Fundamentals and Applications of Sketch Processing

Part II: State-of-the-Art Research & Applications

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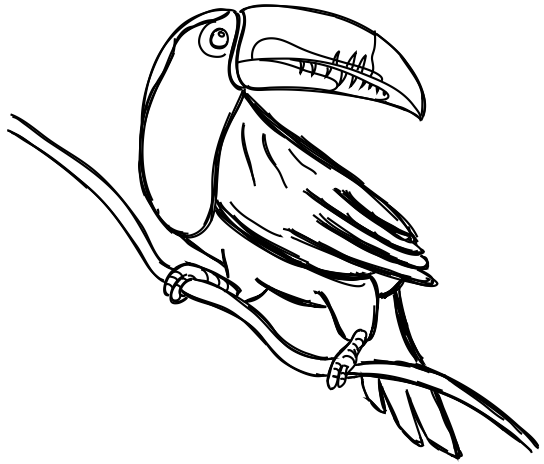
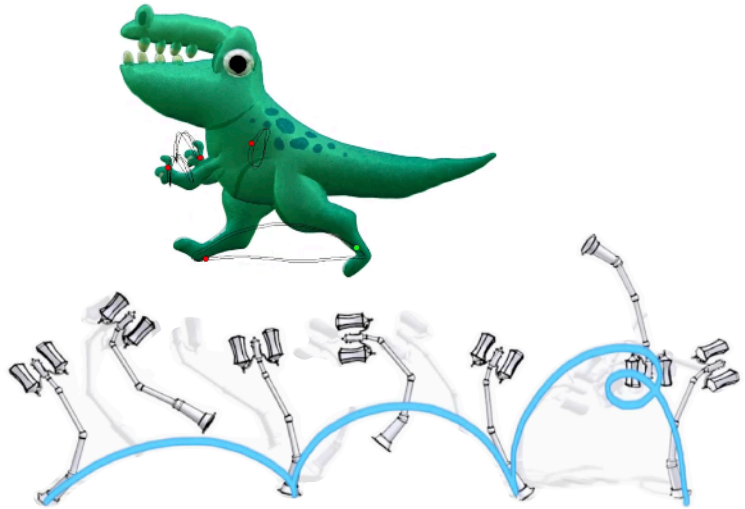
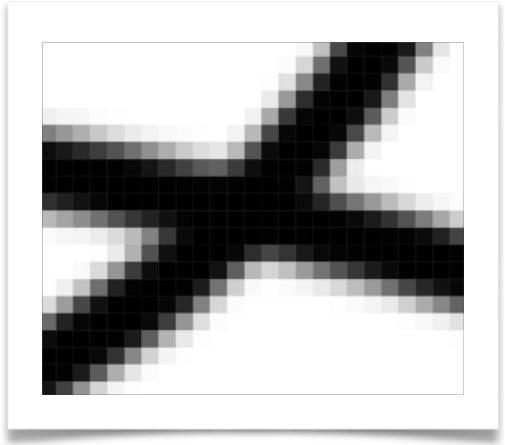
Tracking Samples



2D Sketches



Models & Animations



Raster Samples

3D Sketches

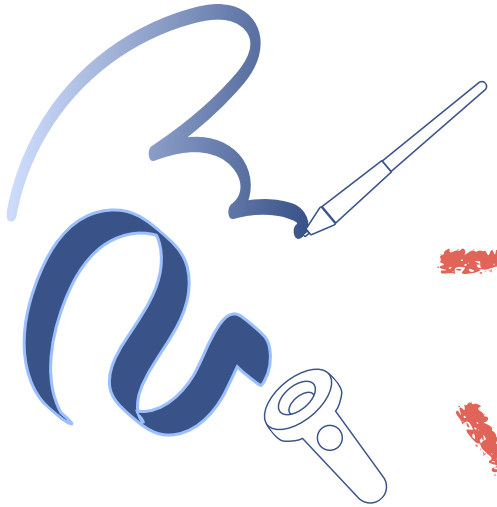
Data for Learning

Creation Process

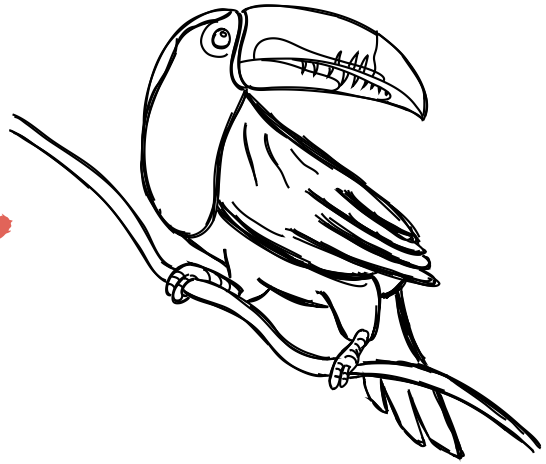
Full Reading List on GitHub

Aims for **broadness**.
Only covers representative papers.

For more:



