BendSketch: Modeling Freeform Surfaces Through 2D Sketching

通过绘制平面草图创造三维自由形状

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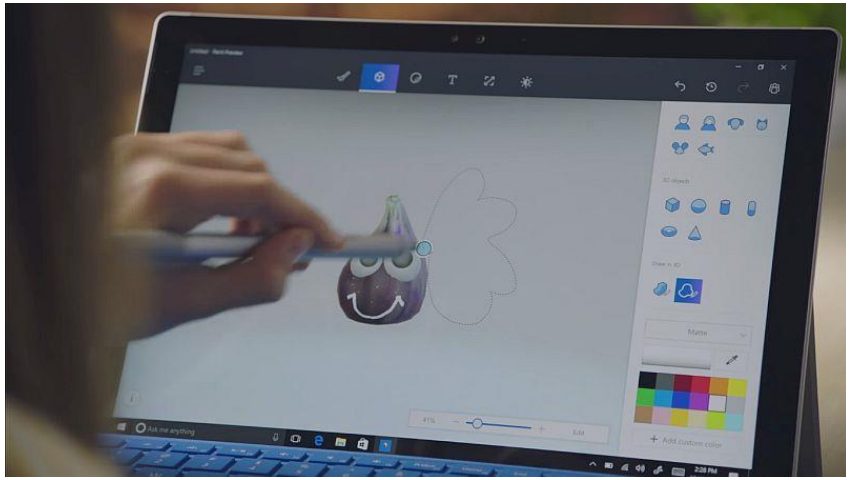
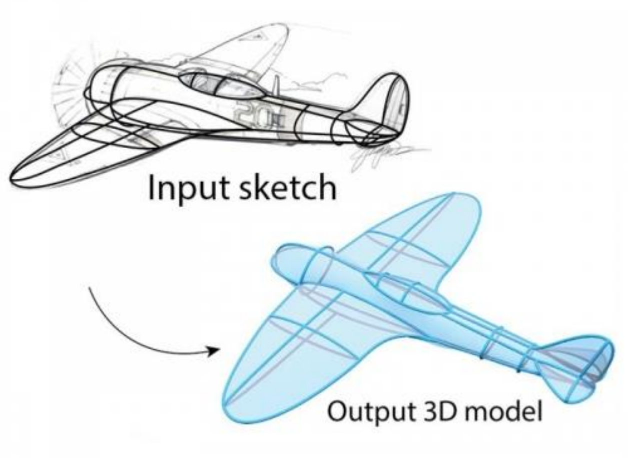
Sketch-based 3D Modeling

- Sketch modeling: *intuitive* and *effective*

Teddy [Igarashi et al. 1999]



Paint 3D [Microsoft Crop.]

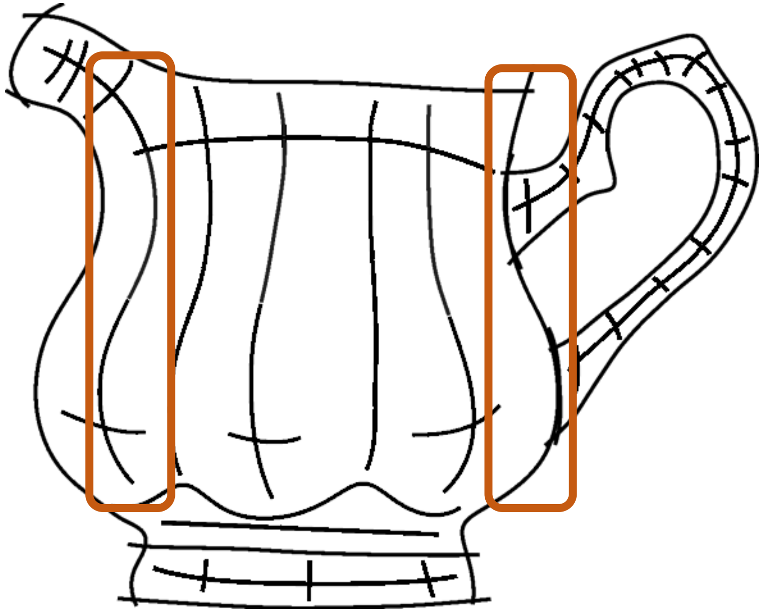


True2Form [Xu et al. 2014]

Our Goal

Model *freeform 3D shapes* with *controlled curvature variation patterns*, by sketching 2D scattered *bending lines* and other curves.

Our Goal



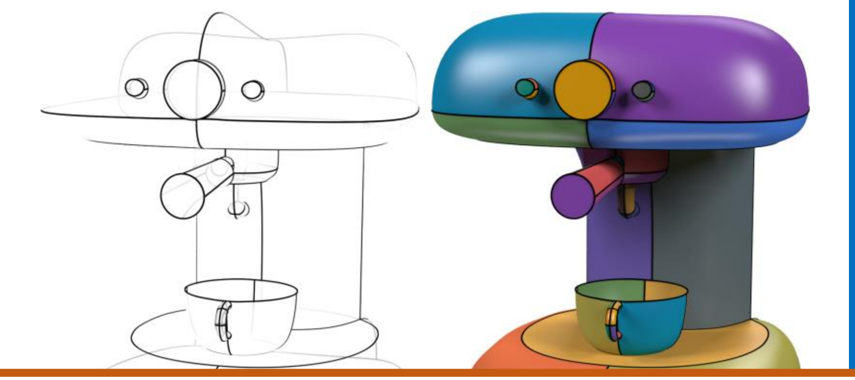
2D sketching

3D shape

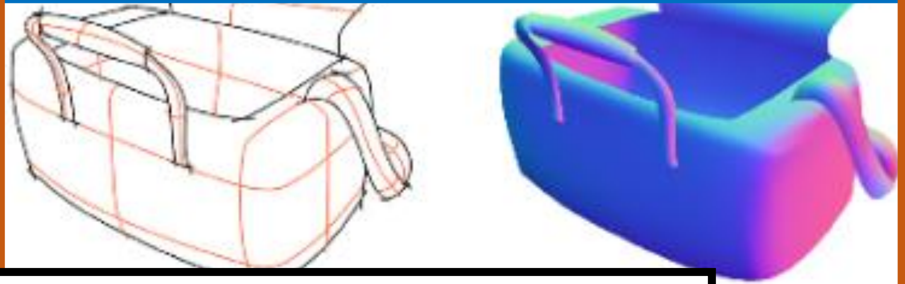
Model *freeform 3D shapes* with *controlled curvature variation patterns*, by sketching 2D scattered *bending lines* and other curves.

Origin of Idea

Two very similar ideas presented in 2015.



Fitting normal vectors to 2D projected curves,
with the normal v



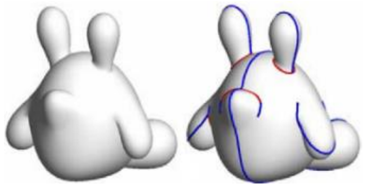
Fitting surface to 3D curve networks, with the surface curvature aligned to the curves.

Combine the two, and model curvature controlled 3D surfaces directly from 2D sketching.

Related Work

Contour-based methods

- Smooth low-frequency surfaces [Igarashi et al. 1999; Nealen et al. 2007; Olsen et al. 2011; Yeh et al. 2016 …]
  - Rounded shape



[Nealen et al. 2007]

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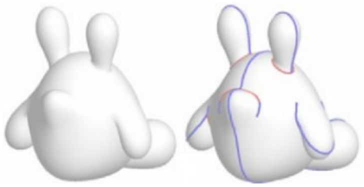

[Nealen et al. 2007]

- Rotational symmetry surfaces [Gingold et al. 2009; Shtof et al. 2013; Chen et al. 2014; Miao et al. 2015 ...]
  - Limited variation (generalized cylinder, ellipsoid)

[Shtof et al. 2013]

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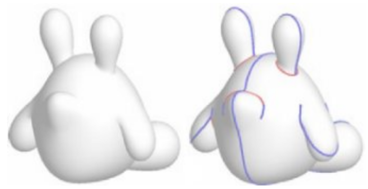

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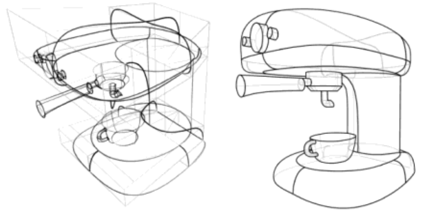
[Shtof et al. 2013]

Surfacing from curve networks

- Man-made shapes [Schmidt et al. 2009; Xu et al. 2014; Bessmeltsev et al. 2012; Pan et al. 2015; Zhuang et al. 2013 ...]
  - High-regularity and low curvature variation



[Schmidt et al. 2009]

Related Work

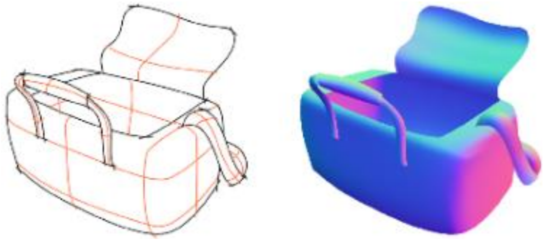
Domain specific methods

- Layered surfaces, developable surfaces… [Bessmeltsev et al. 2015; Jung et al. 2015; De Paolo and Singh 2015 …]
  - Uneasy to generalize

[Paolo et al. 2015]

Normal from sketches

- Infer normal from 2D sketches [Sykora et al. 2014; Shao et al. 2012; Xu et al. 2014; Bui et al. 2015; Iarussi et al. 2015]
  - Inaccurate to recover shape

