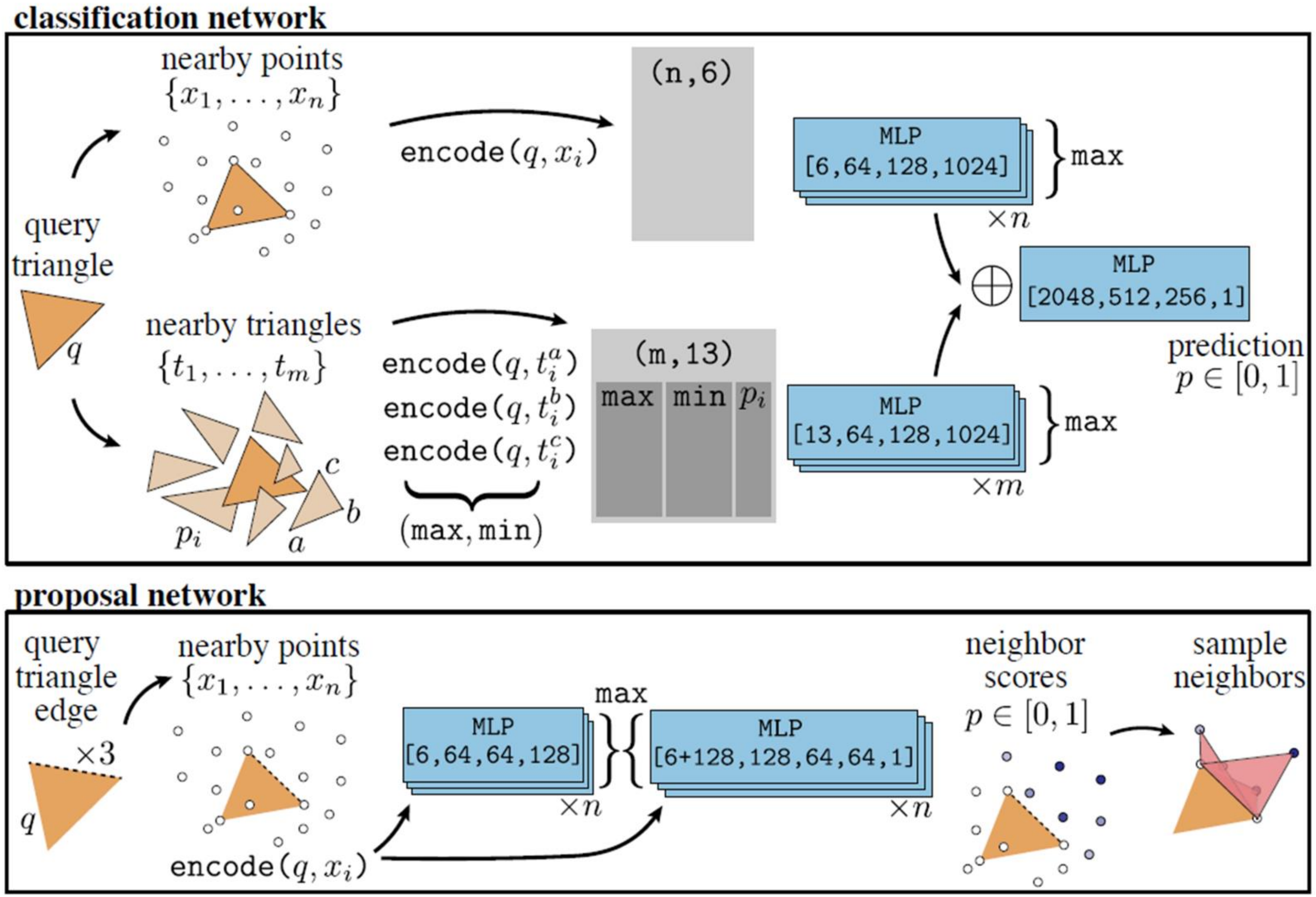
PointTriNet produces state of the art results generating meshes with competitive accuracy. The method consists of 2 main components:

- A classification network taking a candidate triangle as input and outputs the probability of the triangle appearing to the triangulation.
- A proposal network which suggests likely neighbor triangles for an existing triangle.



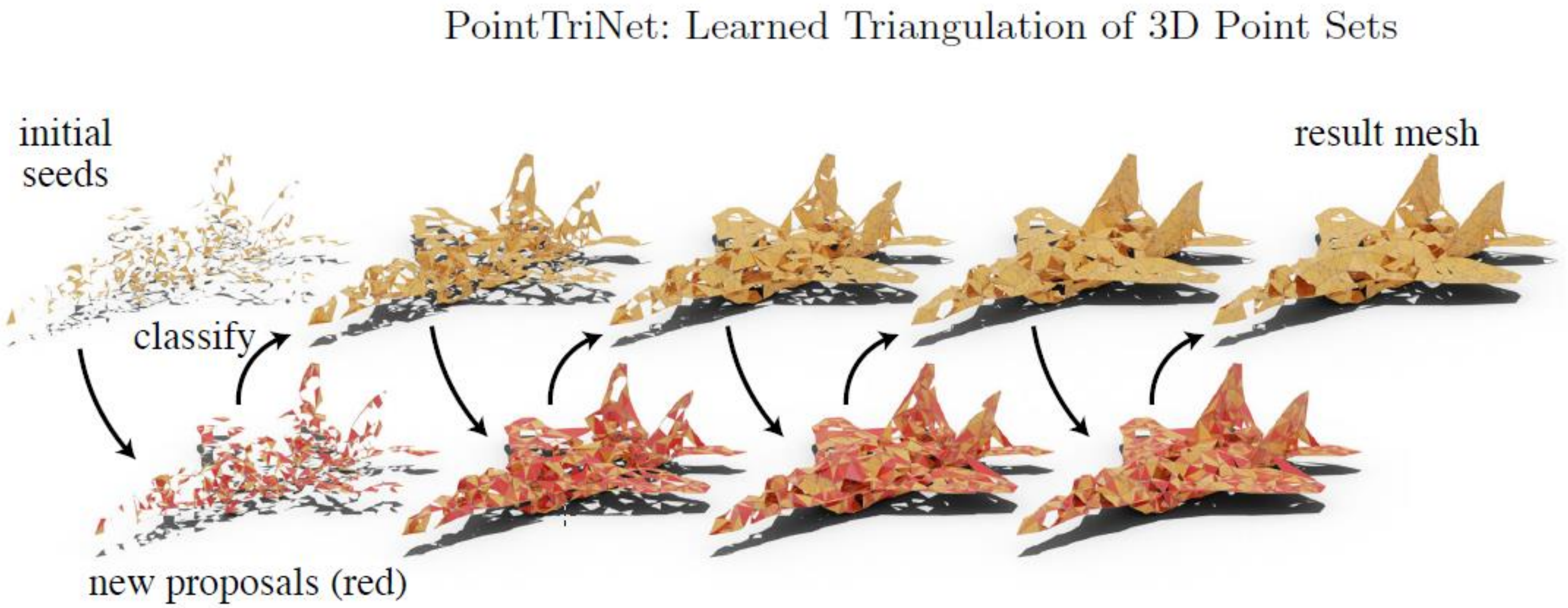

PointTriNet pipeline schematic.

# PointTriNet




PointTriNet network architectures, from [PTN], copyright pending.

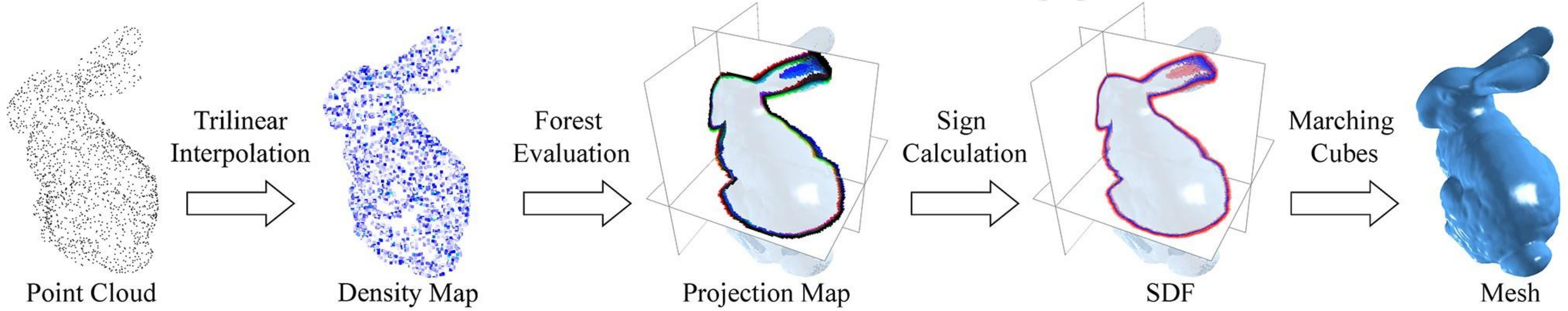
# PointTriNet




PointTriNet iterative procedure, from [PTN], copyright pending.

# From Point Cloud to Mesh using Regression

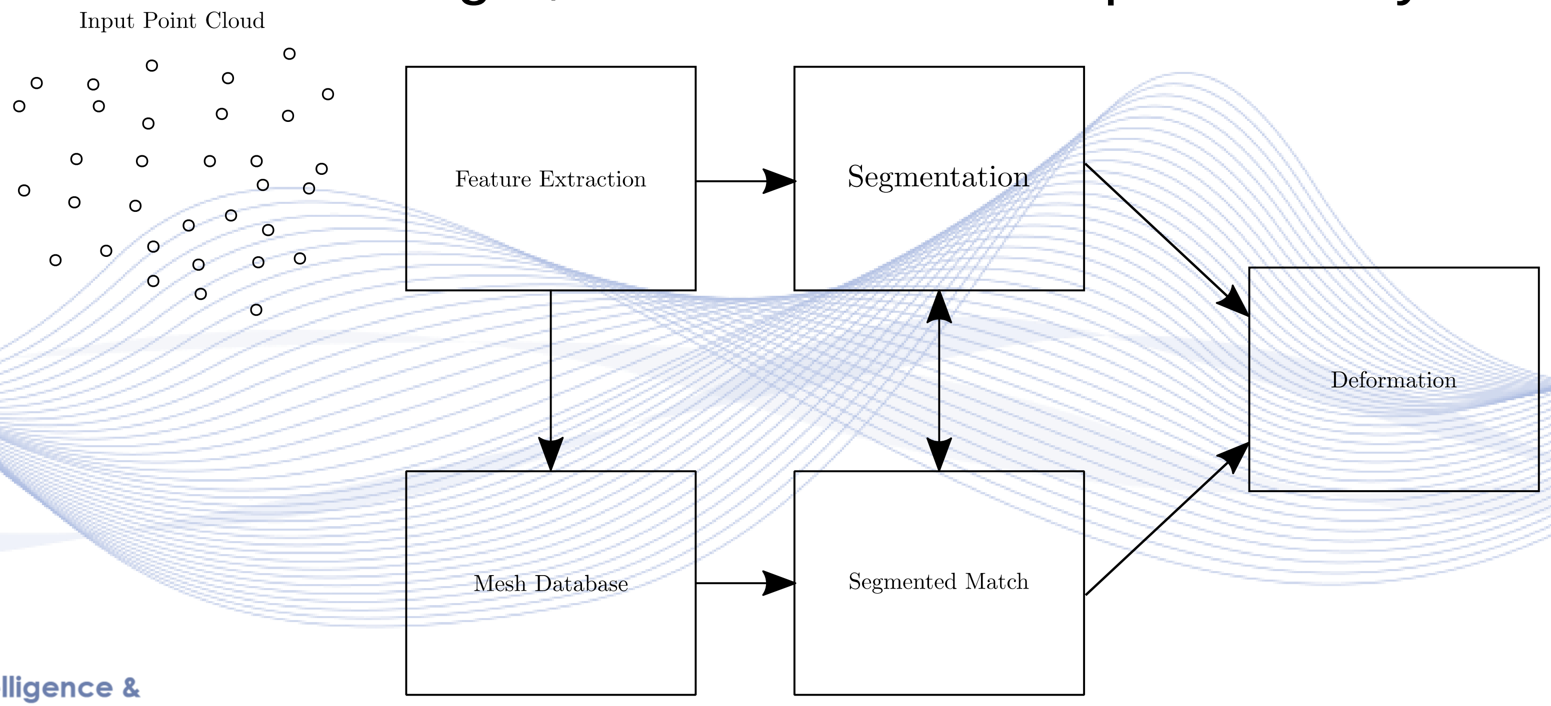
- The algorithm predicts the projection of a given grid point to a surface, used to calculate the signed distance of this grid point.
- The final surface is estimated as a 0-isosurface of the predicted signed distance field using the marching cubes algorithm.