Tracking Samples



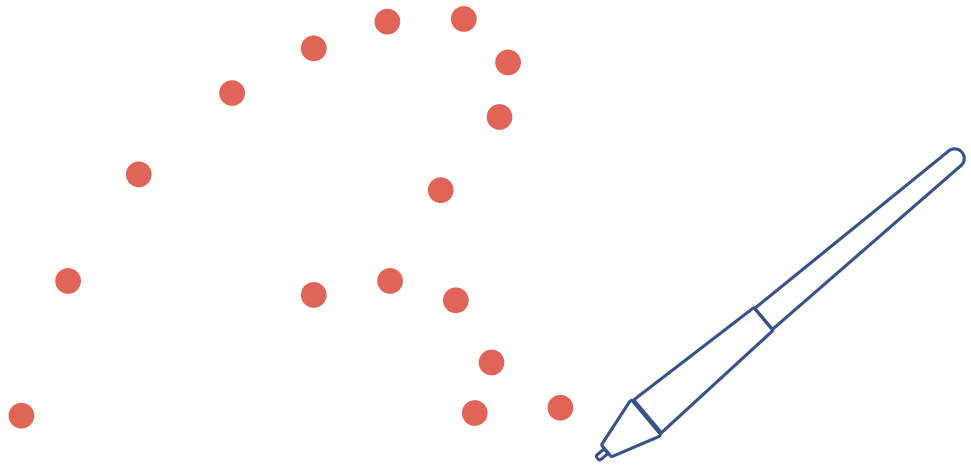
2D Sketches

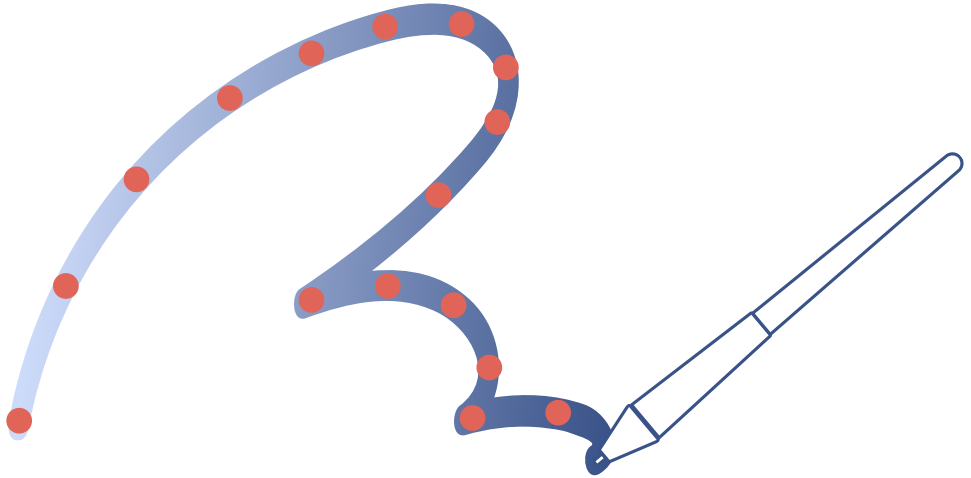
3D Sketches

Stroke Construction & Drawing Interface

Creation Process

2D Stroke Construction





2D sample sequence

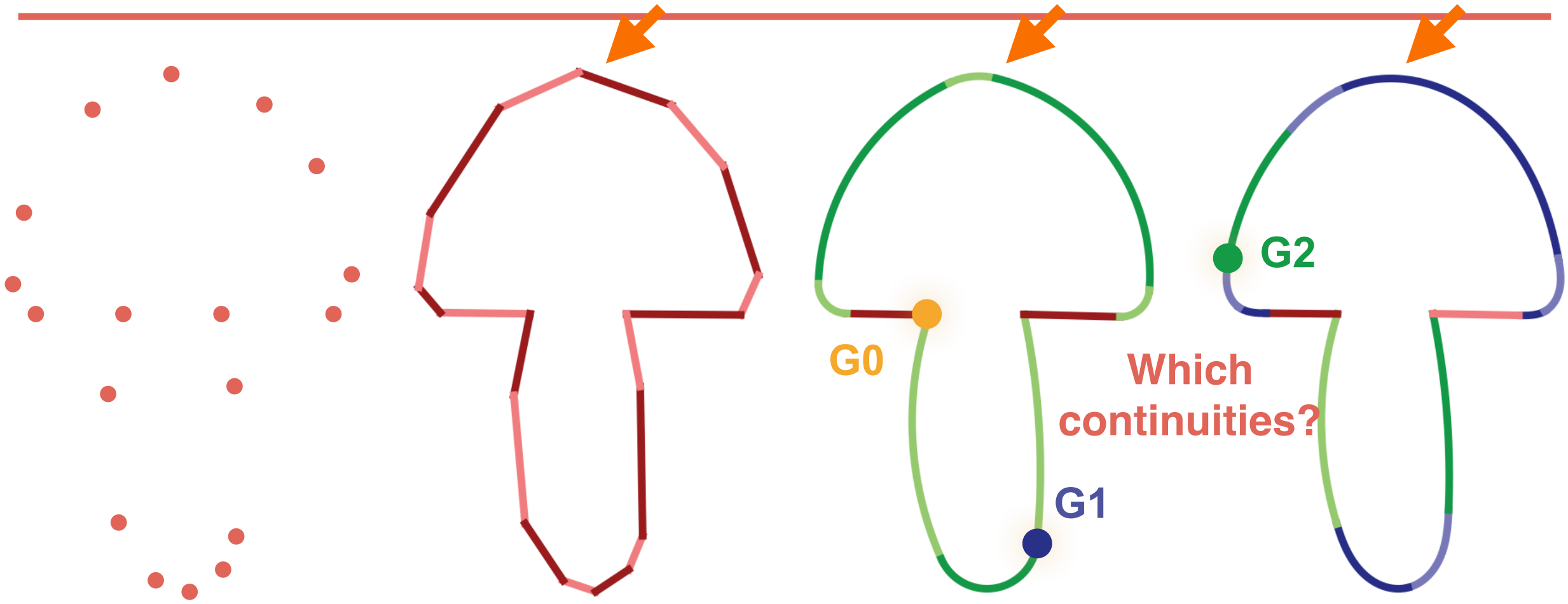
- (x, y)
- Timestamp
- Pressure
- Tilt

2D stroke representations

- Polylines
- Parametric curves
- Splines
- etc.