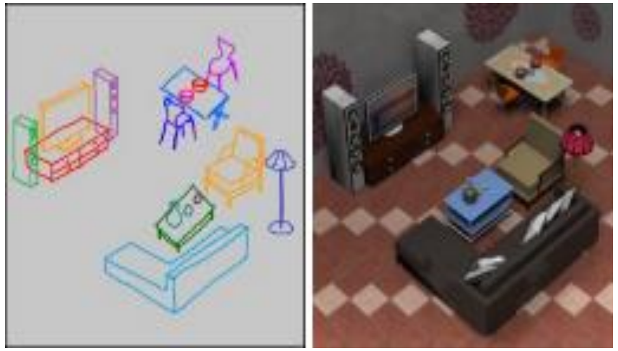


[Iarussi et al. 2015]

Related Work

Data-driven methods

- Retrieve shape or map sketch to 3D shape [Xu et al. 2013; Xie et al. 2013, Huang et al. 2016; Nishida et al. 2016]
  - Limited by dataset diversity
  - Model class-specific shapes



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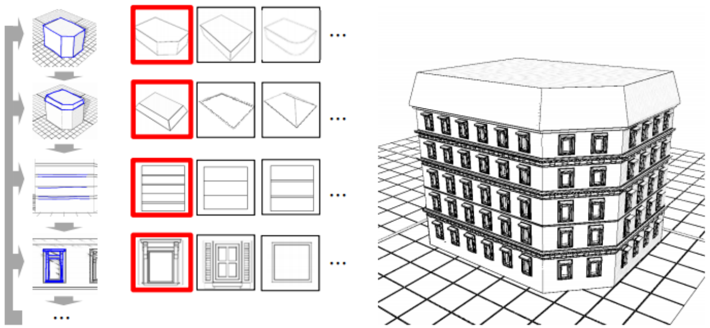
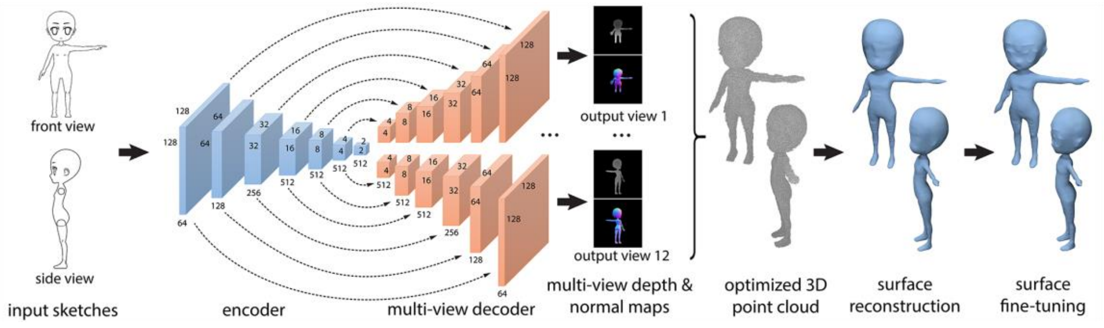


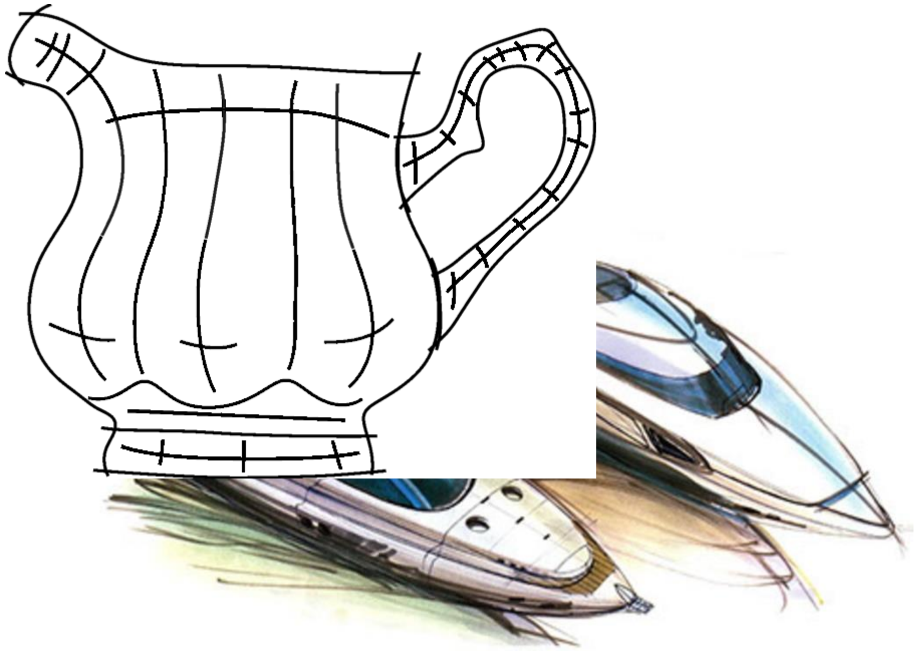
[Nishida et al. 2016]



[Lun et al. 2017]

Bending Lines

Bending lines convey surface bending directions [Eissen and Steur 2011]



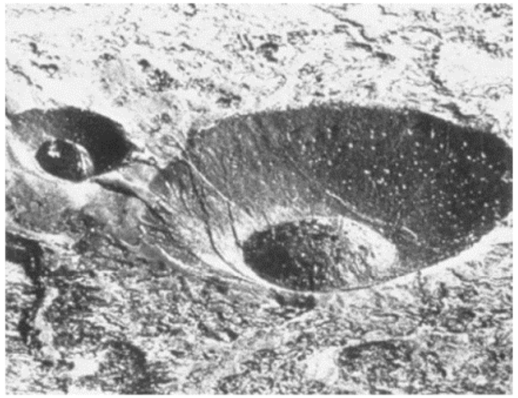
Concept Design
[Eissen and Steur 2011]

NPR rendering
[Hertzmann and Zorin 2000]

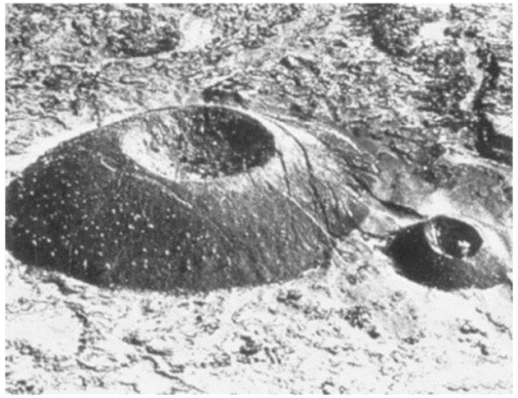
Inverse Problem

Infer 3D surface from sketched bending curves

- Technical challenges:
  - Bas-relief ambiguity: *convex/concave*



Crater? [Pentland 84]



Ash cone [Pentland 84]

Inverse Problem

Infer 3D surface from sketched bending curves

- Technical challenges:
  - Bas-relief ambiguity: *convex/concave*
  - Bas-relief ambiguity: *depth*

Frontal view

Side view

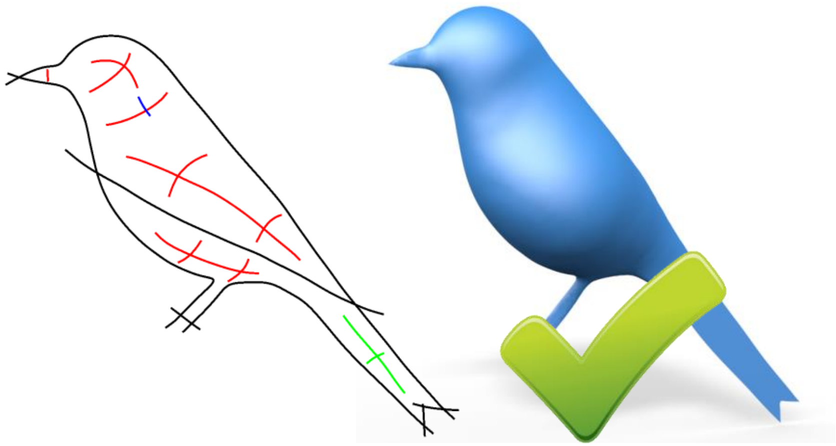
[Belhumeur et al 99]

Inverse Problem

Infer 3D surface from sketched bending curves

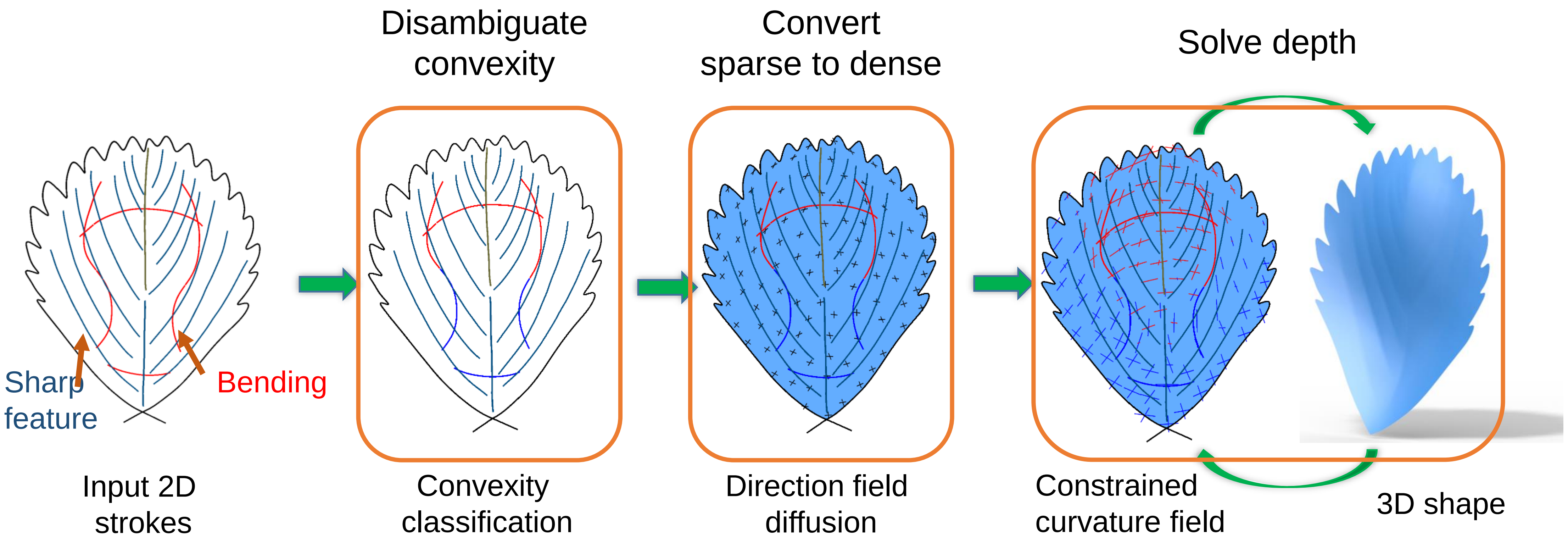
- Technical challenges:
  - Bas-relief ambiguity: *convex/concave*
  - Bas-relief ambiguity: *depth*
  - Sparse input strokes