Point Cloud-to-Mesh using Regression Pipeline from [LAD], copyright pending.

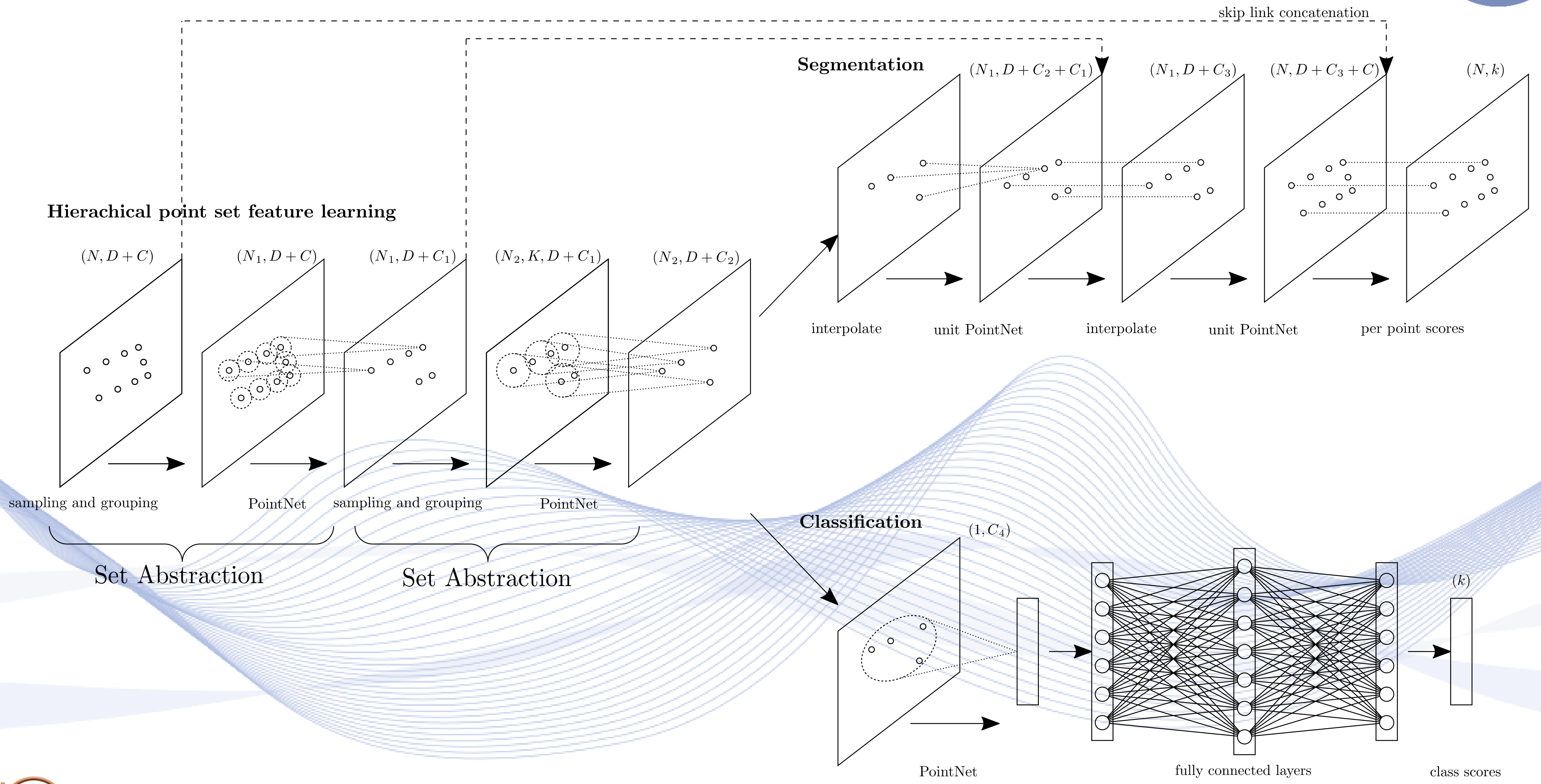
# MatchMesh

- MatchMesh is a knowledge-based method used to reconstruct the surface mesh of a point cloud.
- The method is based on the idea that editing or deforming an existing mesh to match the target, is much more computationally effective.




MatchMesh Workflow

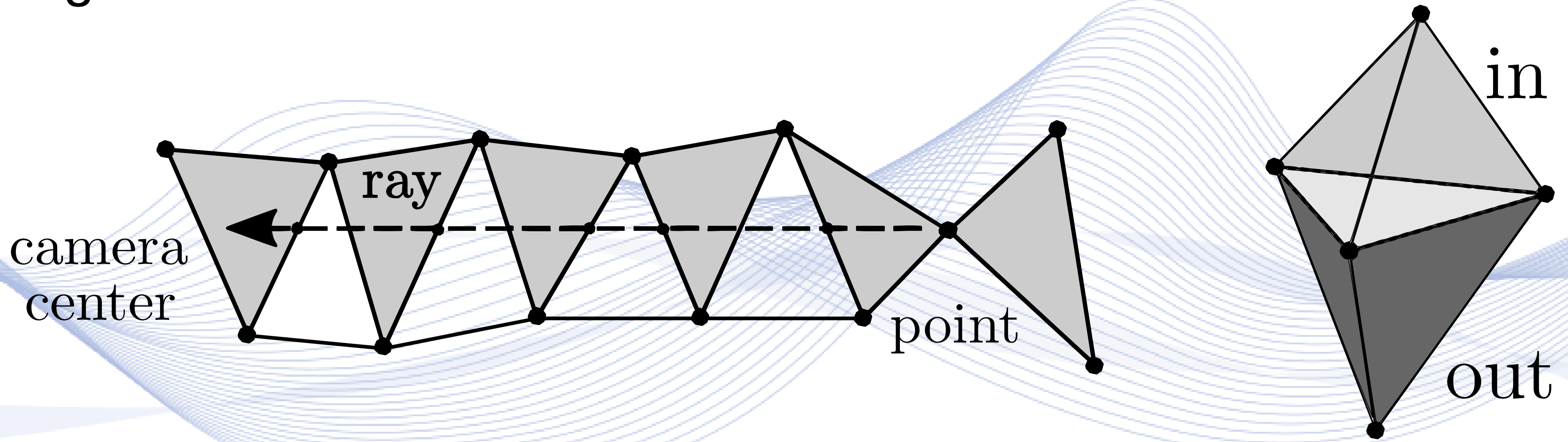
# MatchMesh




MatchMesh Pipeline.

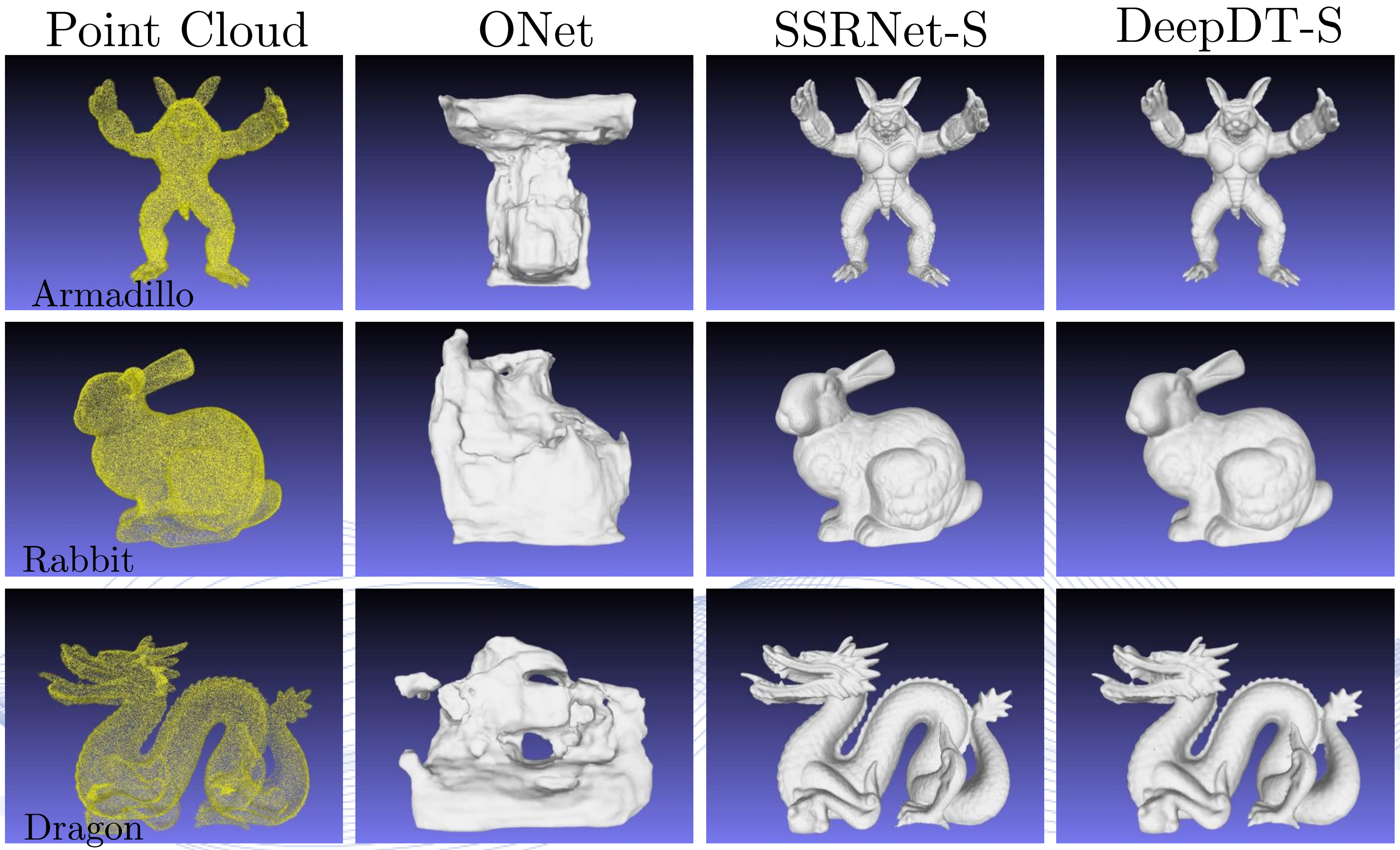
# DeepDT

- DeepDT extracts the surface representation, from Delaunay triangulation of point clouds.
- It learns to predict Camera Ray inside/outside labels of Delaunay tetrahedrons directly from a point cloud and the corresponding Delaunay triangulation.