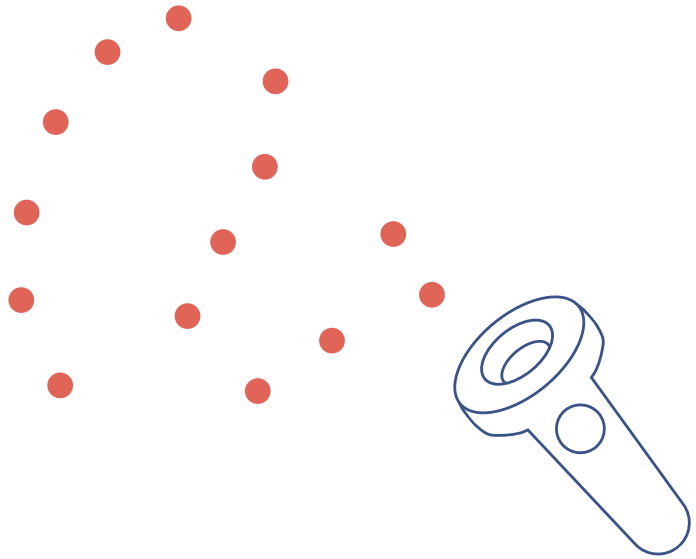
More than connecting dots

Stroke Construction



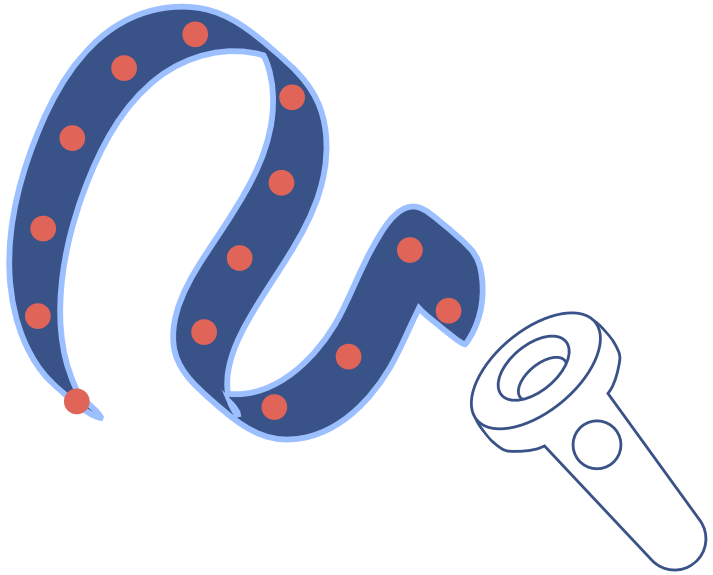
[Sketching clothoid **splines** using shortest paths (Baran et al) Eurographics 2010]

3D Stroke Construction



3D sample sequence

- (x, y, z)
- Timestamp
- Orientation

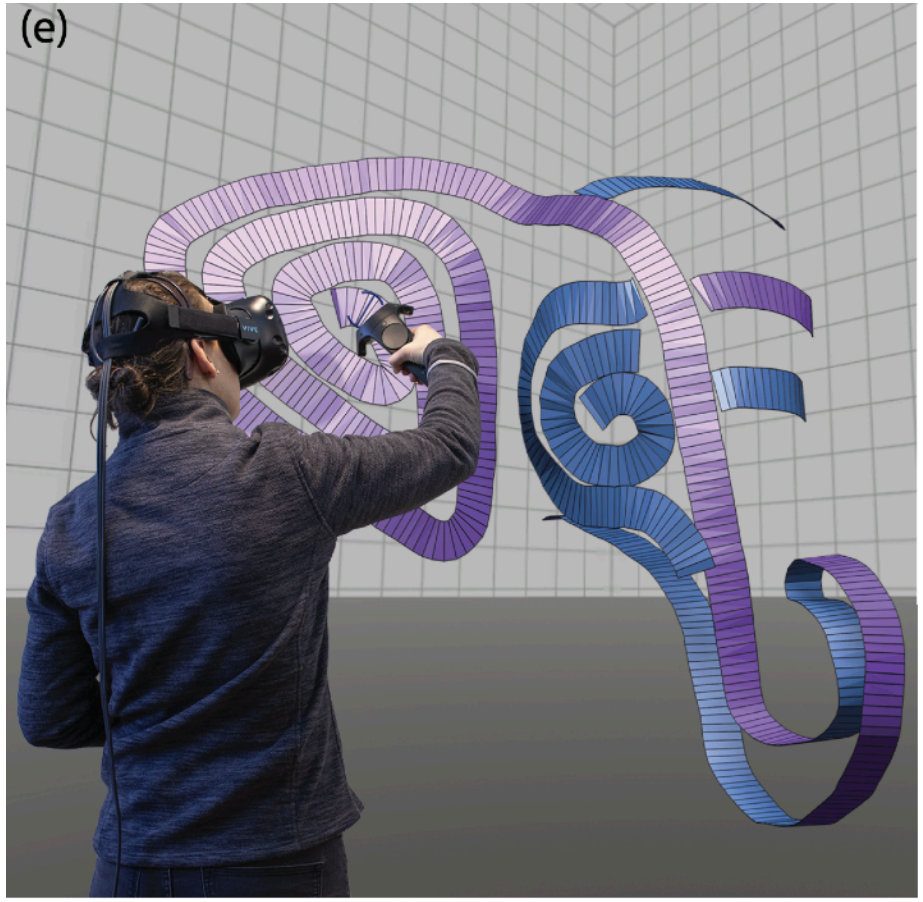


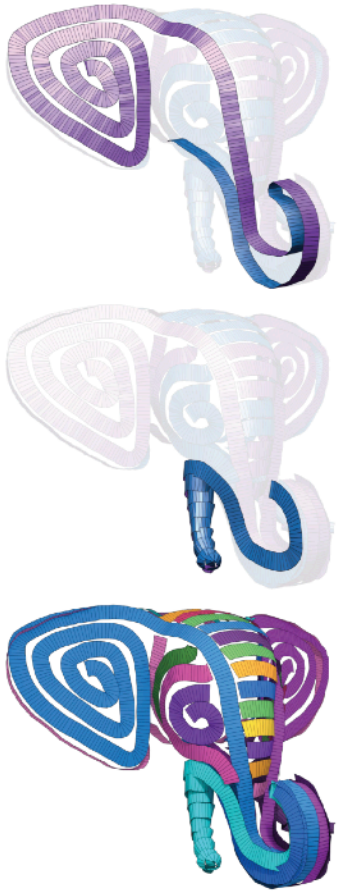
3D stroke representations

- Tubes
- Calligraphic curves (ribbons)
- etc.