Dense lines

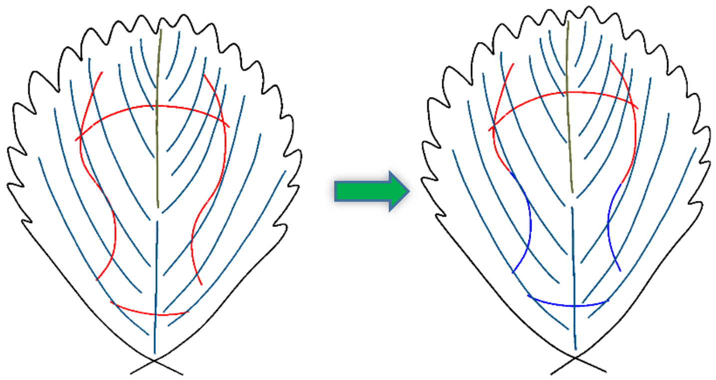


Sparse strokes, about 10

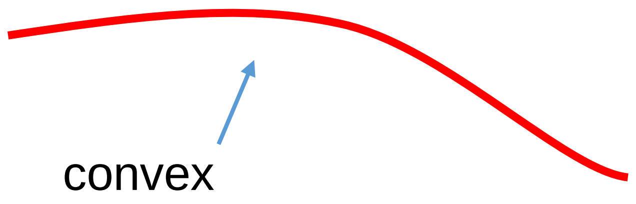
Overview of Our Solution



Our Solution



- *Convexity*: stroke classification
  - Observations
    - Convex - single stroke



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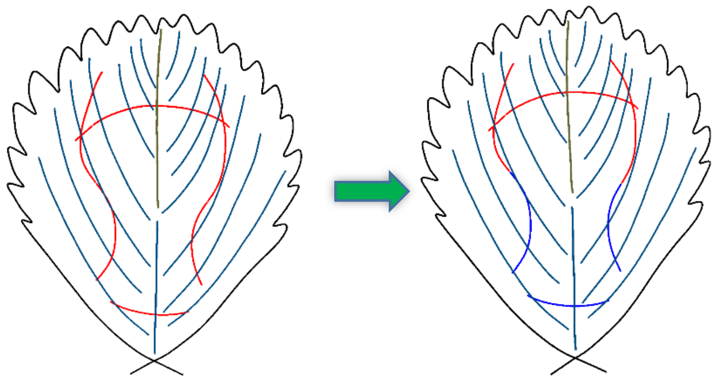

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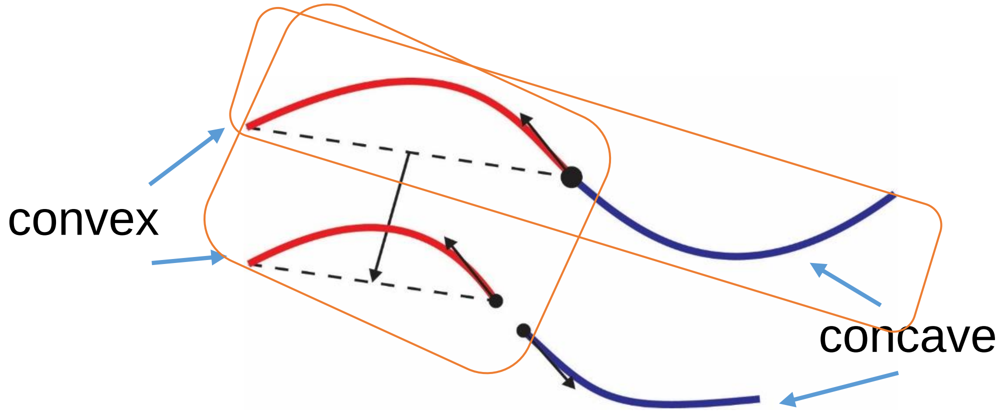

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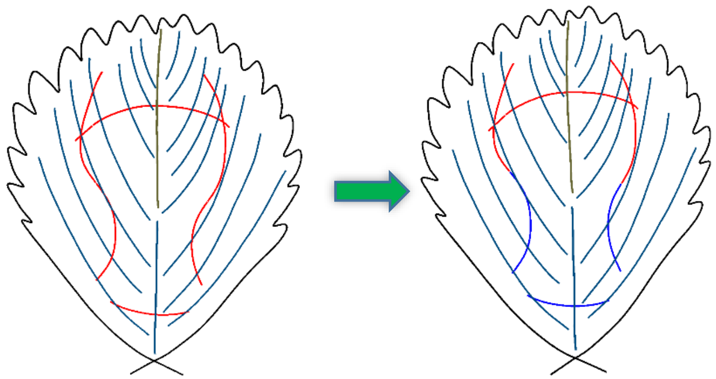

- Convexity: stroke classification
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    - Convex - single stroke
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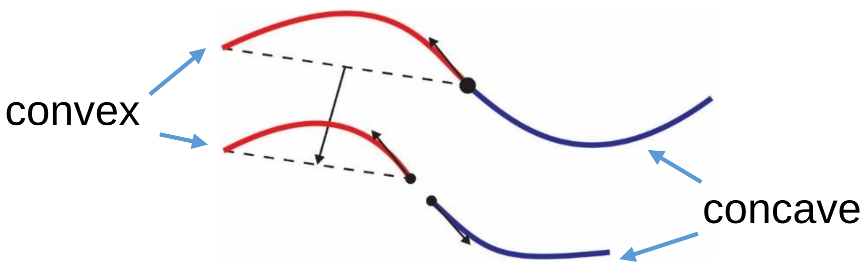
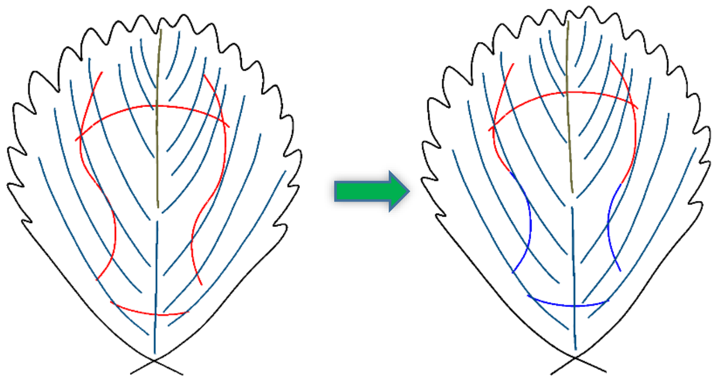
  - Formulation: binary labeling

$$min. E(x) = \sum_{s \in \mathcal{V}} \theta(x_s) + \sum_{(s,t) \in \mathcal{E}} \theta(x_s, x_t)$$



- Unary term: favor convex
- Binary term: relationship between strokes

Our Solution



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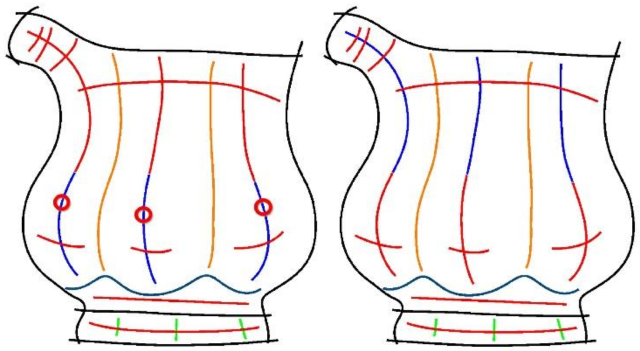
    - Unary term: favor convex
    - Binary term: relationship between strokes
    - Allow user edit stroke label



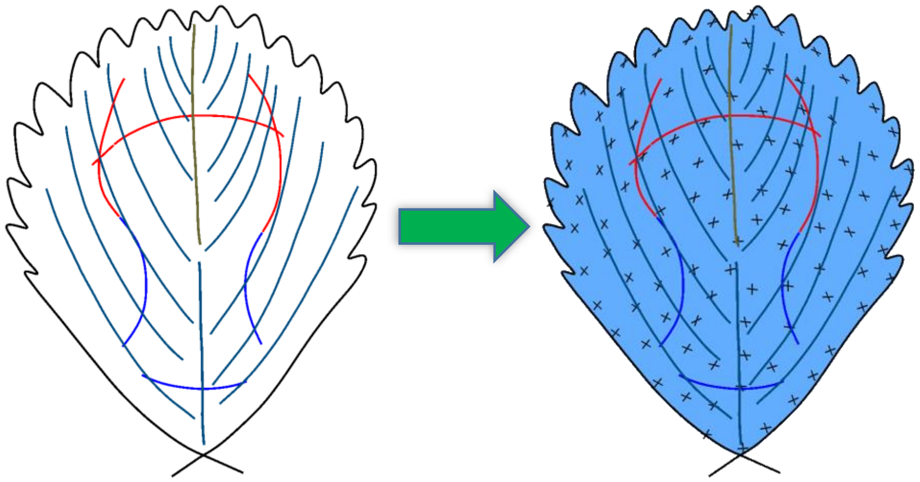
User correction

Our Solution

- *Sparse to dense*: direction field diffusion [Iarussi et al. 2015]

$$E_{BendField}(u,v) = \frac{1}{|\Omega|}\int_{\Omega} \|\nabla_u v\|^2 + \|\nabla_v u\|^2 \, \mathrm{d}\sigma$$

Projected curvature directions u, v
follow the bending stroke directions,
and initialized by harmonic 4-direction fields
[Diamanti et al. 2014].