A 2D example of reconstructing surface by in/out labeling of tetrahedrons, from [DDT], copyright pending.

# DeepDT




Qualitative performance of ONet, SSRNet-S and DeepDT-S from [DTT], copyright pending.

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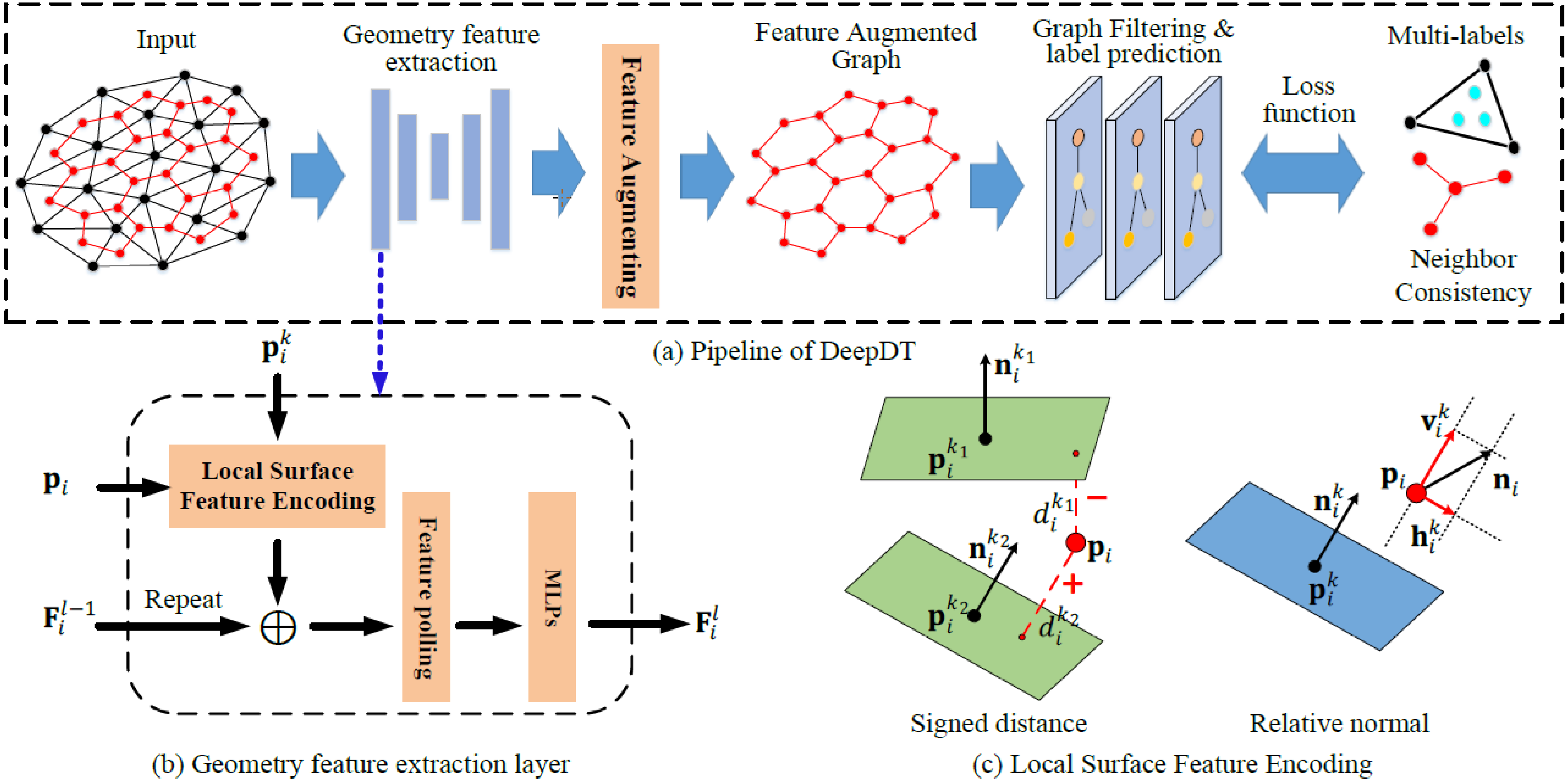
# DeepDT

- The input of the network includes a point cloud $P$ and its Delaunay triangulation $D$.
- $P$ is a set of 3D points with their normal – $D$ is a set of tetrahedrons.
- The Delaunay triangulation structure forms a graph G, with tetrahedrons as nodes and common triangular facets connecting two adjacent tetrahedrons as edges.
- The network consists of the following main parts:
  - The geometry feature extraction component.
  - The graph feature aggregation component.
  - The filtering component.

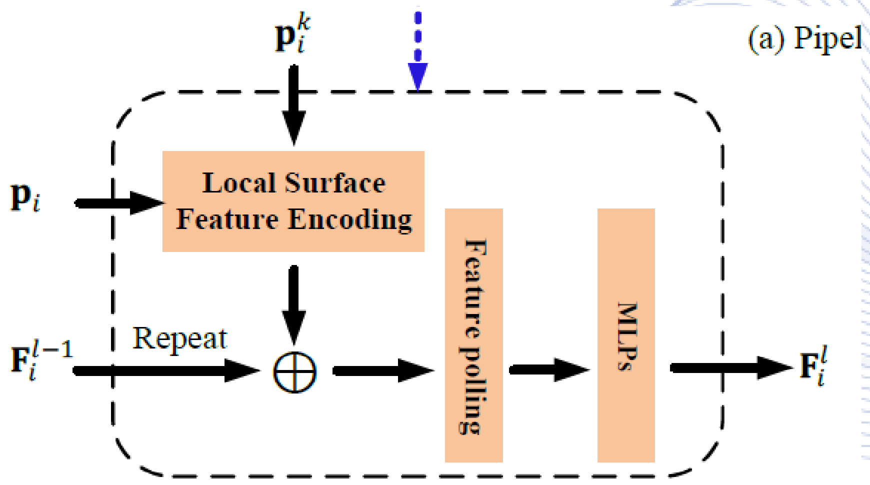
# DeepDT




DeepDT Pipeline, from [DTT], copyright pending.

# DeepDT

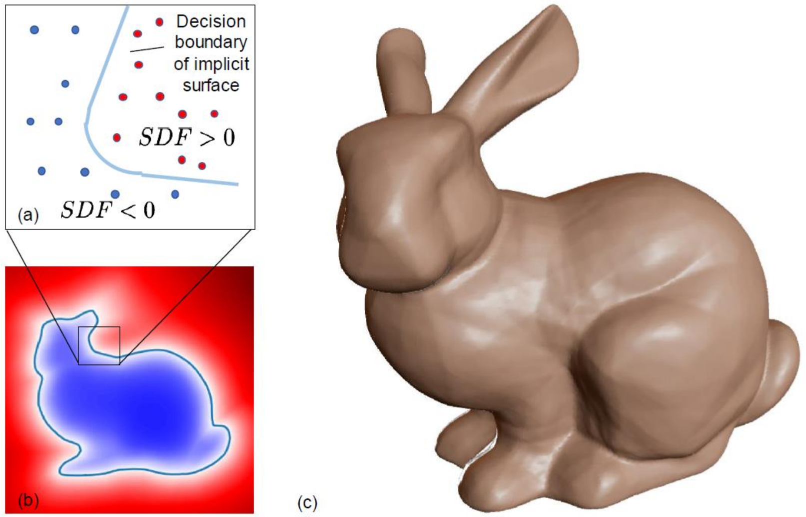
- The layer of geometry feature extraction has three basic properties to better complete local surface feature encoding:
  - It provides in and out information directly with respect to the implicit surface.
  - It encodes in and out information locally, to capture geometry details.
  - To process large point clouds, it is computationally efficient.




Geometry feature extraction, from [DTT], copyright pending.