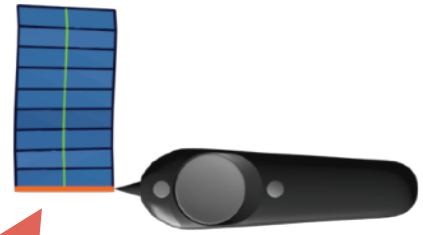
3D Ribbon Construction

Stroke Construction





Curved ribbon



Bent ribbon

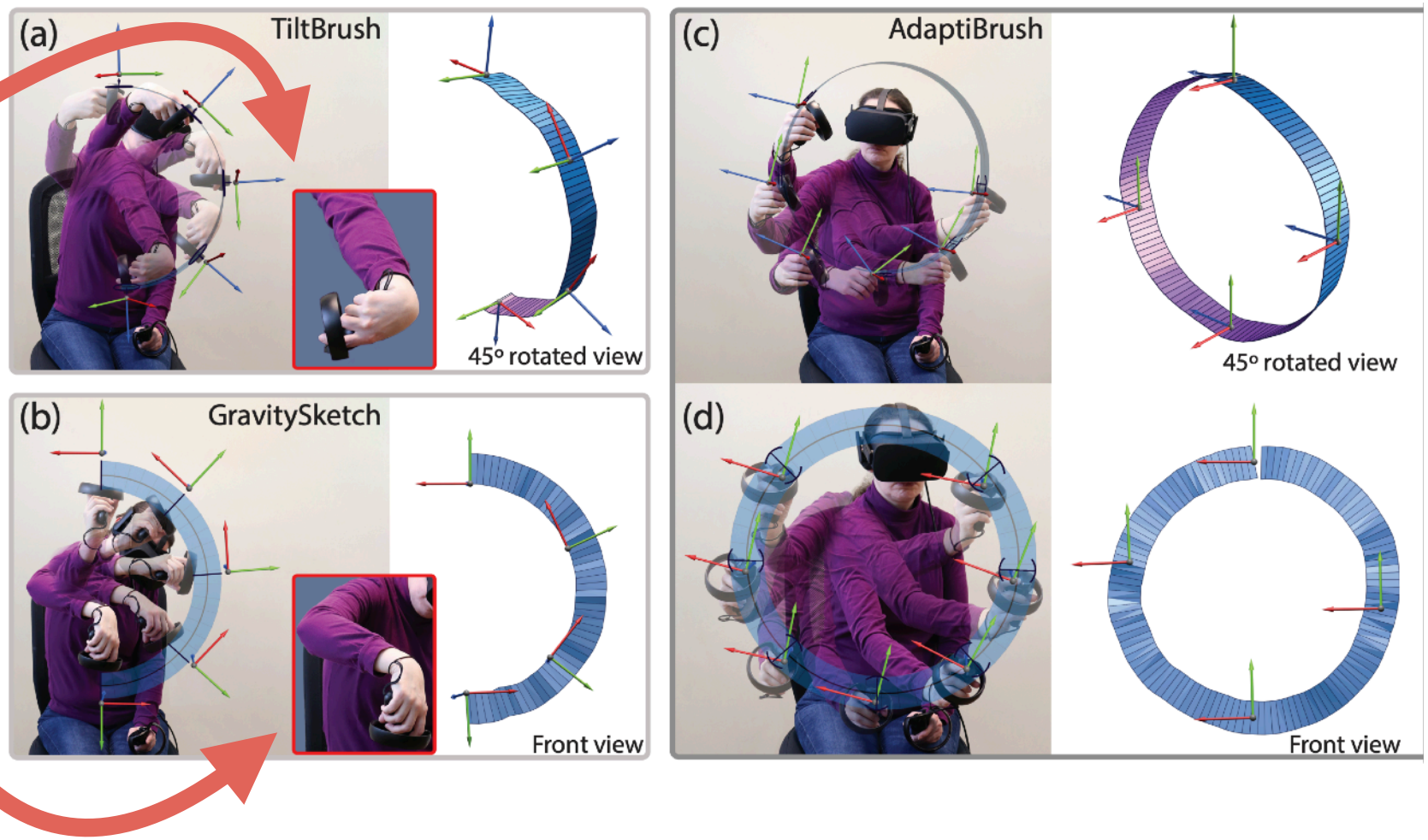
What ruling direction?