Our Solution

- *Depth*: surface from projected curvature tensors

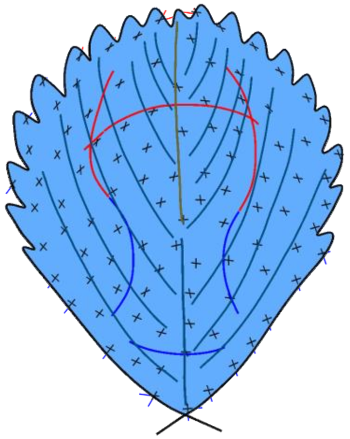
Height field surface z from curvature:

Minimize $E_{match}(z) = \frac{1}{|\Omega|}\int_{\Omega} \|dN \cdot u - \lambda_u u\|^2 + \|dN \cdot v - \lambda_v v\|^2 d\,\sigma$

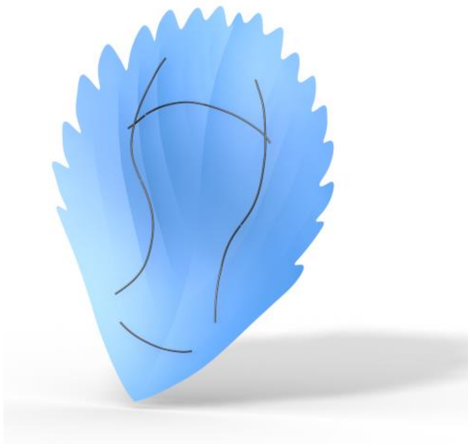
curvature tensor matching

Projected curvature tensors

Direction field



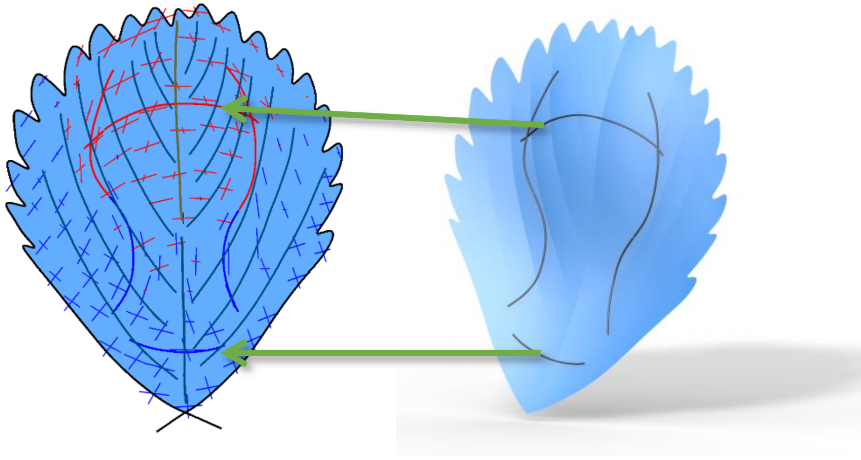
Surface & lifted strokes



Our Solution

- *Depth*: surface from projected curvature tensors

Projected curvature tensors   Surface & lifted strokes



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Minimize $E_{match}(z) = \frac{1}{|\Omega|}\int_{\Omega} \|dN \cdot u - \lambda_u u\|^2 + \|dN \cdot v - \lambda_v v\|^2 d\,\sigma$

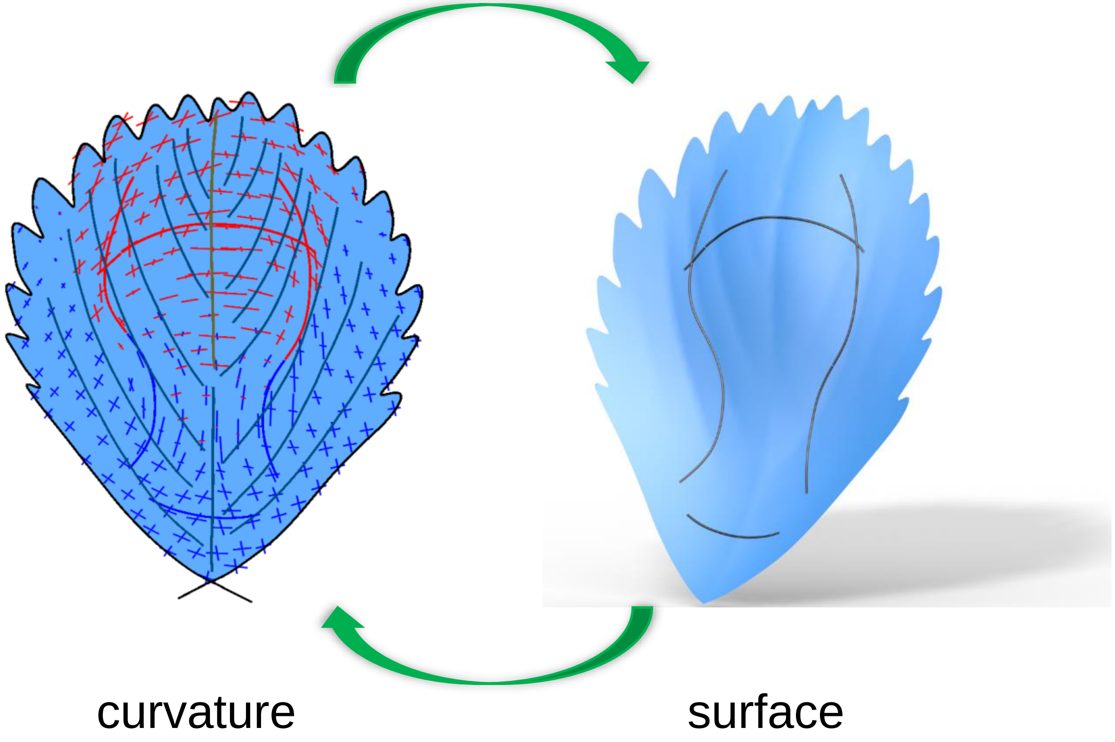
with magnitudes λ_u λ_v:

Minimize $E_{\lambda}(\lambda_u, \lambda_v) = \frac{1}{|\Omega|}\int_{\Omega} \|\nabla_u \lambda_v\|^2 + \|\nabla_v \lambda_u\|^2 + \beta(\|\nabla_u \lambda_u\|^2 + \|\nabla_v \lambda_v\|^2) d\,\sigma$

constrained by the spatial curvature of lifted strokes.

curvature value diffusion

Our Solution



Search $(z, \lambda_u, \lambda_v)$ in a fast iterative process, solving linear equations per iteration.

Boundary Conditions and Other Strokes

Boundary conditions

- Position constraints
- Regularity constraints: smoothness

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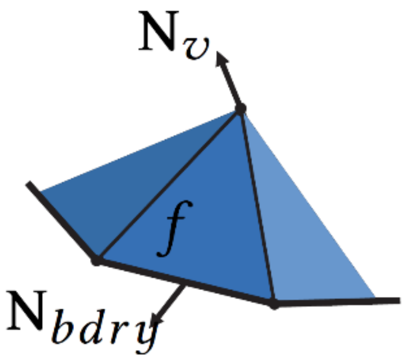
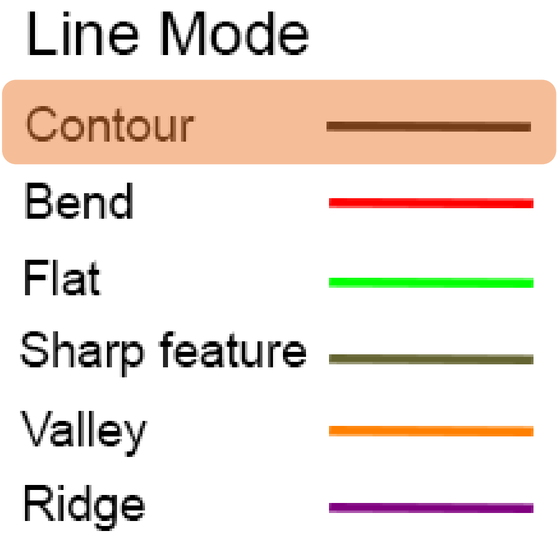
- Regularity constraints: smoothness

Other supported strokes

- Contour stroke: normal constraints





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- Position constraints
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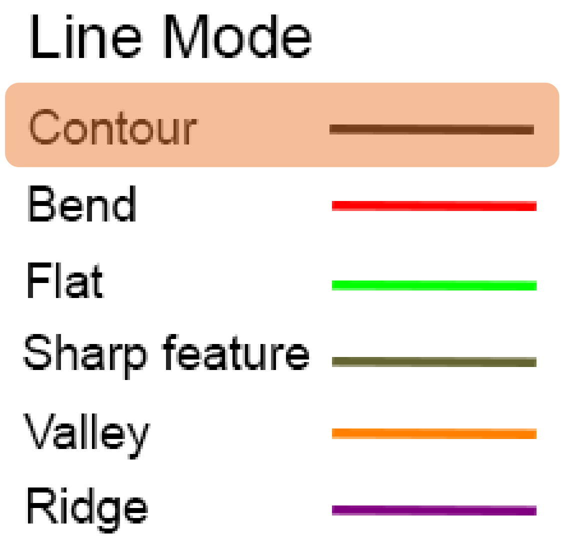
- Flat stroke: parallel normal vector
- Sharp feature: sharp angle