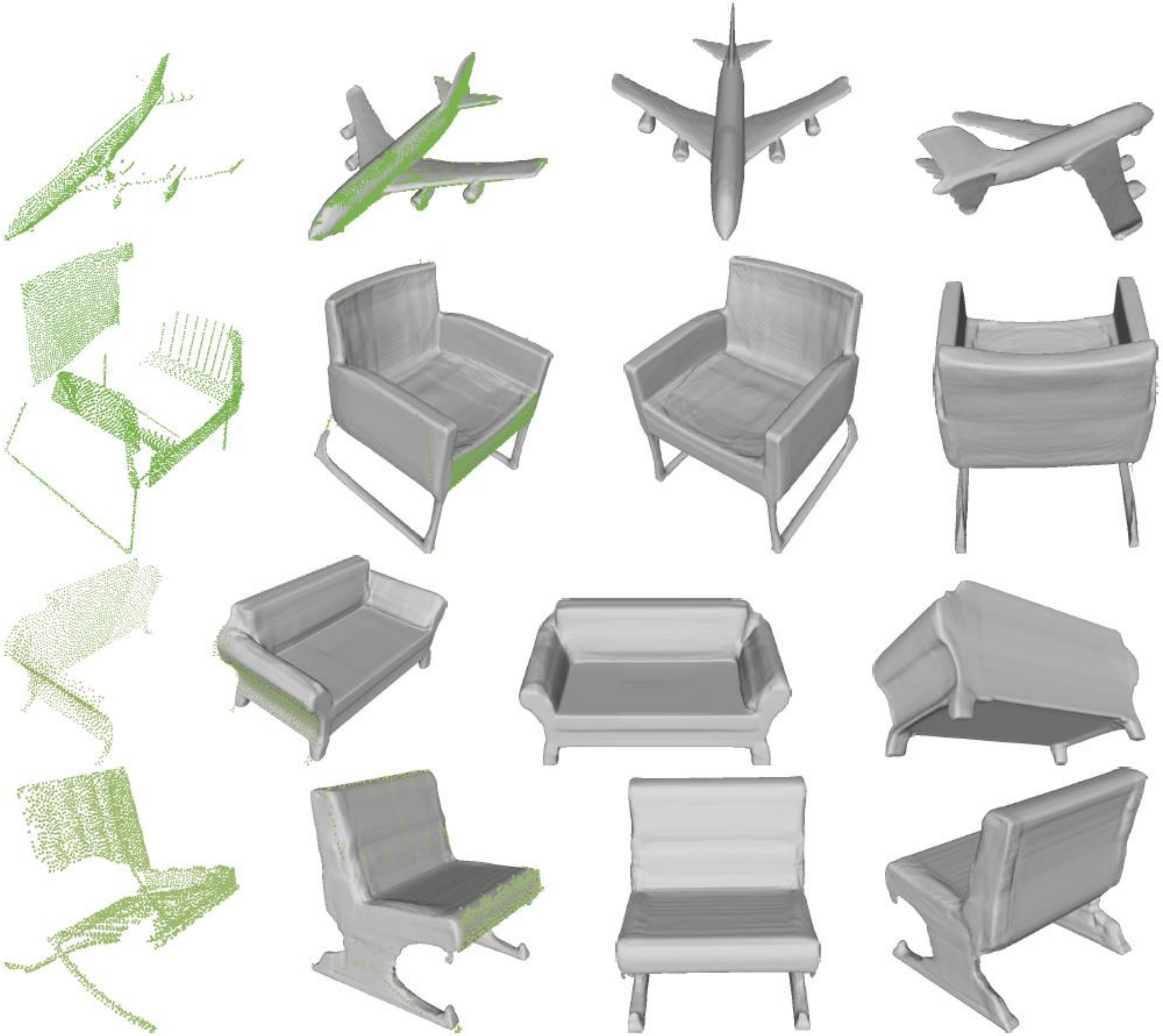
# DeepSDF

- DeepSDF is used to learn a continuous Signed Distance Function (SDF) to reconstruct the 3D geometry from noisy 3D point clouds.
- DeepSDF encodes the surface boundary as the zero-set of the learned signed distance function, with the ability to represent an entire class of shapes,




Stanford Bunny example, from [SDF], copyright pending.

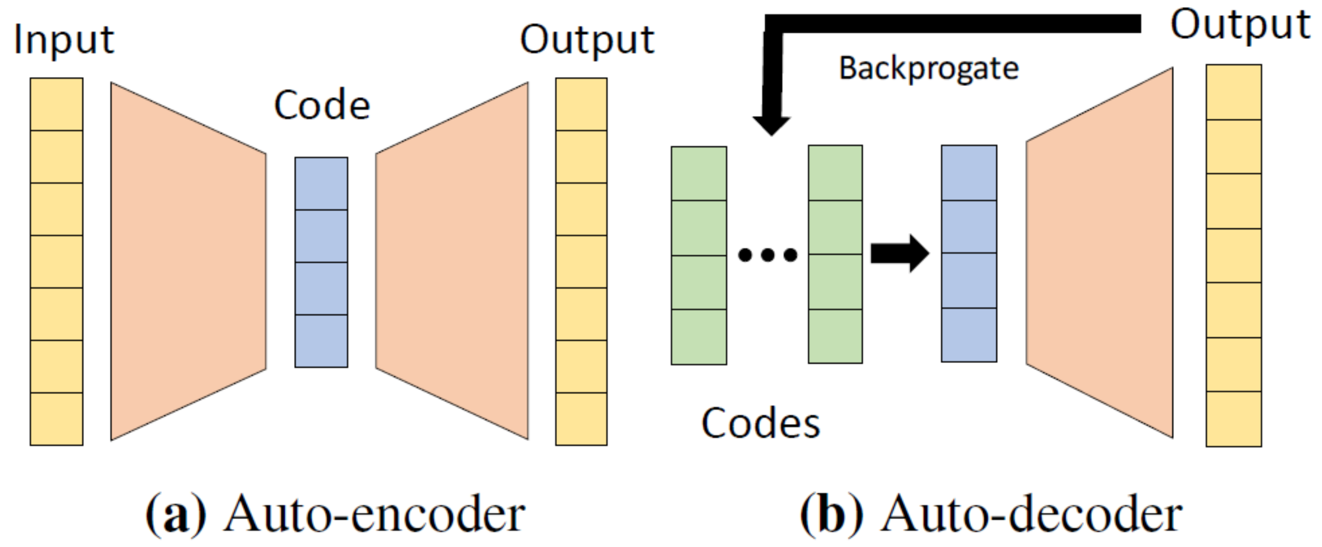
# DeepSDF



DeepSDF shape completions, from [SDF], copyright pending.

# DeepSDF

- The encoding of the shapes is performed using an auto-decoder to save on computational resources.
- The proposed auto-decoder concept lacks the encoder part commonly encountered in an autoencoder scheme.




Auto-encoder vs Auto-decoder,
from [SDF], copyright pending.

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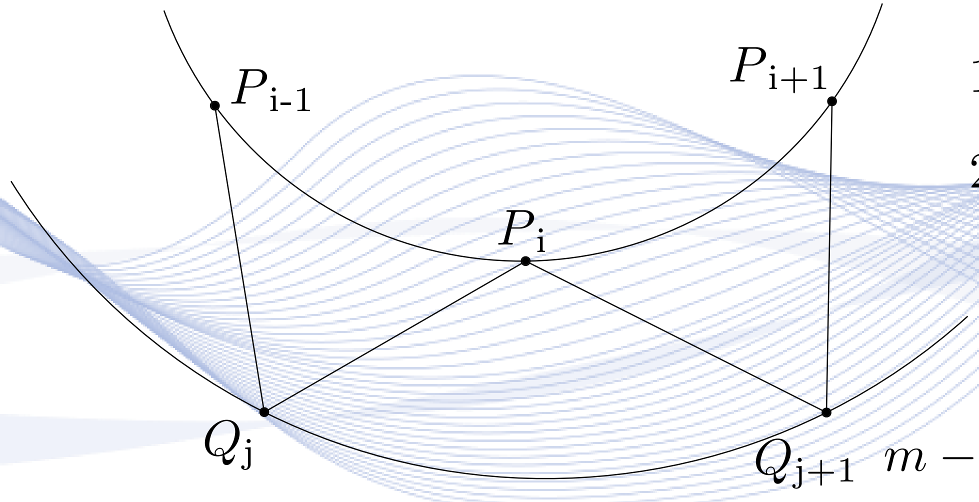
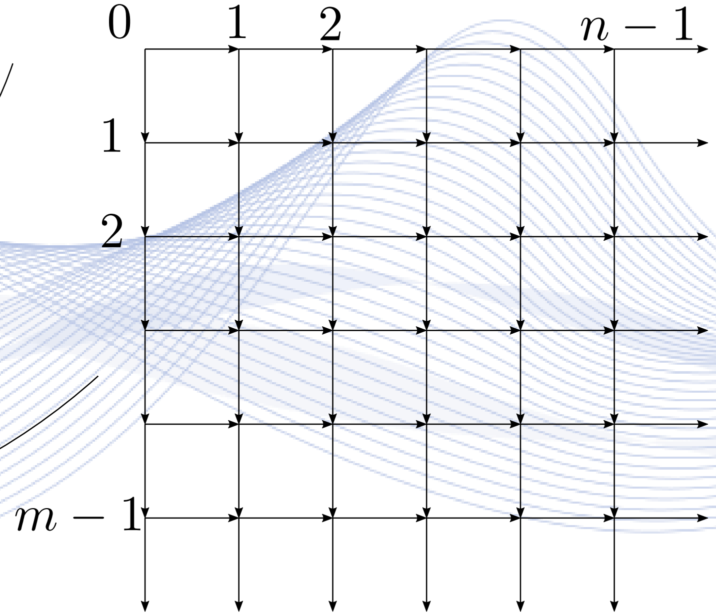
# Surface reconstruction from planar sections

- Contours: sequence of contour points $P_0, \dots, P_{m-1}, Q_0, \dots, Q_{m-1}$.
- Each triangle $\{P_{i-1}, Q_j, P_i\}$ is bounded by the contour segment $P_{i-1}P_i$ on 1 contour and 2 linear segments $P_iQ_j$ & $Q_jP_{i-1}$, each connecting an end of the contour segment with a single point on the other segment.
- The toroidal directed graph is constructed.

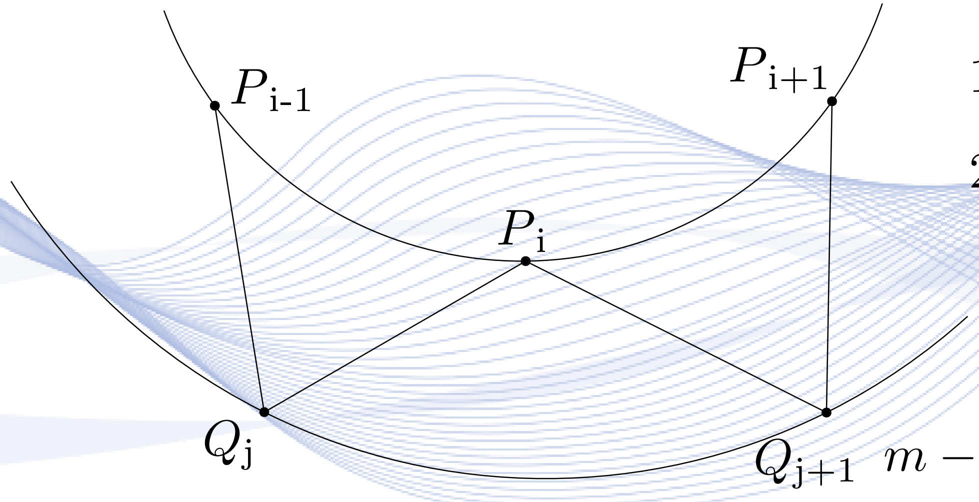


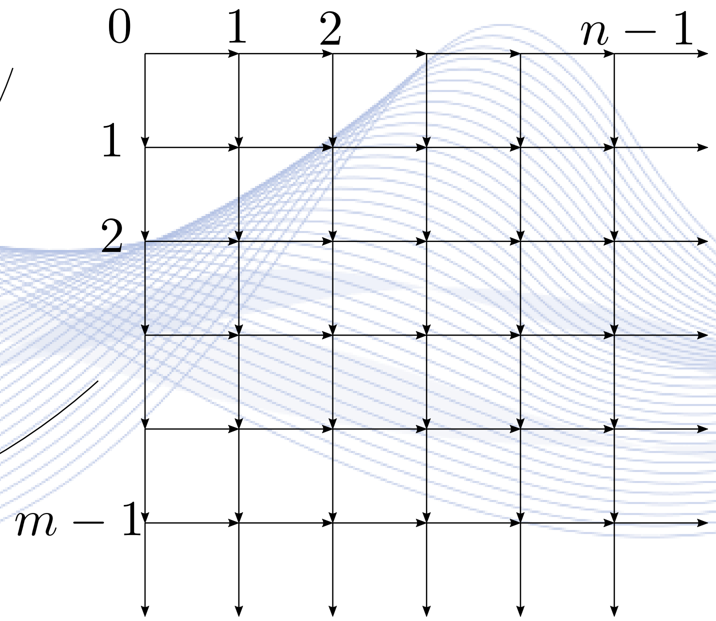




Contour triangulation.