[AdaptiBrush (Rosales et al) SIGGRAPH 2021]

3D Ribbon Construction

Stroke Construction

Challenging gestures



[AdaptiBrush (Rosales et al) SIGGRAPH 2021]

2D Drawing Software

Classic/Desktop

Photoshop

Clip Studio Paint

Krita

Cartoon

Harmony

Animate

Touchable Display

Procreate

Fresco

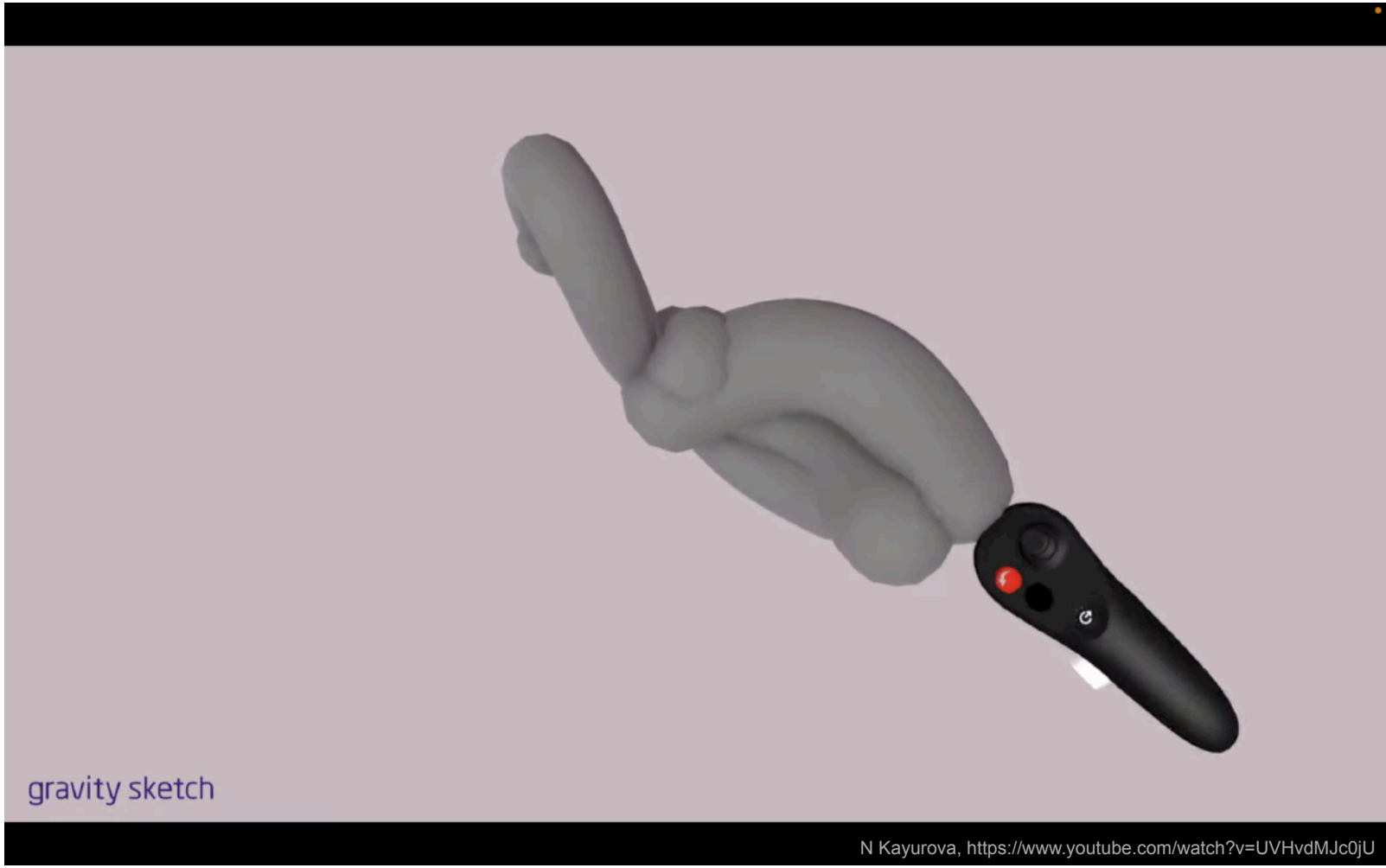
Painting Simulator

3D Sketching Interface

gravity sketch™

shapes xr