Boundary Conditions and Other Strokes

Boundary conditions

- Position constraints
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Other supported strokes

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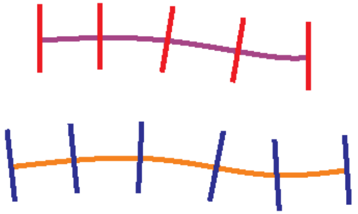
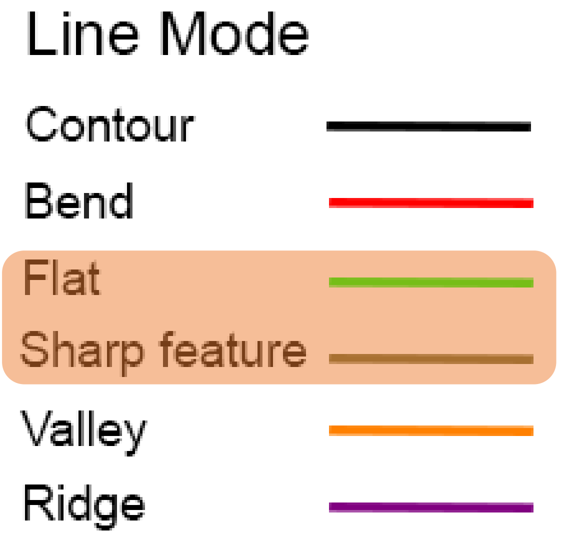
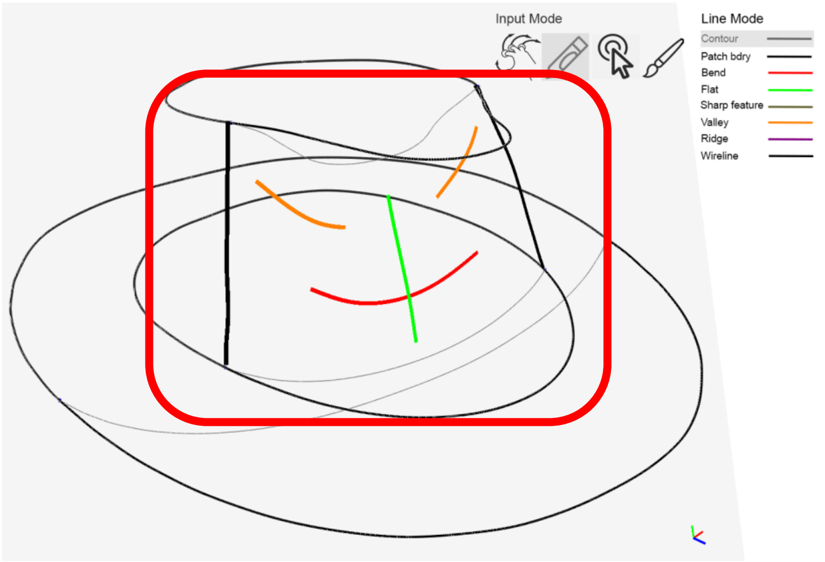
- Flat stroke: parallel normal vector
- Sharp feature: sharp angle

