Learning Manifold Patch-Based Representations of Man-Made Shapes

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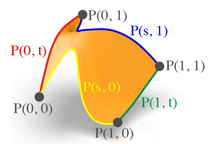
Summary

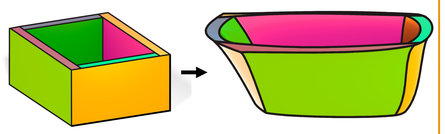
We propose a fully self-supervised method for learning a **patch-based representation** of **piecewise-smooth manifold 3D geometry**. This representation is **sparse, interpretable, and easily editable**, making it a convenient choice for downstream tasks in design and modeling.

Deformable Patch-Based Representation

Our network directly outputs control points that define a collection of CAD parametric patches (right). The topology and rough geometry of these patches are defined by a deformable template, which automatically generate per shape category (below).

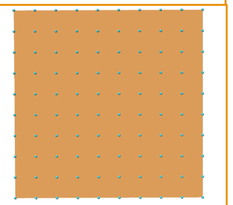


$$P\colon [0,1]^2 \to \mathbb{R}^3$$
$$P(s,t) = \sum a_{i,j} s^i t^j$$



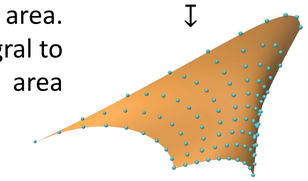
Area-Weighted Chamfer Loss

A naive way to compare a mesh and a collection of patches is to uniformly sample the patch parametric domain, uniformly sample the mesh, and compute Chamfer distance between the two point clouds. Sampling uniformly in parameter space, however, yields a point cloud that is not uniform with respect to surface area. Instead, we pull back the surface integral to the parameter domain and include area weights for an unbiased evaluation.



uniform

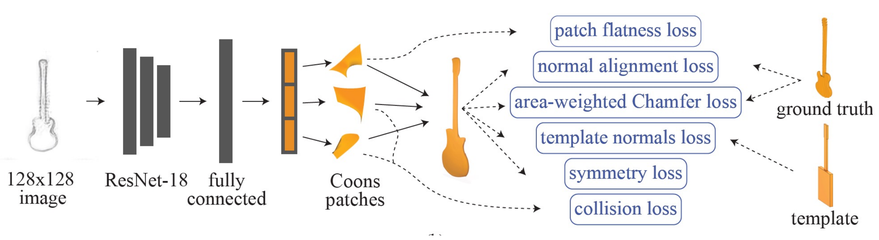
↧



✖ non-uniform

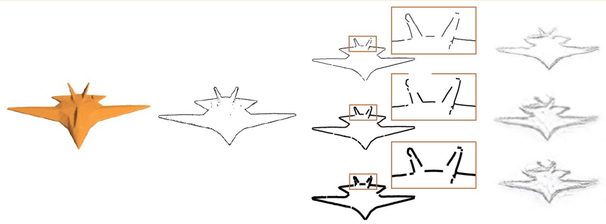
$$\mathcal{L}(P) = \frac{1}{\text{Area}(P)} \int_P \mathrm{d}(x)\, dx$$
$$= \frac{1}{\text{Area}(P)} \int_0^1 \int_0^1 \mathrm{d}(P(s,t)) |J(s,t)|\, ds\, dt$$

Pipeline Overview



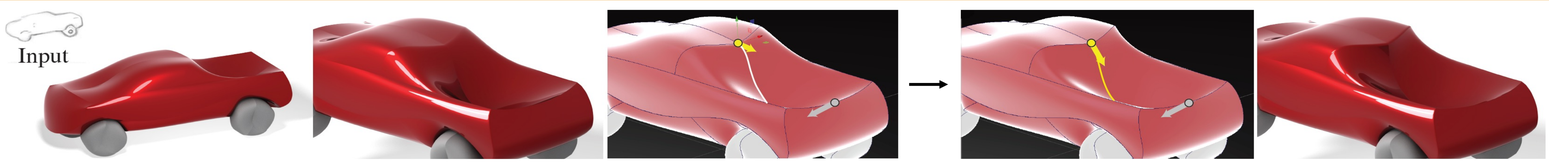
During training, we optimize a reconstruction loss and several regularizers.

Data Generation



We generate synthetic training data from 3D models.

CAD Model Editing

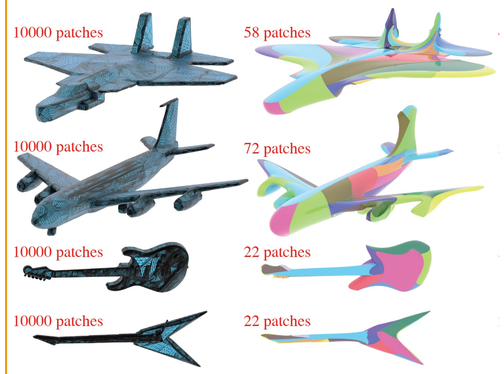


Because we output 3D geometry as a collection of consistent, well-placed NURBS patches, user edits can be made in conventional CAD software by simply moving control points. Here, we are able to refine the trunk of a car model with just a few clicks.

3D Sketch Reconstruction

For each input sketch, we show the reconstruction obtained using a generic sphere template and a category-specific template (top to bottom).

Mesh → NURBS Conversion



We can use our method to automatically decompose a mesh into a collection of NURBS patches. Compared to a standard CAD software tool (left), our method (right) is several orders of magnitude more parsimonious, and our patches are placed consistently across different models.

Project Webpage

http://people.csail.mit.edu/smirnov/learning-patches/