# Surface reconstruction from planar sections

- The graph vertices correspond to the various spans that connect $P_0, \ldots, P_{m-1}, Q_0, \ldots, Q_{m-1}$ whereas the arcs correspond to the set of all possible triangles, each defined by 2 spans represented by arc vertices.

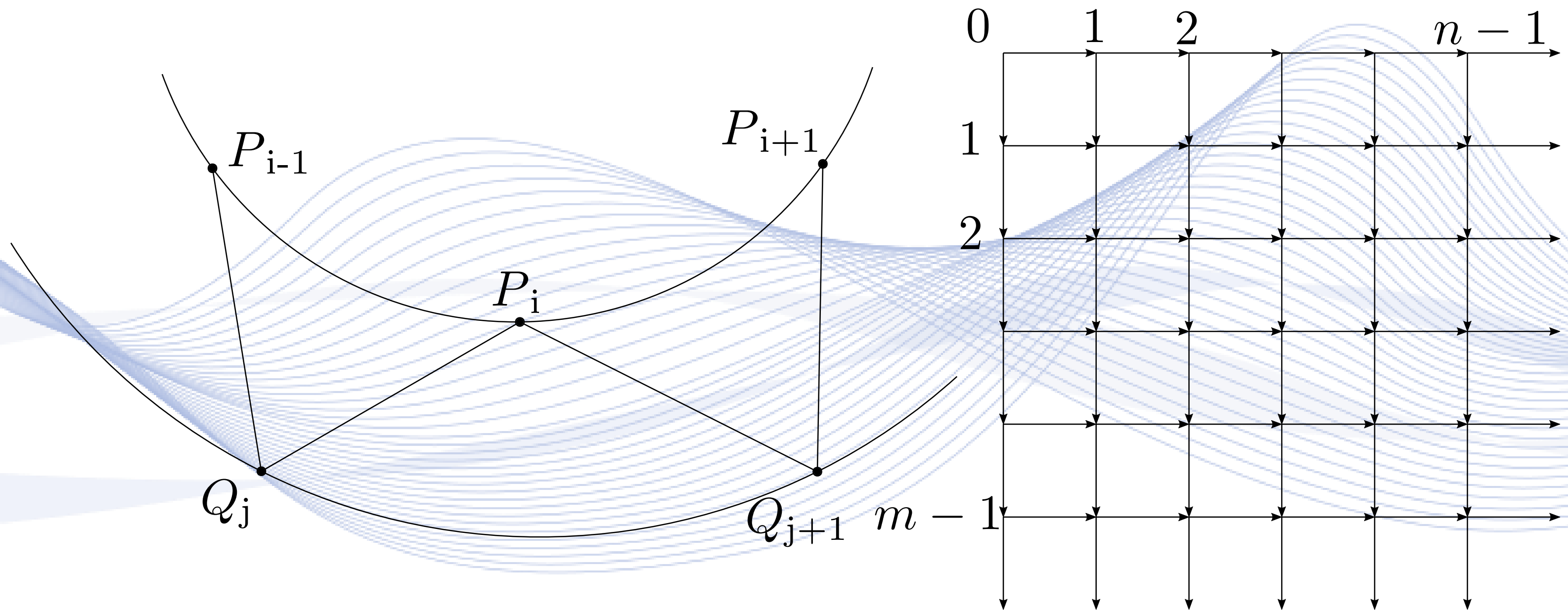



Contour triangulation.

# Surface reconstruction from planar sections

- A set of triangles that correspond to an acceptable surface can be proved to be an Eulerian subgraph.
- To choose among the various acceptable surfaces, a cost value to each arc is introduced and a search for the minimum cost graph is conducted.




Contour triangulation.

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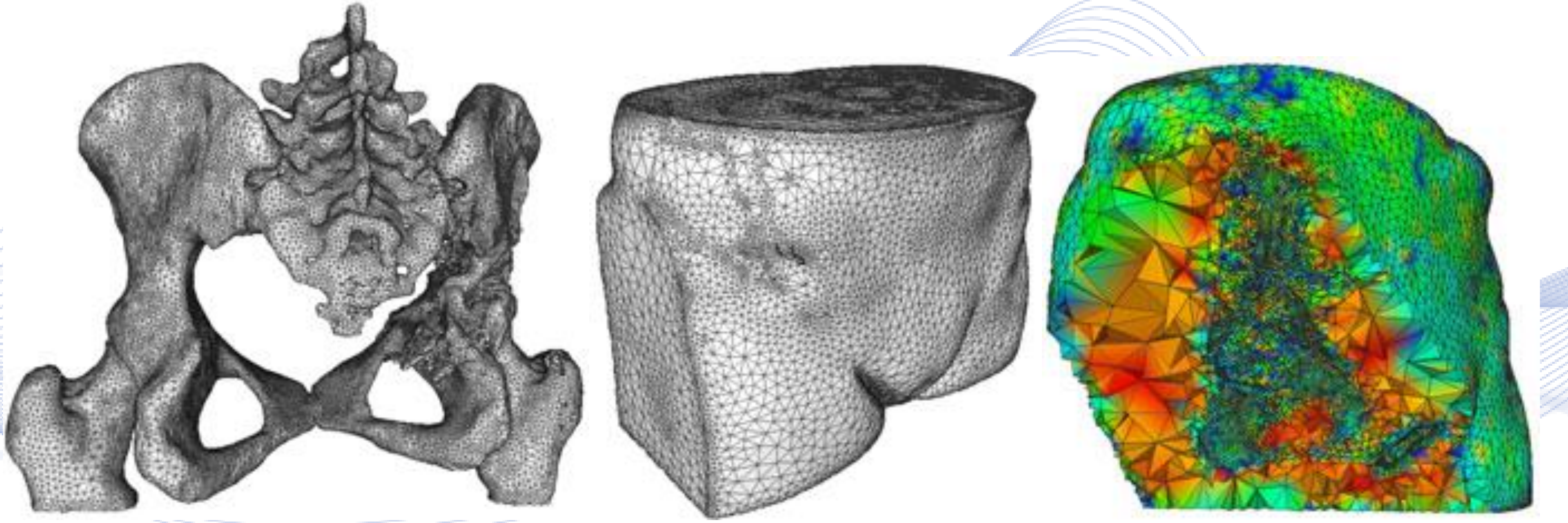
# Volumetric image to mesh triangulation

- Includes methods for meshing 3D images.
- These methods are mainly applied in medical imaging.
- First, the segmentation of the image is implemented.
- A mesh is generated on the segmented image, using Delaunay based triangulation algorithms (Constrained Delaunay Tetrahedralization, 3D Delaunay Triangulation).

# Tetrahedral Meshing of Volumetric Medical Images

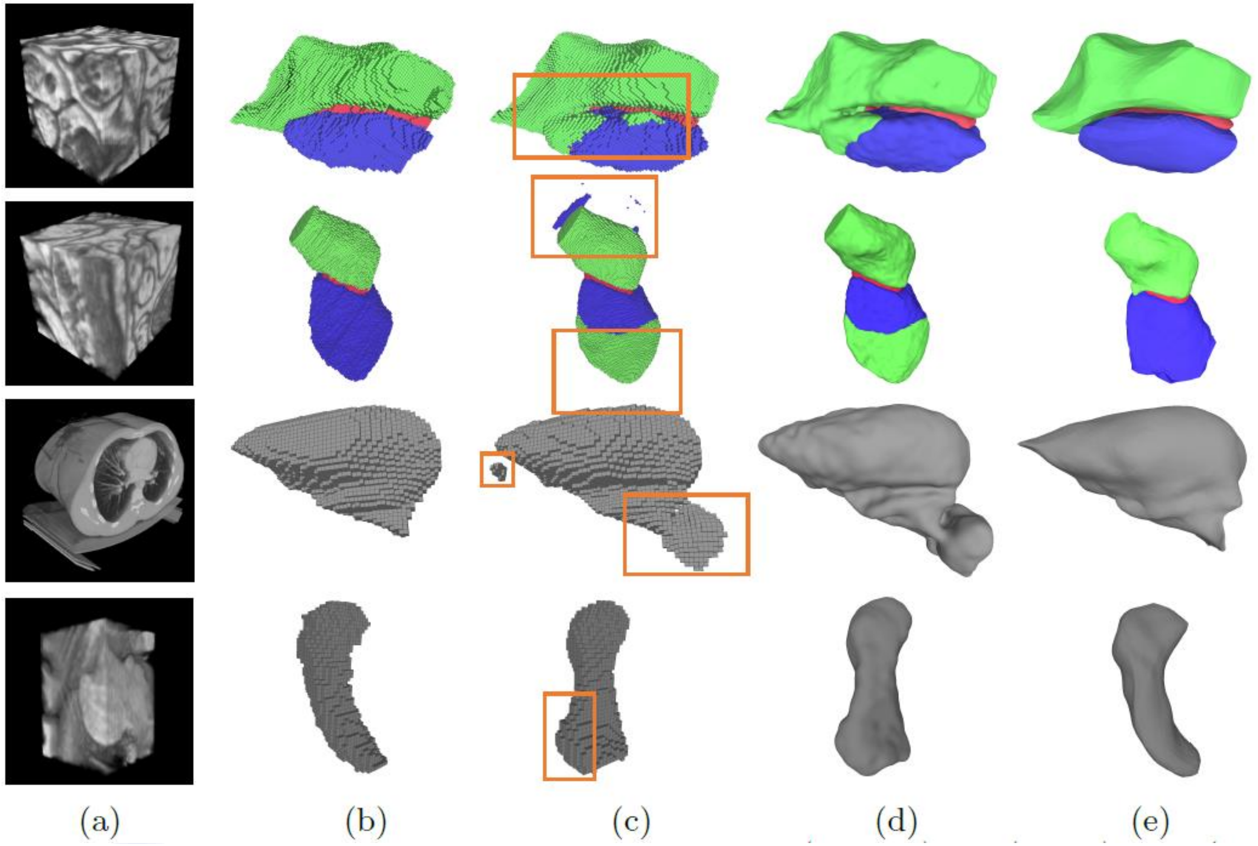
- Iterative adaptation:
  - First, the isotropic edge splitting is performed, introducing new points are by creating points on edges that already exist.
  - The variational meshing is following, optimizing the tessellation grid by moving vertices.
  - Finally, the boundary refinement is performed, which guarantees that the accurate grid approximation  in all existing edges, by creating new vertices along image edges.



Meshing extraction with vector segmentation,
from [VSM], copyright pending.