Tilt Brush by Google



N Kayurova, https://www.youtube.com/watch?v=UVHvdMJc0jU

3D Sketching Interface

gravity sketch™

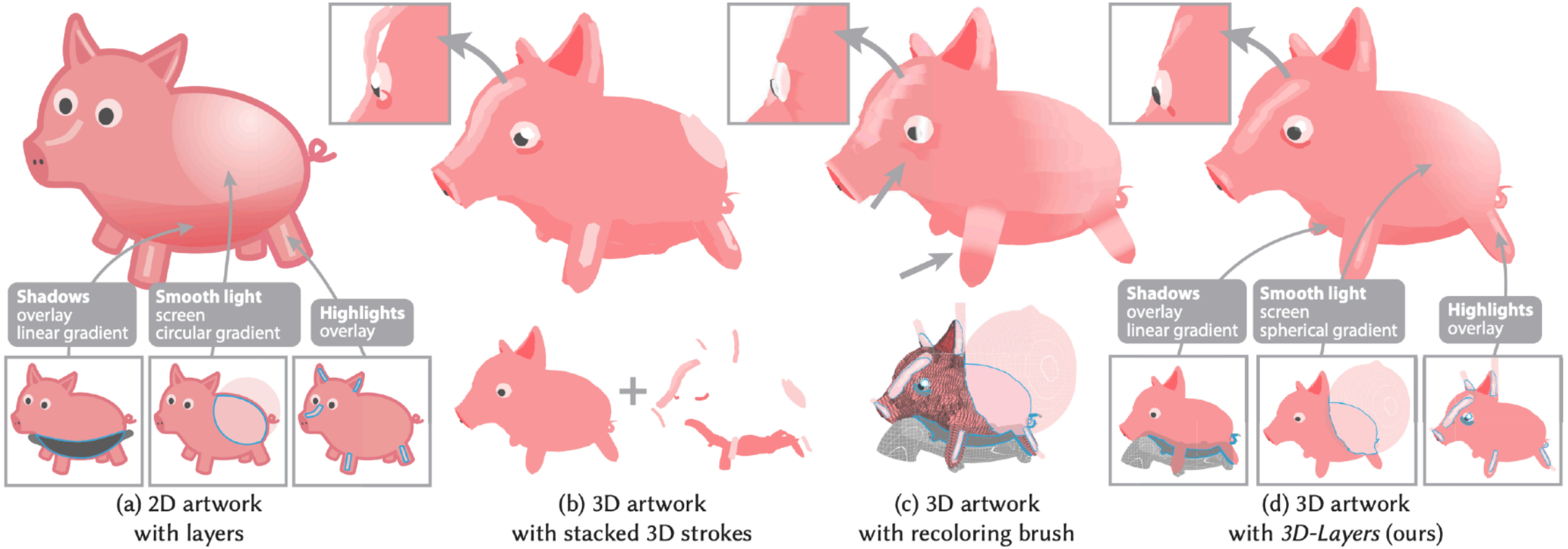
Tilt Brush by Google

N Kayurova, https://www.youtube.com/watch?v=UVHvdMJc0jU

Open problems…

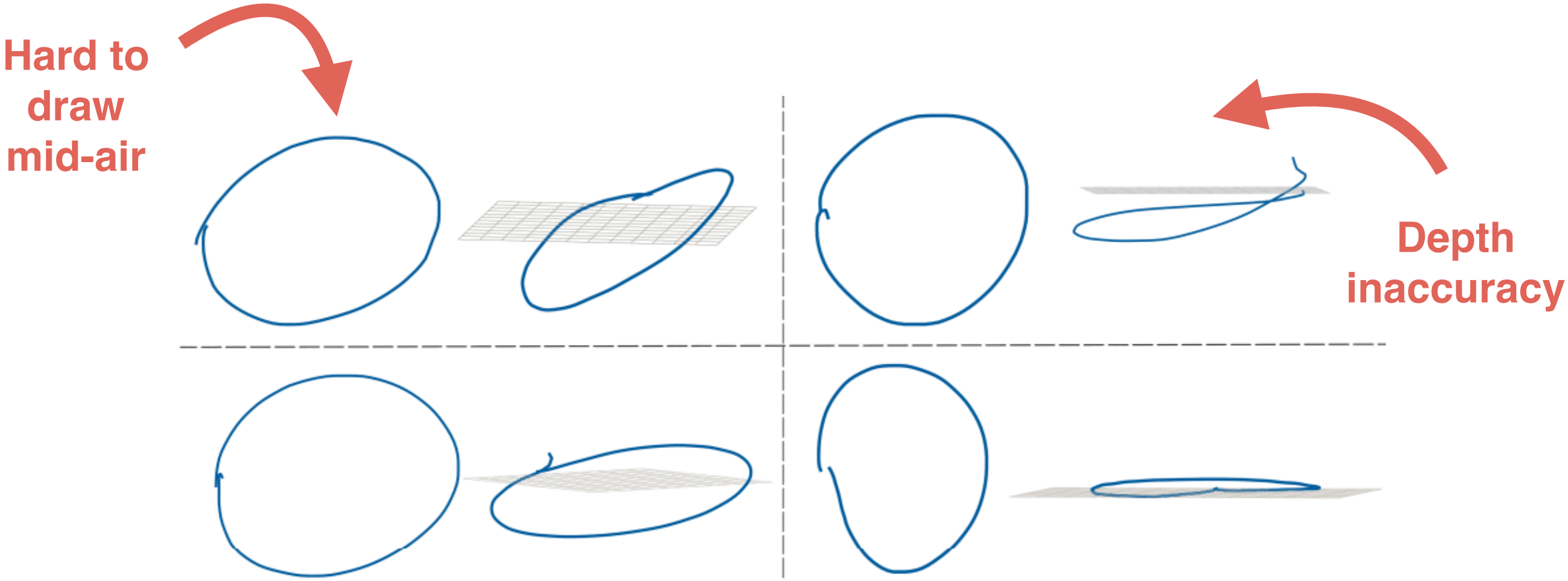
3D Sketching Interface: Analogy to 2D Drawing

Drawing Interface



[3D-Layers (Yu et al.) **SIGGRAPH 2024**]