- Ridge/valley stroke: a set of bending lines with known convex and concave

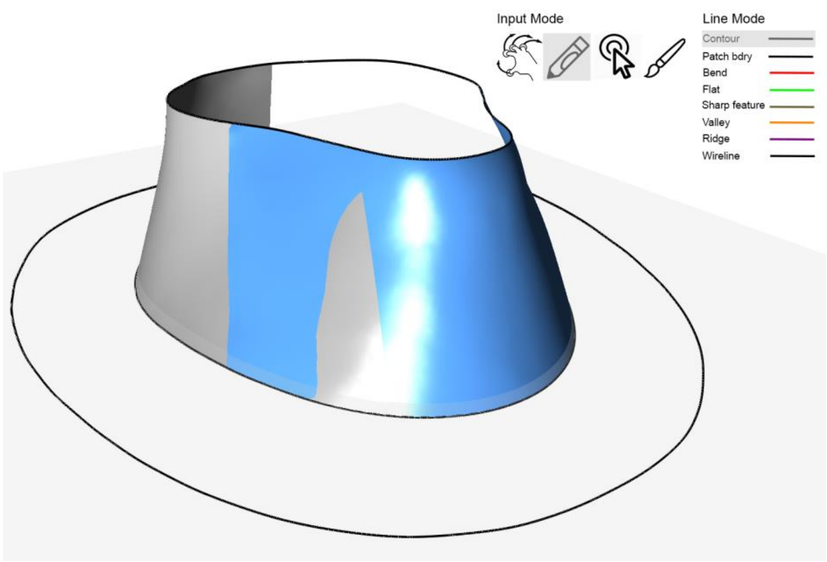




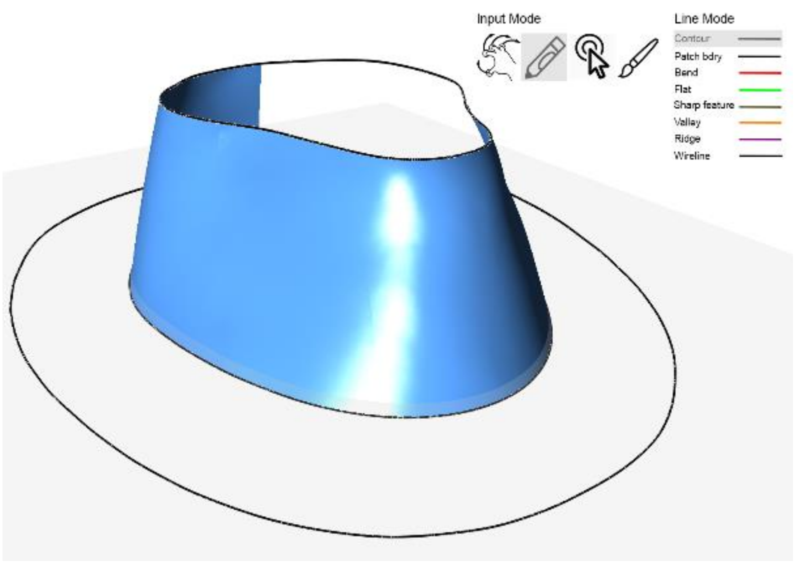
Multi-View Sketching



Sketching on the current view



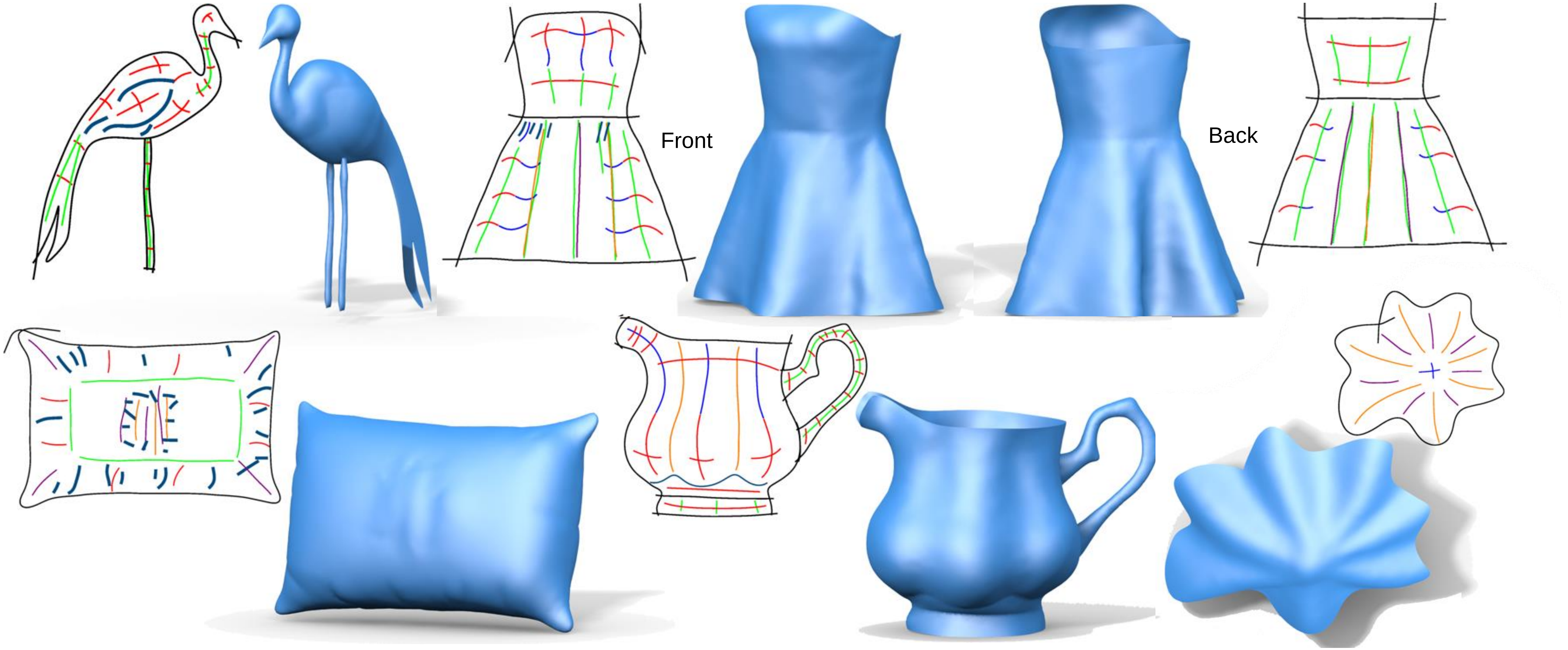
Surface patch for the current view



Patches merged

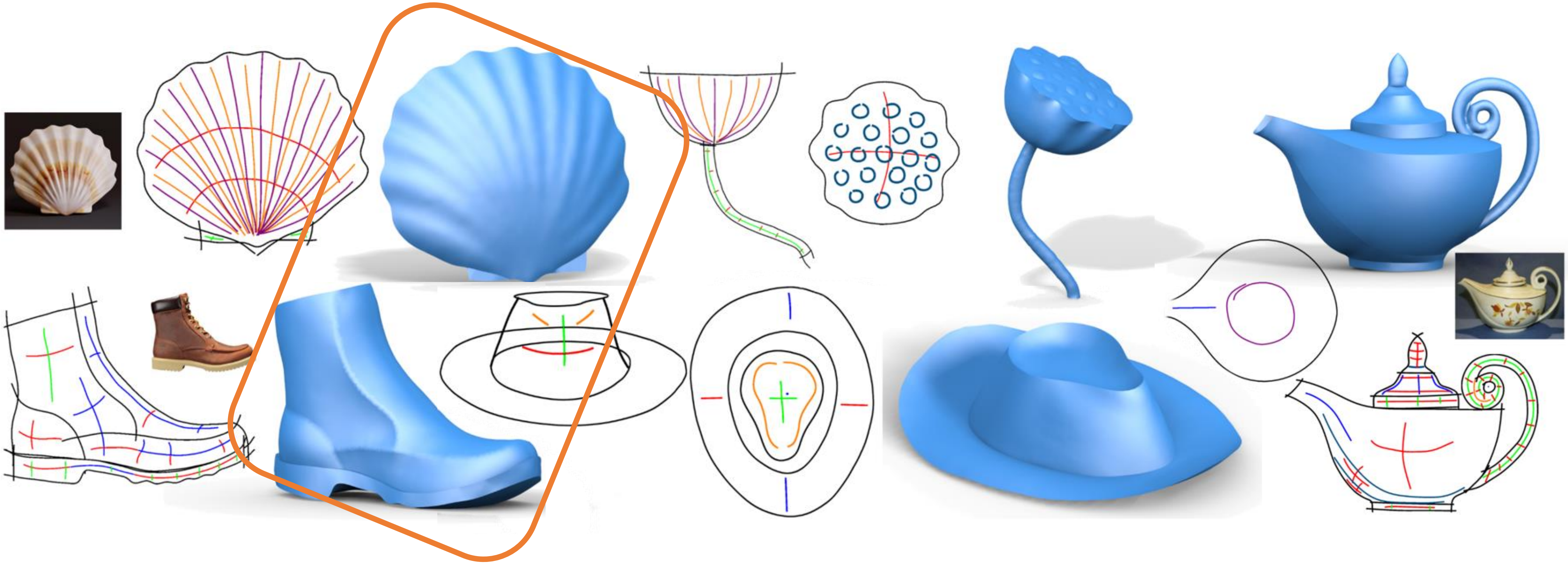

Input Mode
Line Mode
Contour
Patch bdry
Bend
Flat
Sharp feature
Valley
Ridge
Wireline

Results



Stroke number: 20 ~ 40. Time: < 3s per patch computation.

Results



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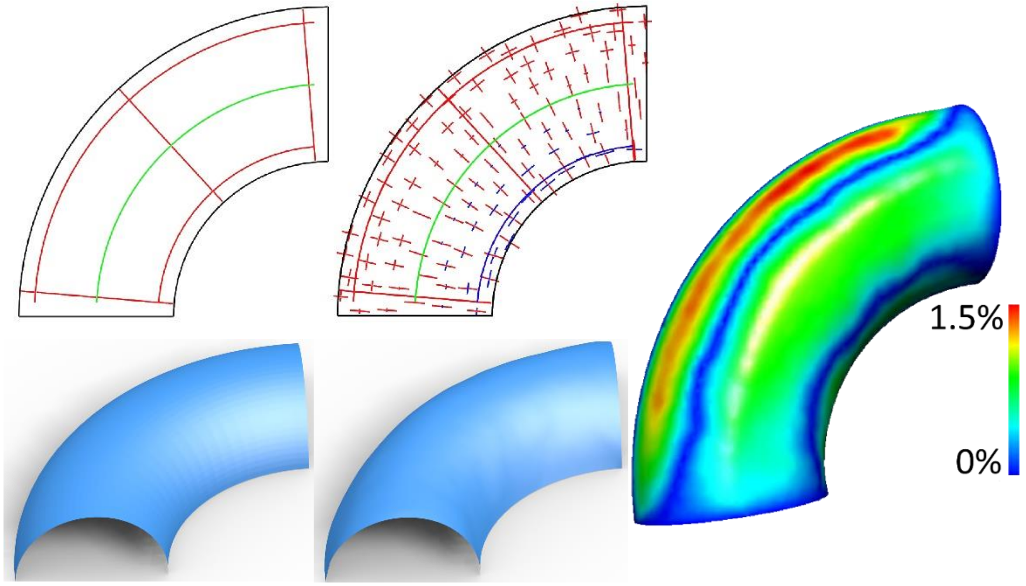
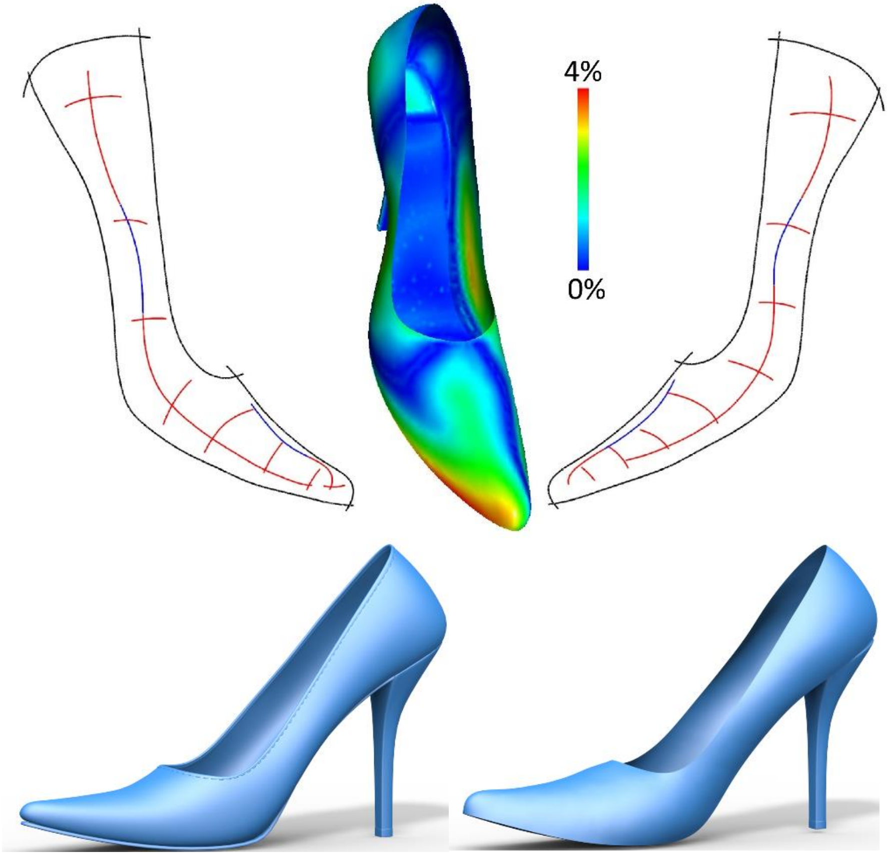
Validation