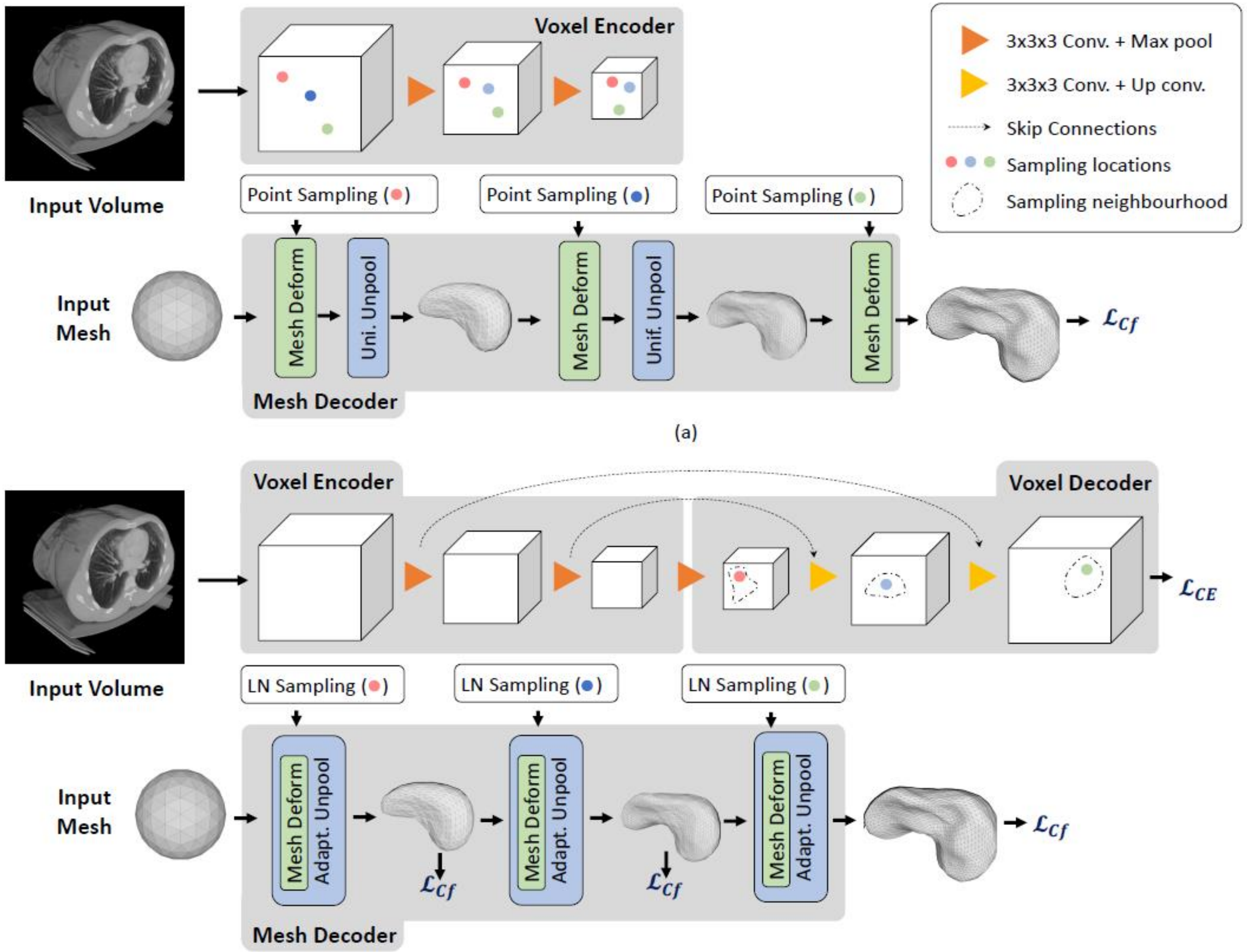
# Voxel2Mesh

- Voxel2Mesh is an end-to-end deep learning CNN-based method, that extracts 3D surfaces directly from volumetric images.




Qualitative results, from [V2M], copyright pending.

# Voxel2Mesh

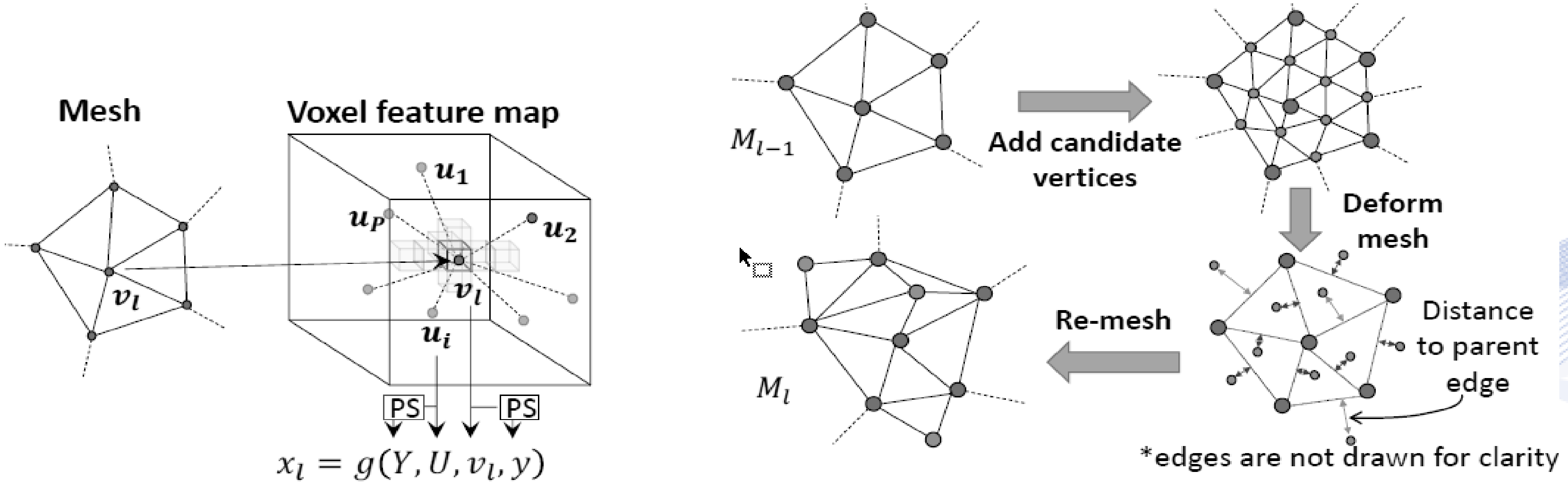



Schematic pipeline, from [V2M], copyright pending.

# Voxel2Mesh

- A set of features $Y = \{y_i\}_{i=1}^{P}$ are sampled at $\{u_i\}_{i=1}^{P}$, using point sampling. The vertex $v_l$ feature vector is given again by training another neural function:

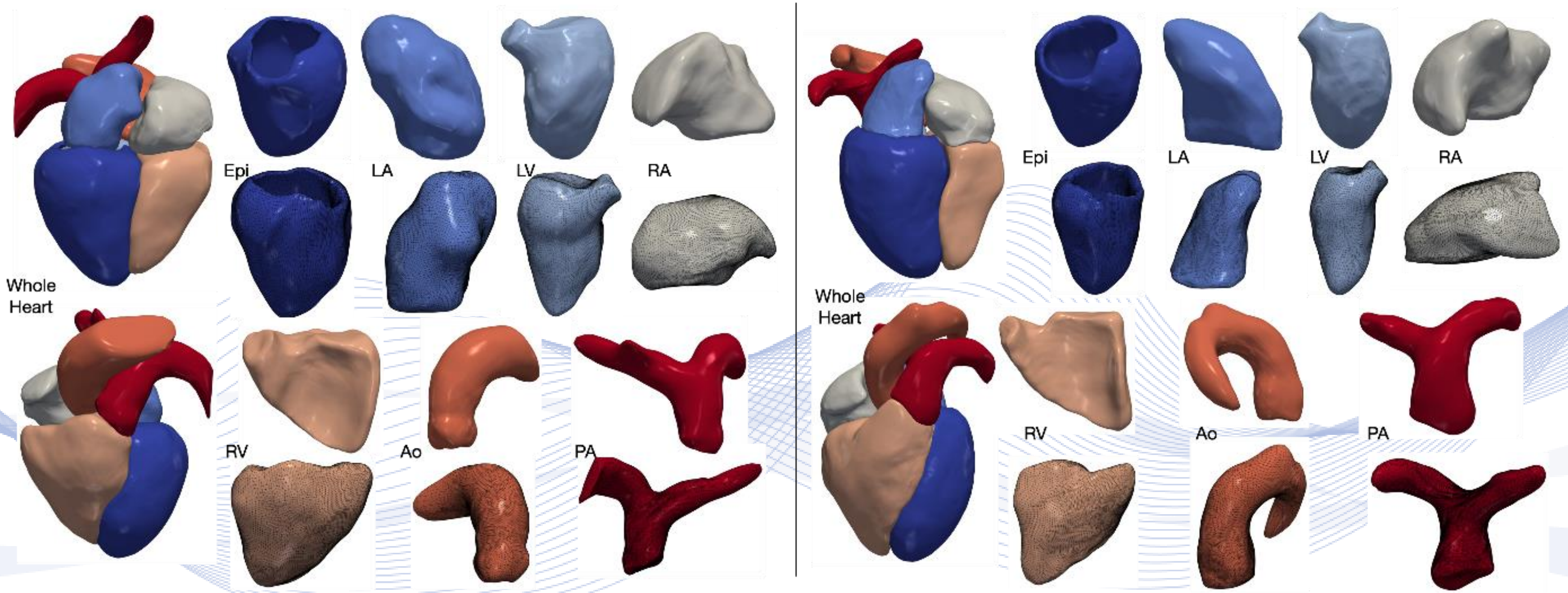
$$x_l = g(Y, U, y, v_l)$$




LNS schematic pipeline, from [V2M], copyright pending.

# Deep Learning for Heart Mesh Extraction

An end-to-end deep learning model is described used to directly predict whole heart surface models from volumetric CT and MR images.




Example reconstructions for CT (left) and MR (right), from [H2M], copyright pending.