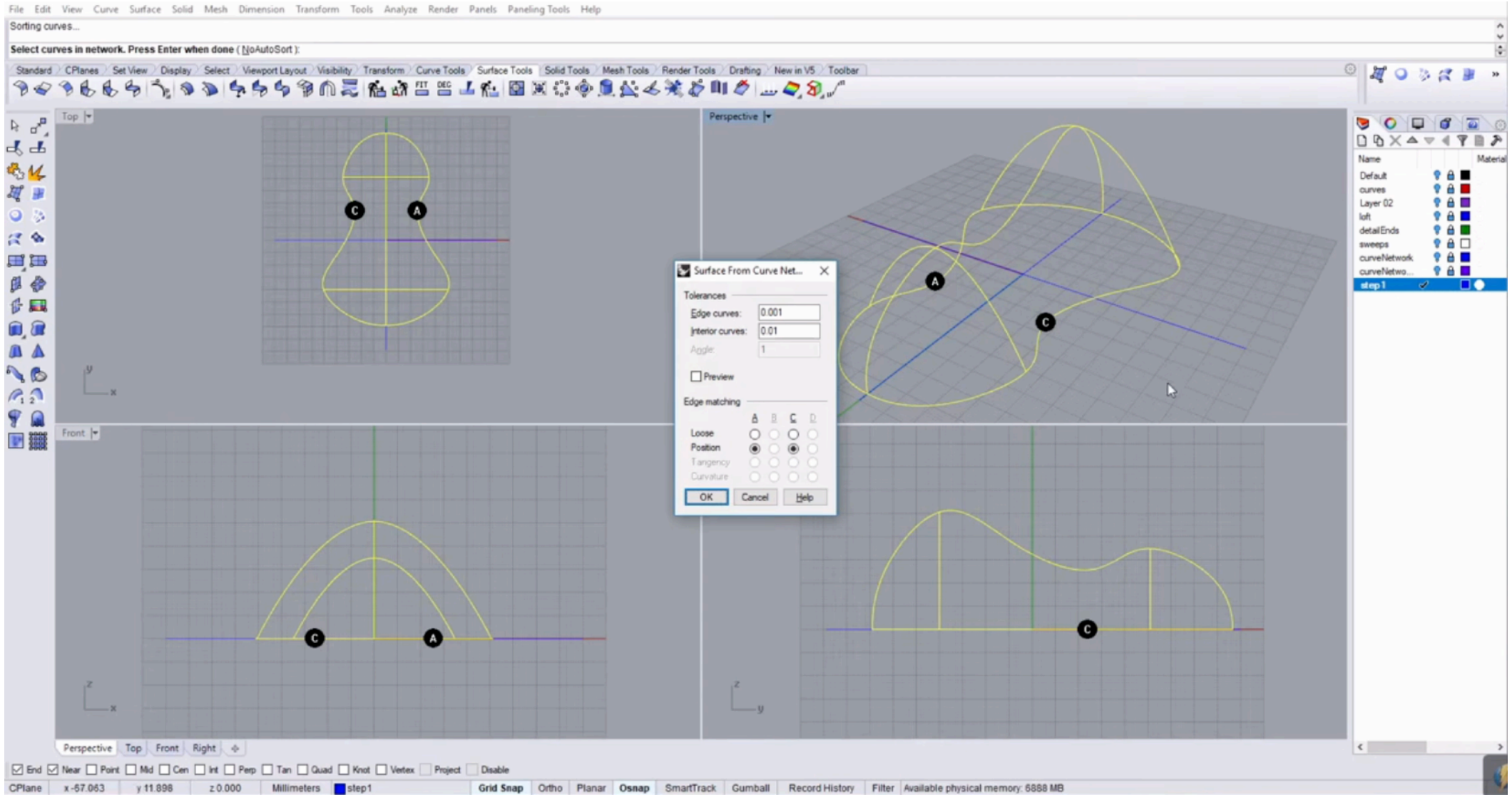
3D Sketching Challenges



[Experimental Evaluation of Sketching on Surfaces in VR (Arora et al.) CHI 2017]

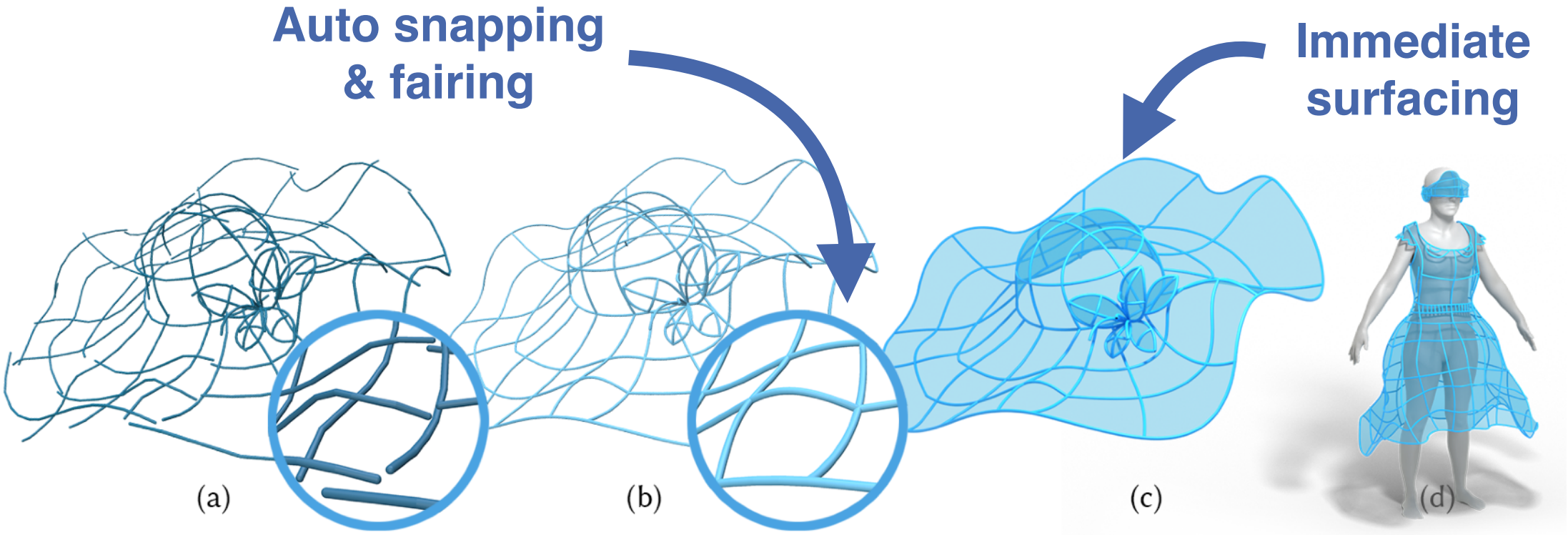
3D Sketching Interface: Domain-Specific

Drawing Interface



3D Sketching Interface: Domain-Specific

Drawing Interface



[Cassie (Yu et al.) CHI 2021]

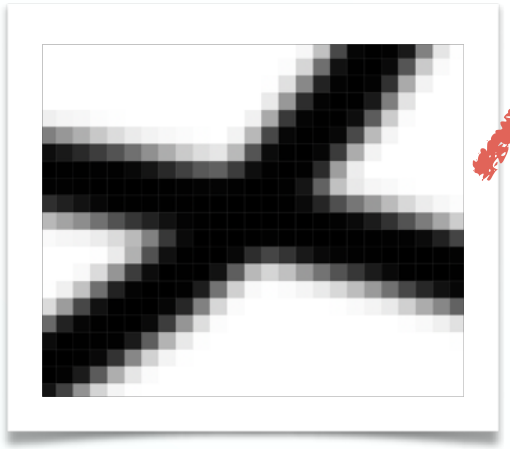
Takeaways

- 2D software is mature with a fixed set of features while 3D hardware, interface and practice are still developing.
- Real-time response for sketching & drawing interface.
- Useful tool for your 2D sketch processing toolbox:
  - https://github.com/ilya-baran-personal/cornucopia-lib