Compare with the ground truth data

- 1/8 torus and shoe model



GT result Our result



GT result Our result

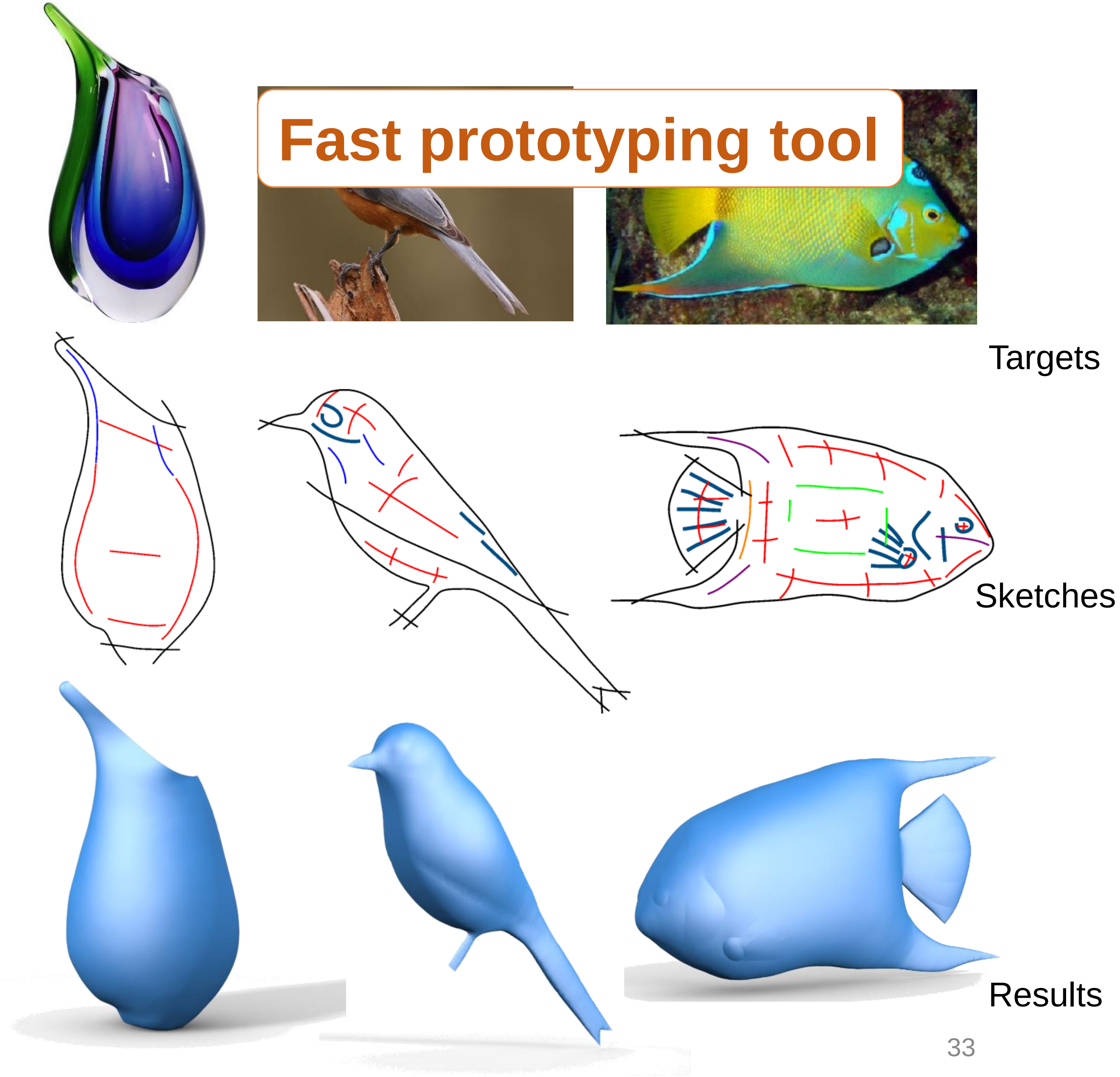
User Evaluation

Users

- 7 novice users w/o background
- 2 professional 3D artists

Results

- ~30 min learning
- ~10 min creation
- robust to user input diversity

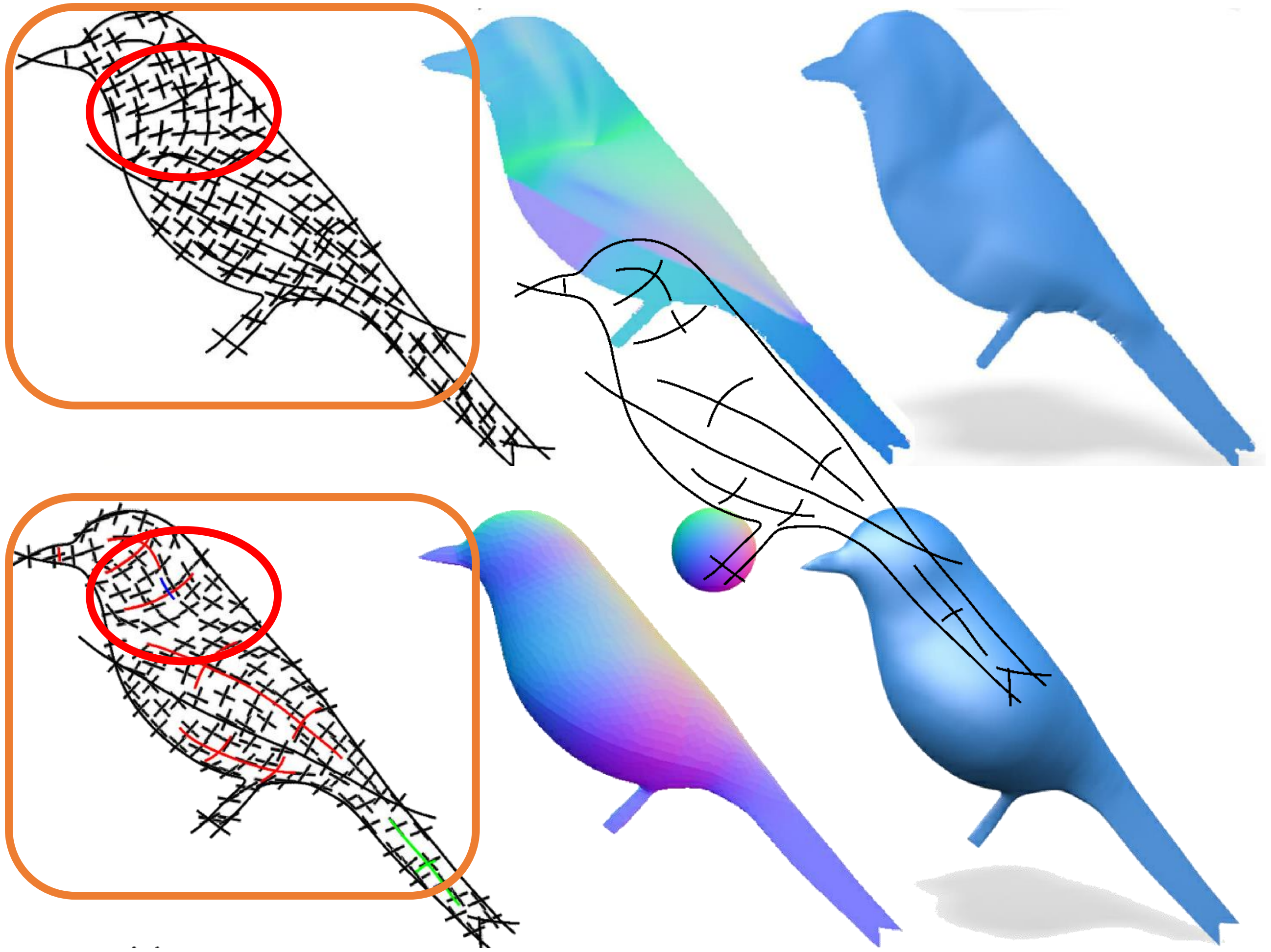


Comparison

- BendField [Iarussi et al. 2015]
  - Curvature direction field
  - Inaccurate normal field for 3D reconstruction

- Our method:
  - Complete curvature tensor field (direction, magnitude)
  - Real 3D shape

Comparison

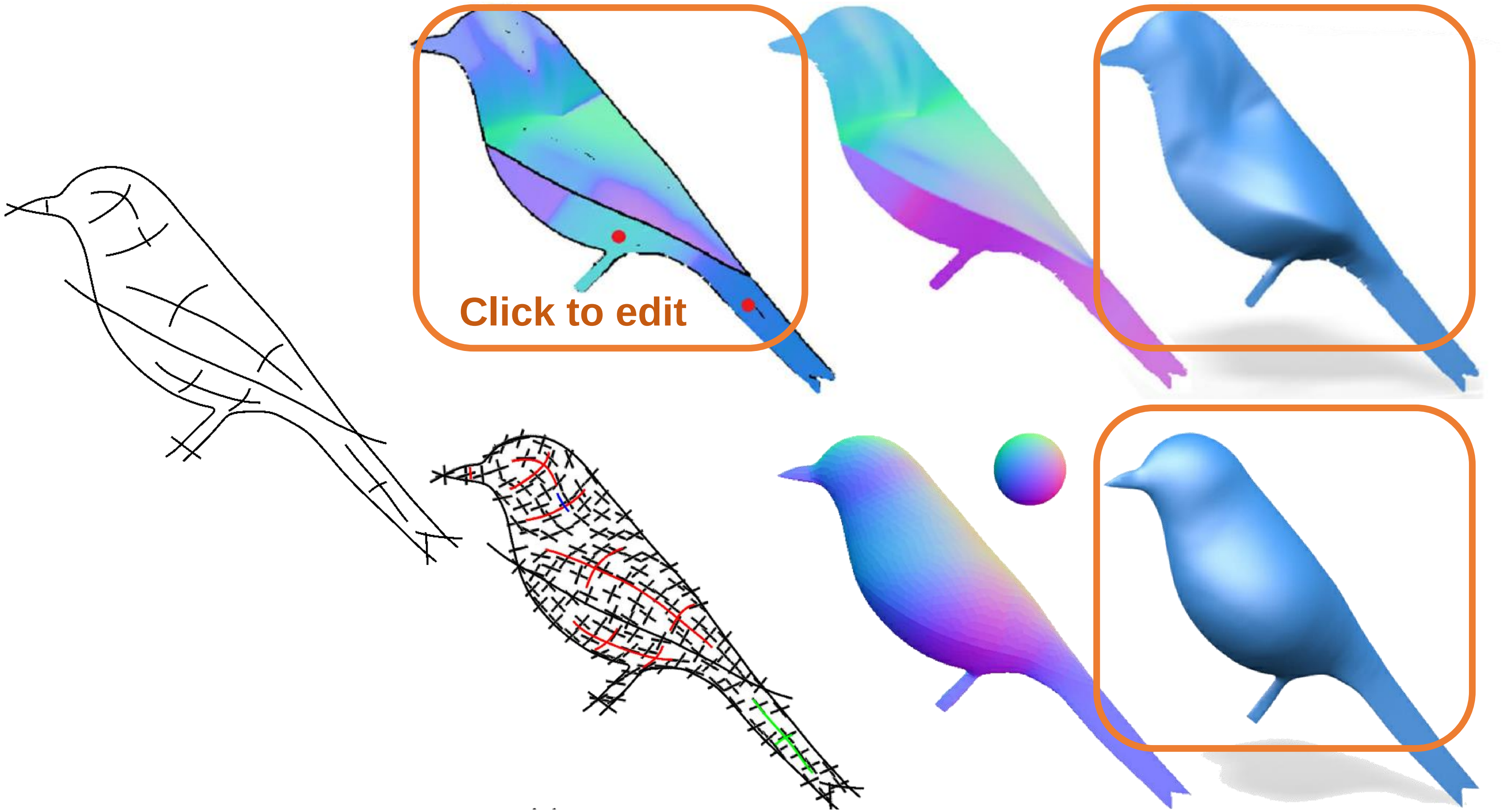


BendField [Iarussi et al. 2015]