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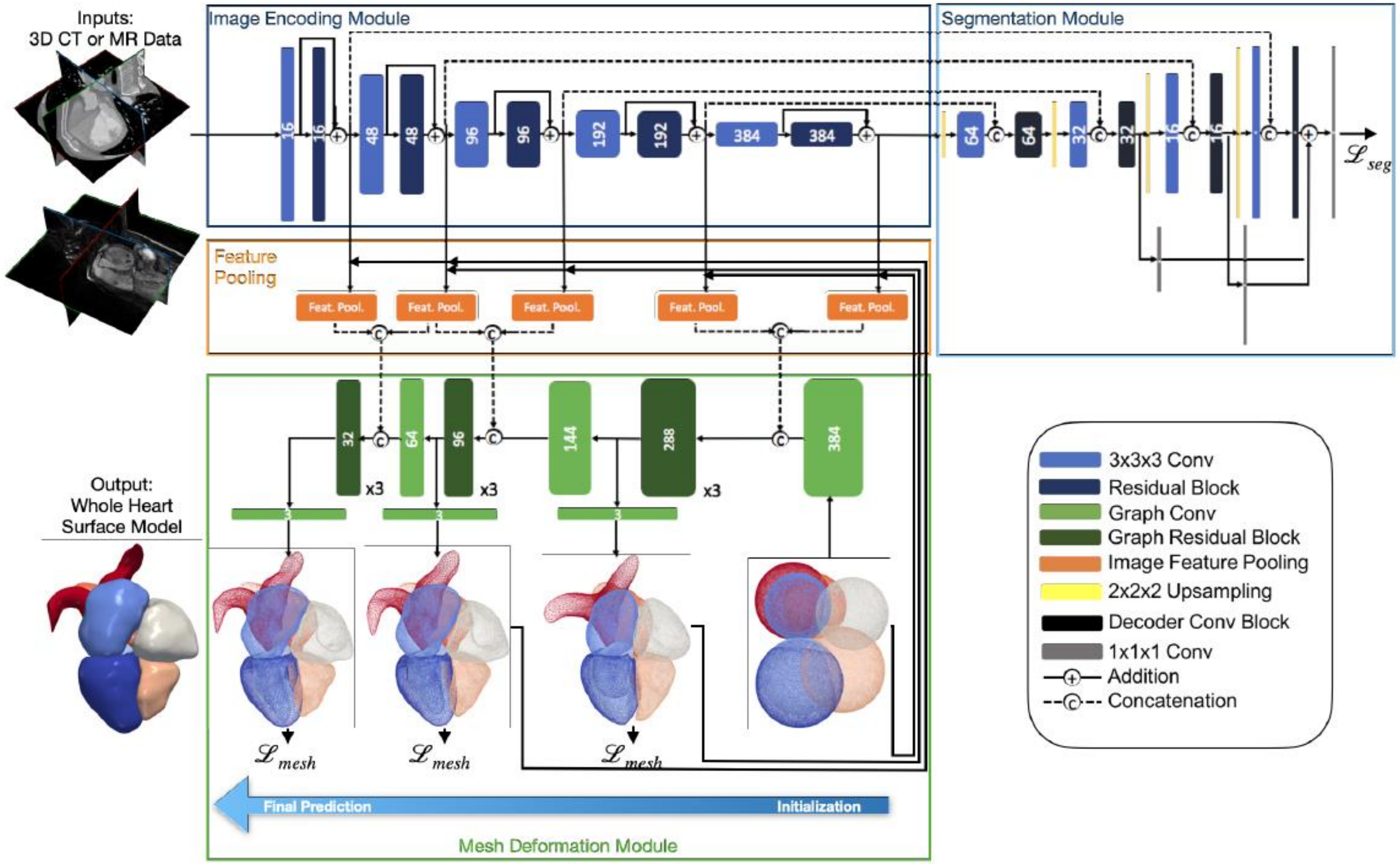
# Deep Learning for Heart Mesh Extraction




Model's schematic pipeline, from [H2M], copyright pending.

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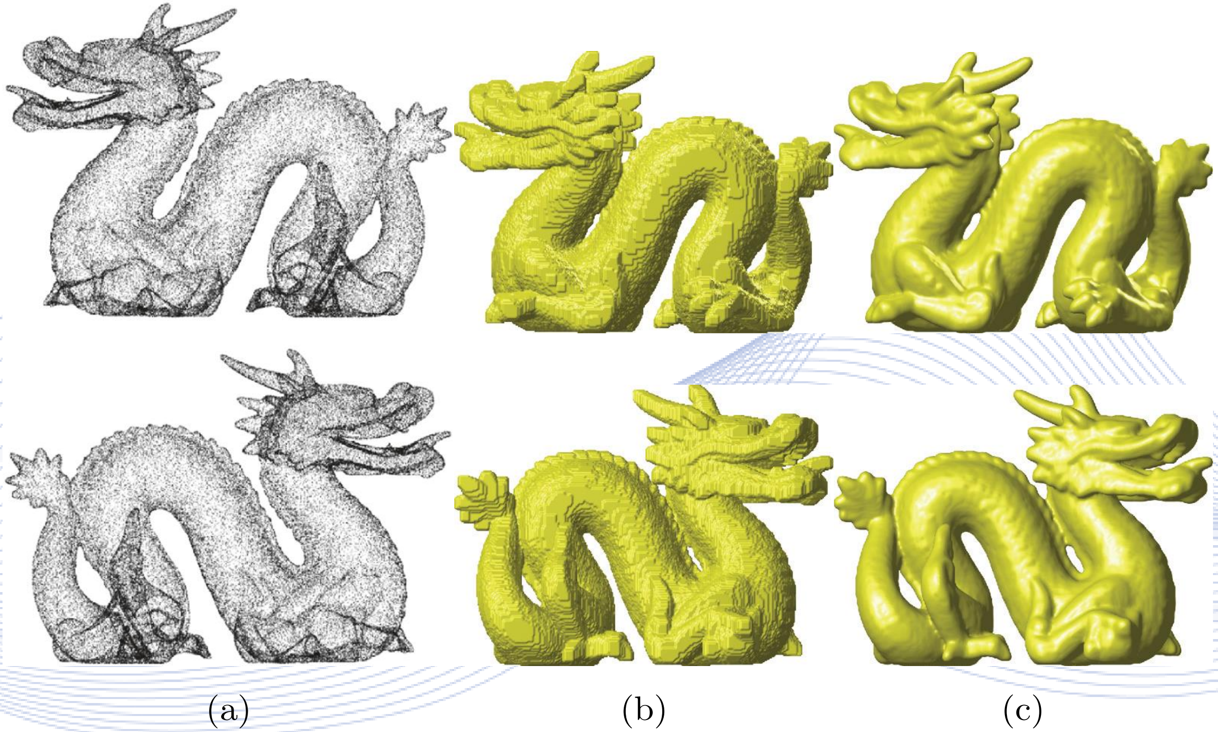
# Phase-Field Method

- The algorithm proposed in [JNG] is based on a phase-field method for calculating the volume reconstruction of a point cloud, implementing an explicit hybrid algorithm using a phase-filed method.




3D reconstruction from point clouds – examples from [JNG], copyright pending.

# Phase-Field Method

- Let $\boldsymbol{X_l} = (X_l, Y_l)$ and denote the coordinates of a points in a 2D and a 3D point cloud respectively. The geometric active contour model is based on the mean curvature motion and is calculated by the following evolution equation:

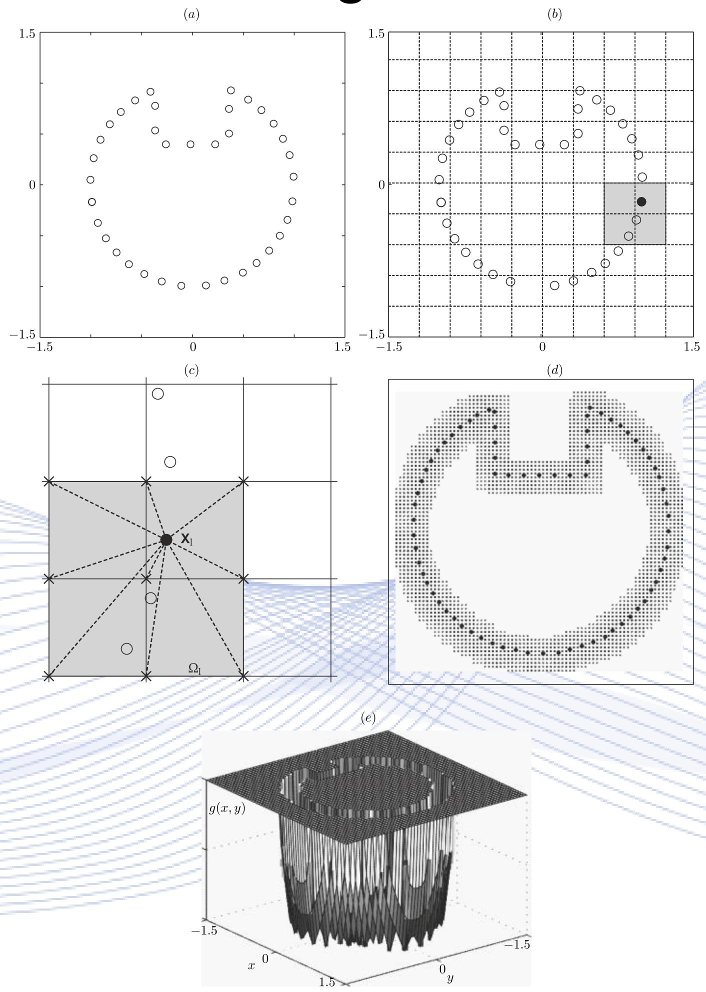
$$\frac{\partial\varphi(x,t)}{\partial t} = g(x)\left[-\frac{F'\big(\varphi(x,t)\big)}{\epsilon^2} + \Delta\varphi(x,t) + \lambda F\big(\varphi(x,t)\big)\right] \quad (1)$$

$$F(\varphi) = 0.25(\varphi^2 - 1)^2$$

- Where $g(x)$ is an edge indicator function, $F(\varphi)$ and $\epsilon$ are constants related with the phase transition width.

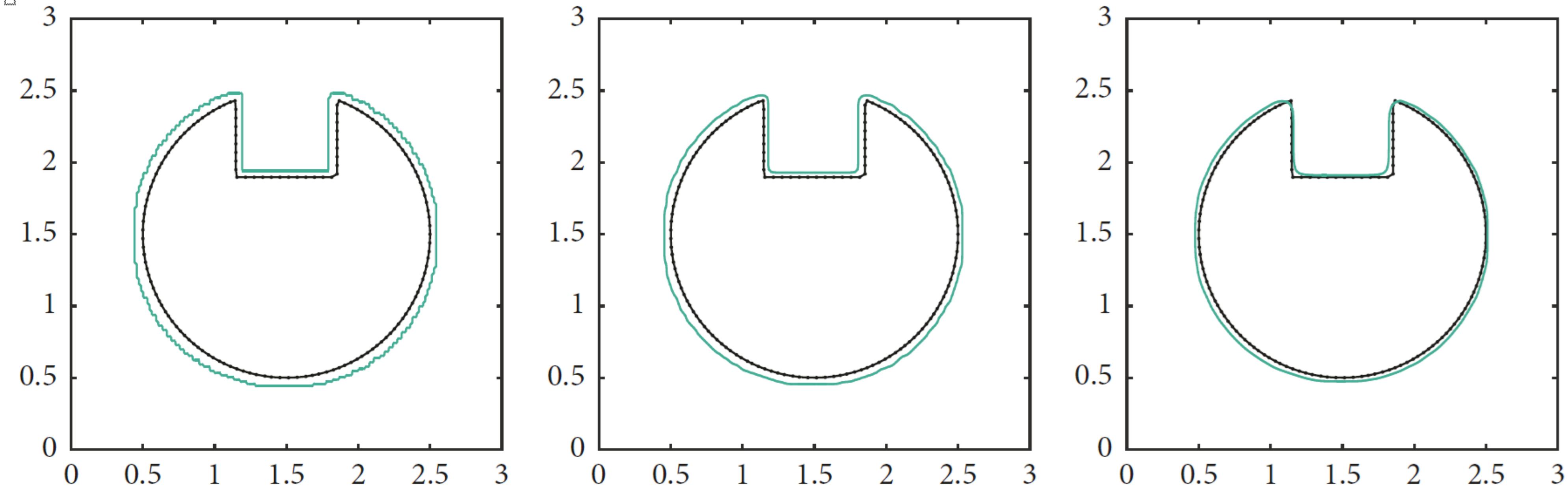
# Phase-Field Method

Outside the narrow band domain, we set a large value to the edge indicator function, as shown in the figure below:




Schematic of SDF, from [JNG], copyright pending.

# Phase-Field Method




Temporal evolution of the interface (initial condition, 100 iterations, 1000 iterations), from [JNG], copyright pending.

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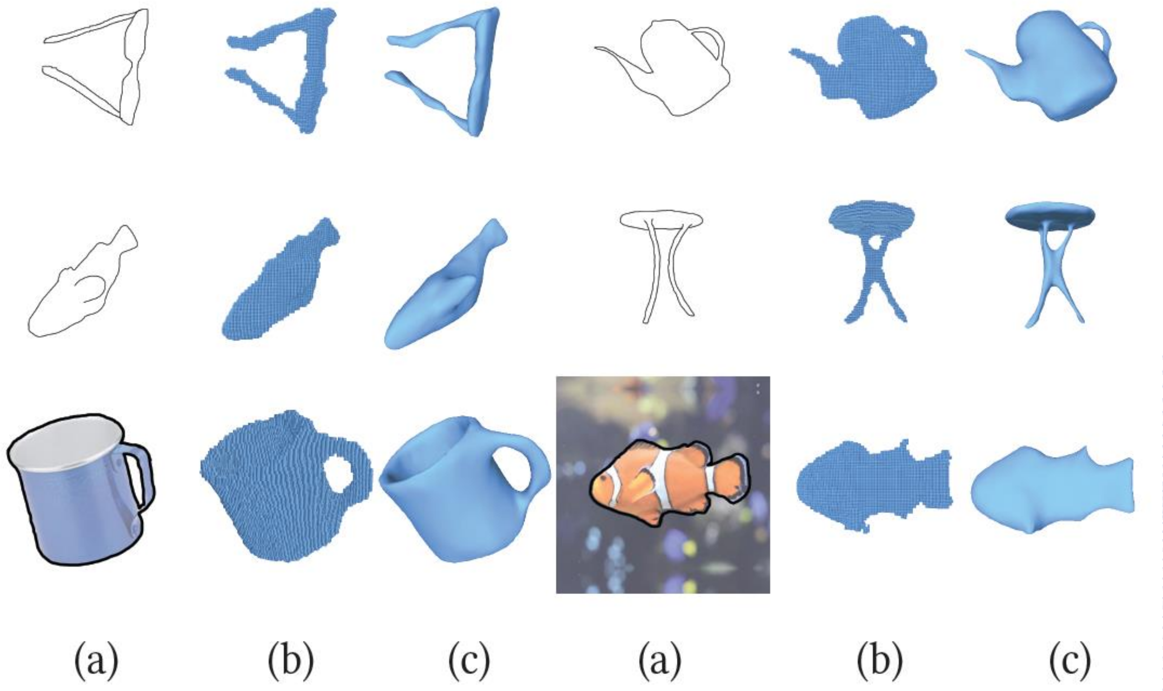
# Contour-based 3D Modeling

- A recent developed method is presented, that utilizes deep learning to compute the 3D representation from contour images.
- The method can be used to extract both volumetric images or polygon meshes from three orthogonal occluding contours.



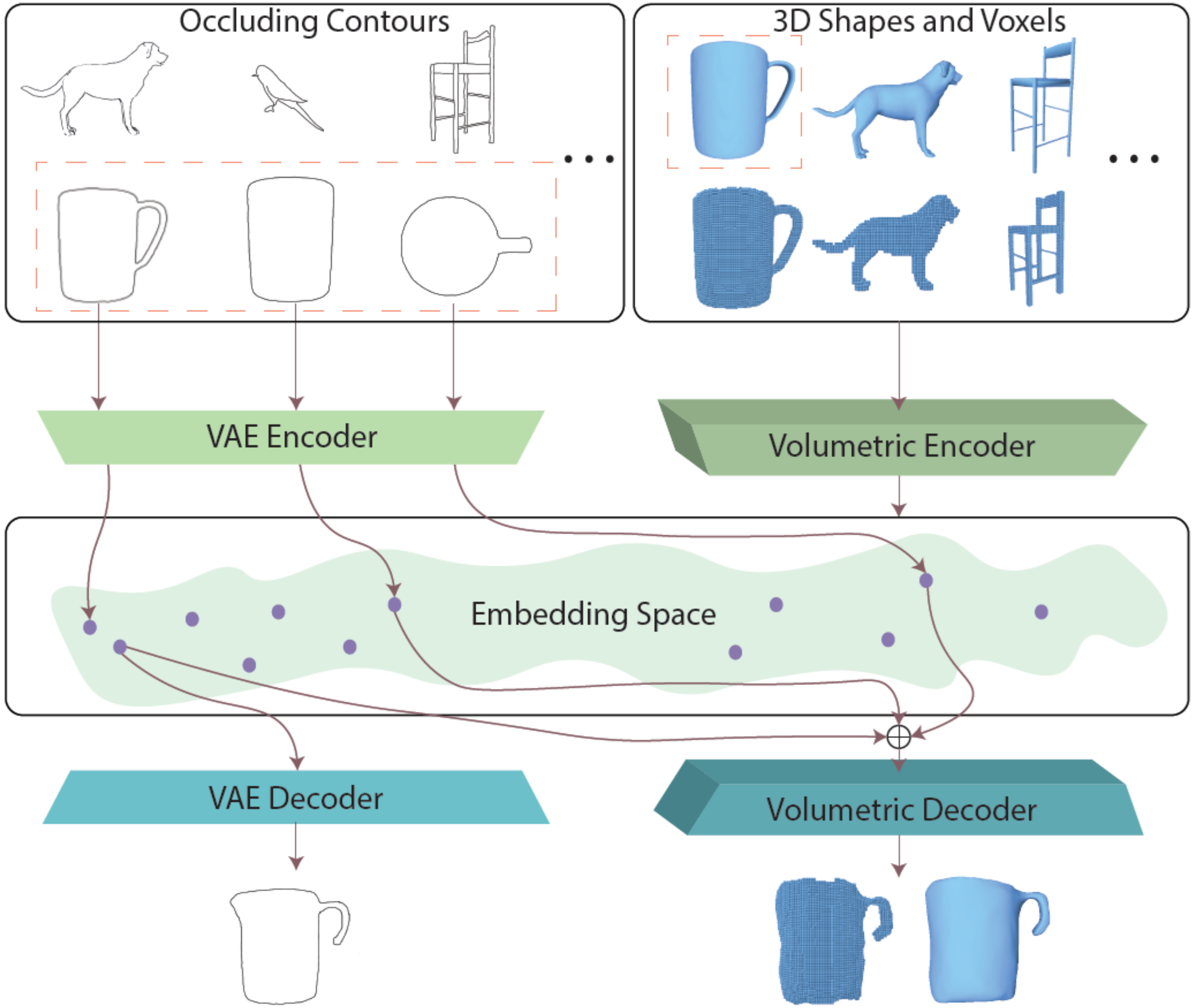

Gallery of modeling results, from [CNT], copyright pending.

# Contour-based 3D Modeling

(a) (b)

Examples of the projections for a 3D shape, from [CNT], copyright pending.

# Contour-based 3D Modeling




Schematic pipeline, from [CNT], copyright pending.

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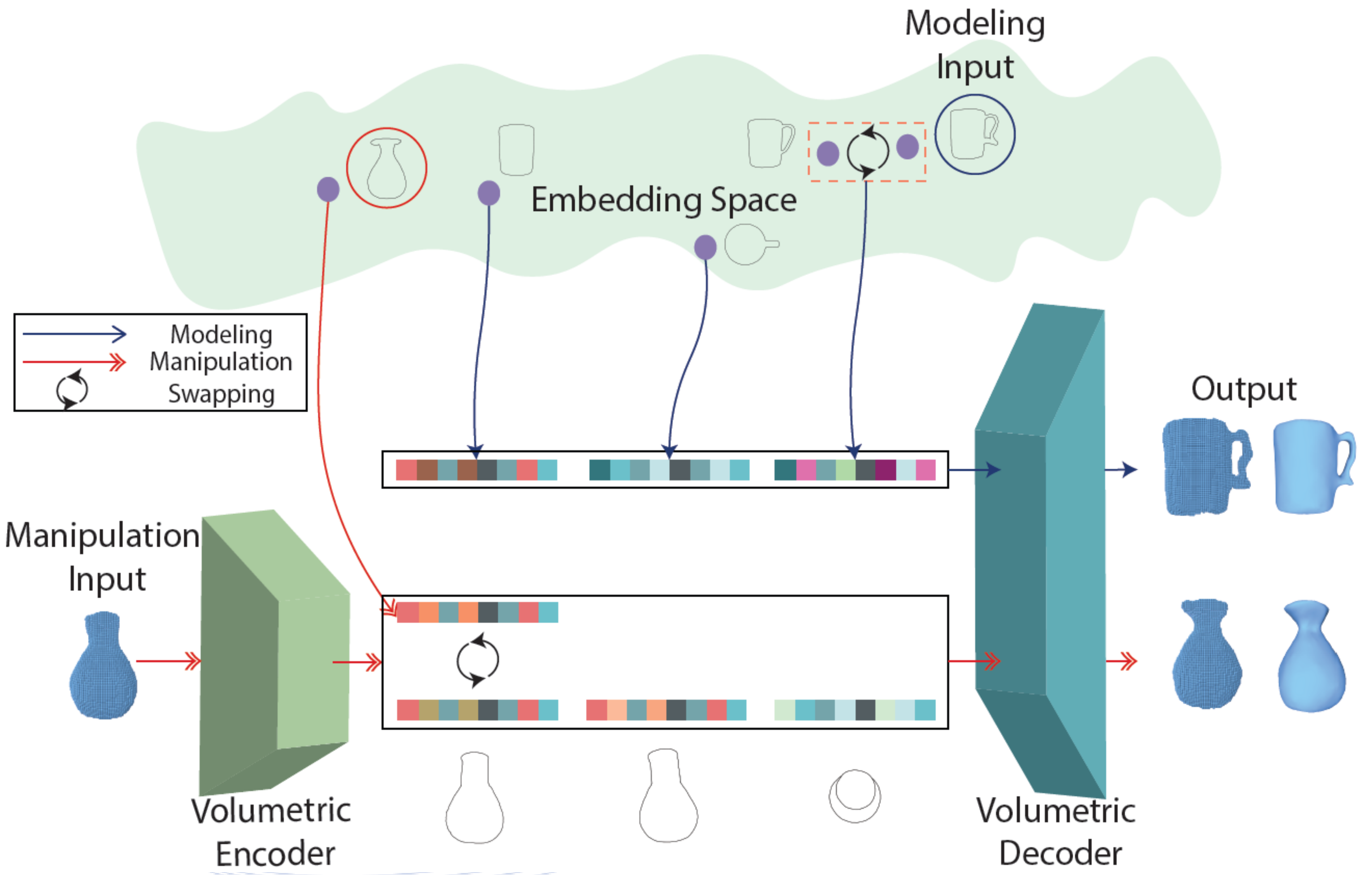
# Contour-based 3D Modeling




Volumetric Autoencoder, from [CNT], copyright pending.

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# Q & A

**Thank you very much for your attention!**

**More material in**
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