Ours

Direction field Normal map 3D shape

Comparison



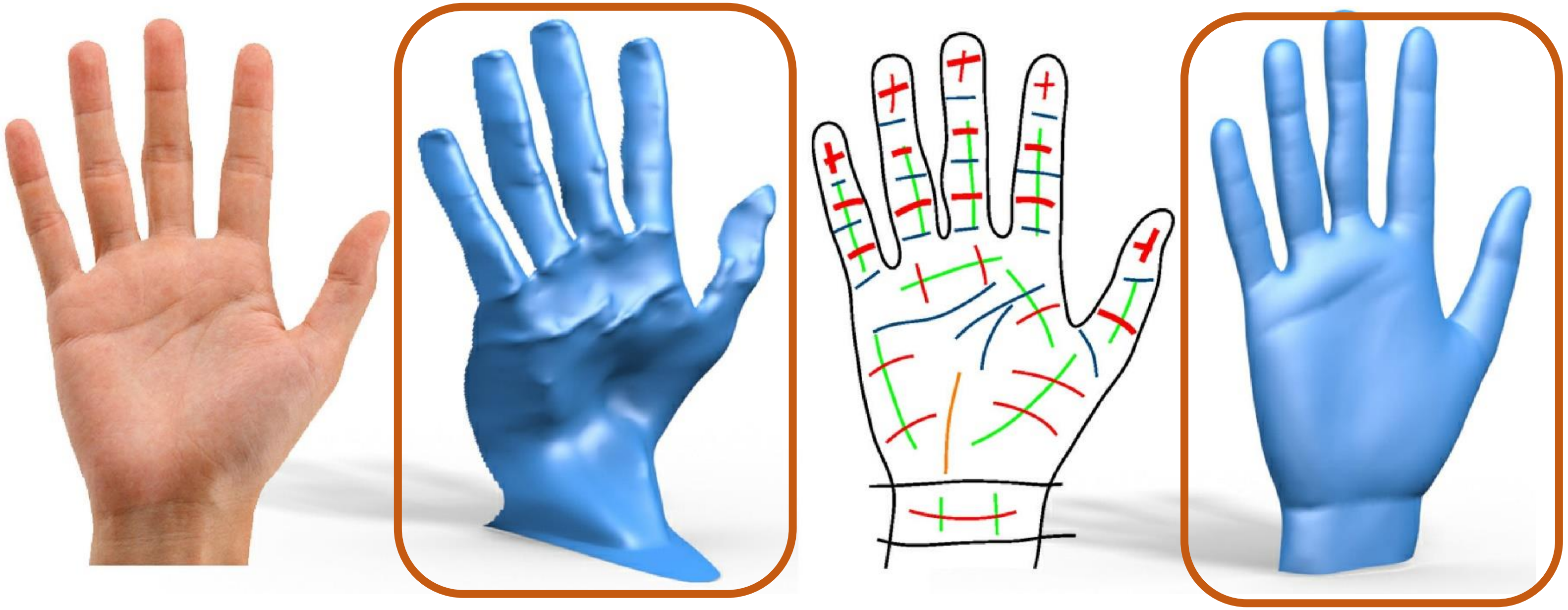
BendField
with editing [Iarussi et al. 2015]

Ours

Normal map 3D shape

Comparison

- Shape from Shading [Barron and Malik 2015]



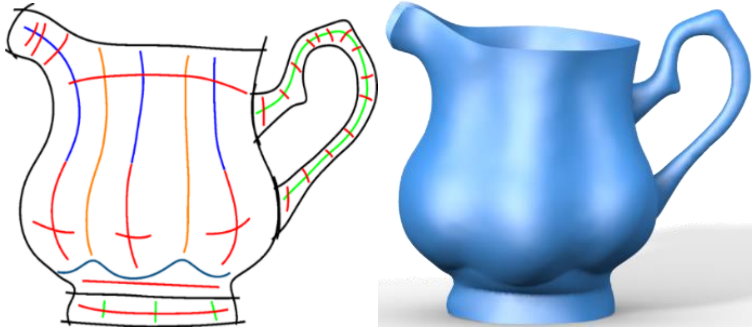
SfS results

Ours

Conclusion

An intuitive and effective tool to model freeform shapes with complex curvature variation.

- Technical contributions:
  - Disambiguate bending stroke convexity
  - Estimate bending magnitudes
  - Construct surface from sparse bending strokes



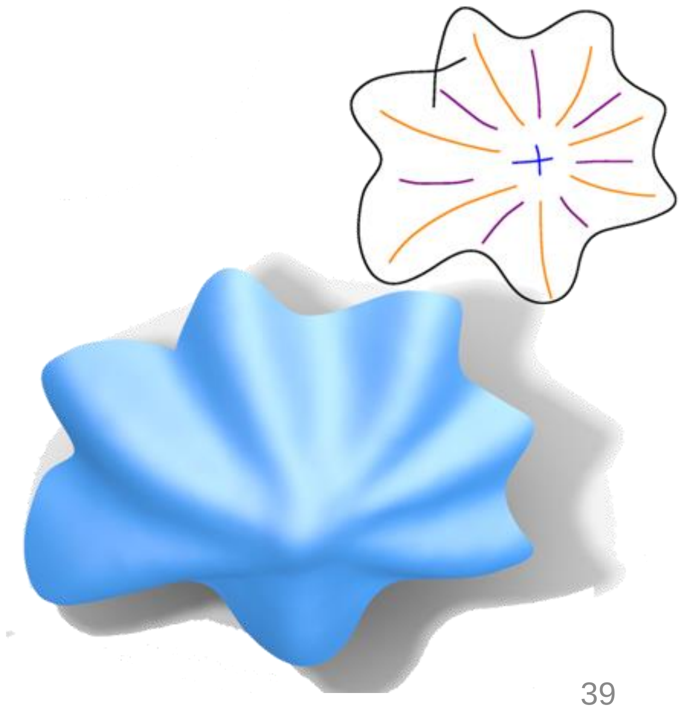
Limitation and Future Work

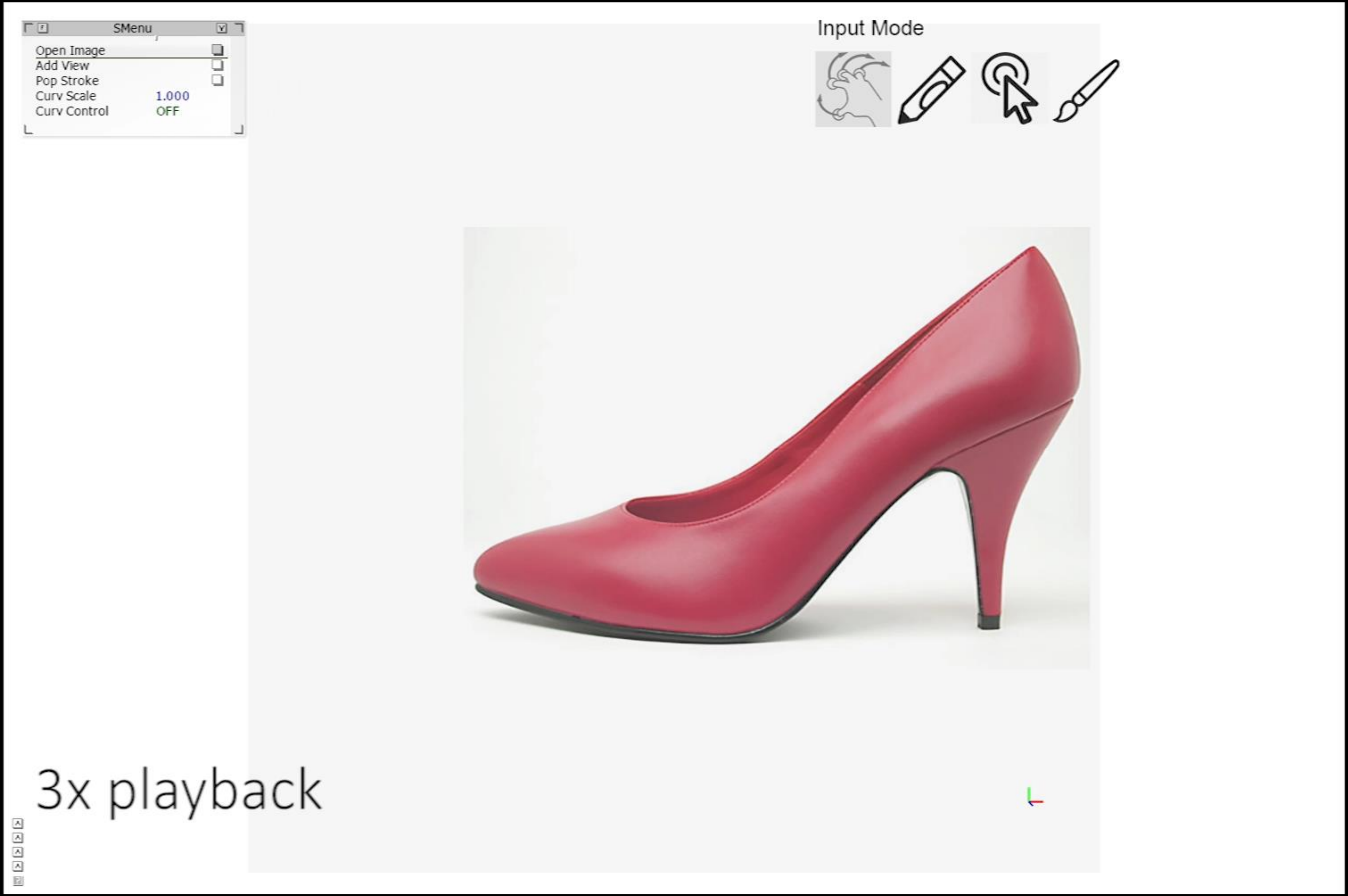
Limitation

- Self-occlusion or layered objects should use multi-view pipeline

Future Work

- Improve user interface
- Extract information from reference image
- Integrate with other tools

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Open Image
Add View
Pop Stroke
Curv Scale 1.000
Curv Control OFF
Input Mode
3x playback