More papers:

Tracking Samples

2D Sketches

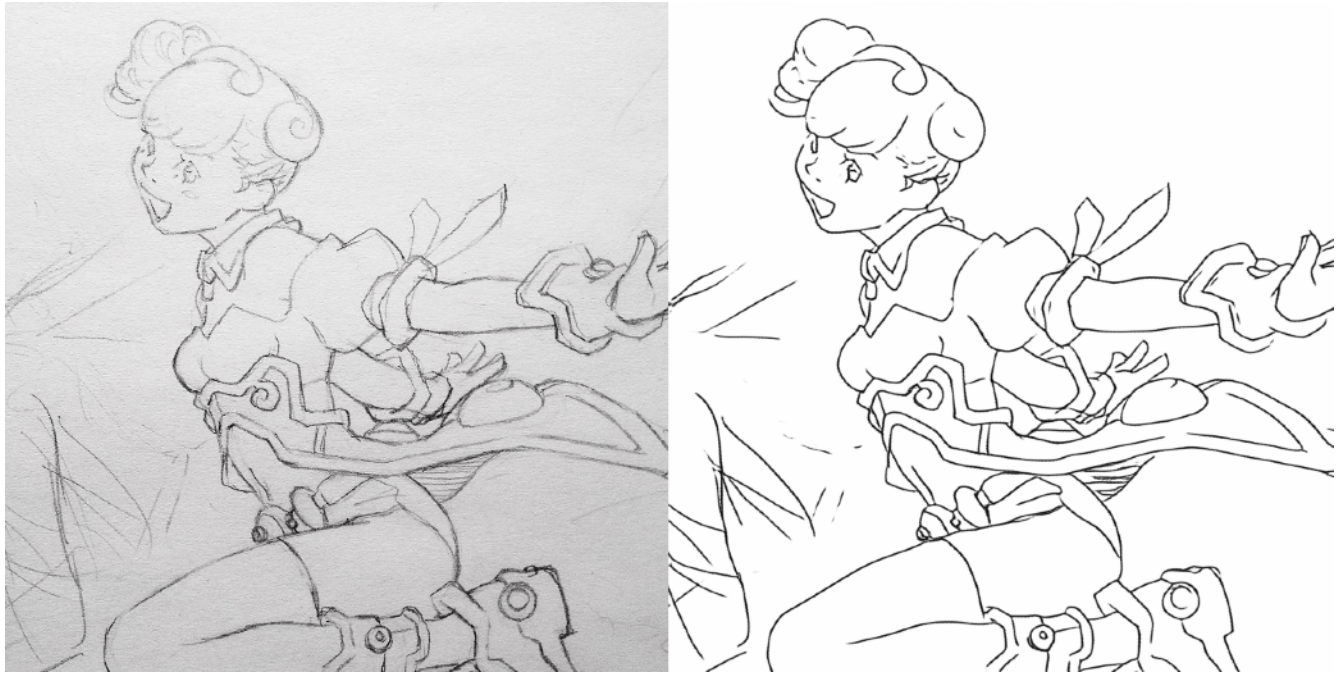


Raster Samples

Vectorization

Creation Process

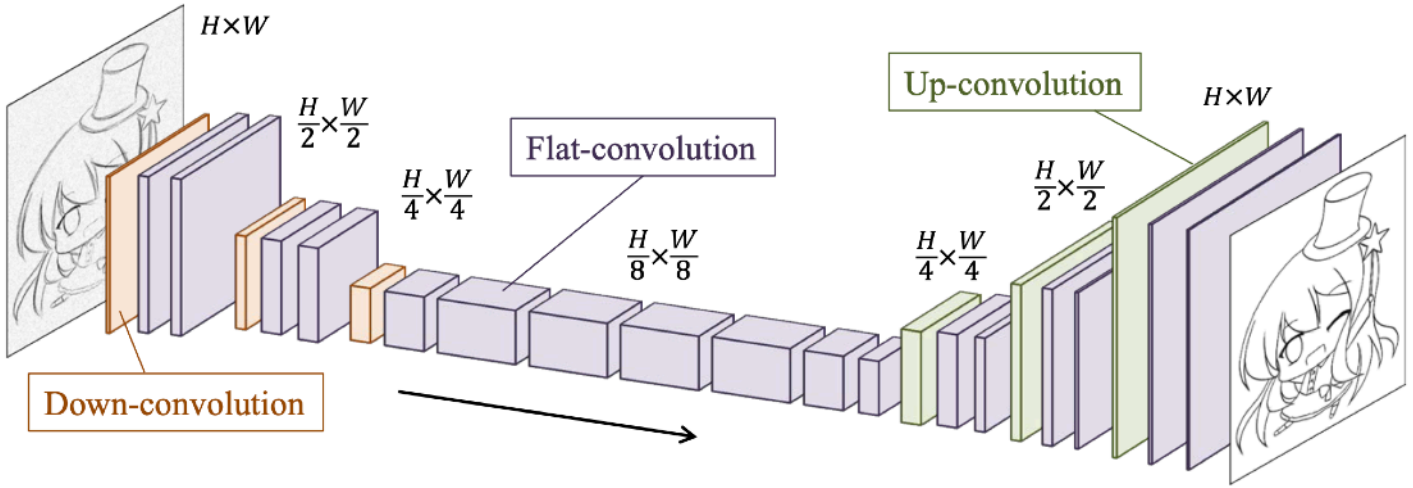
Working with Raster Sketches

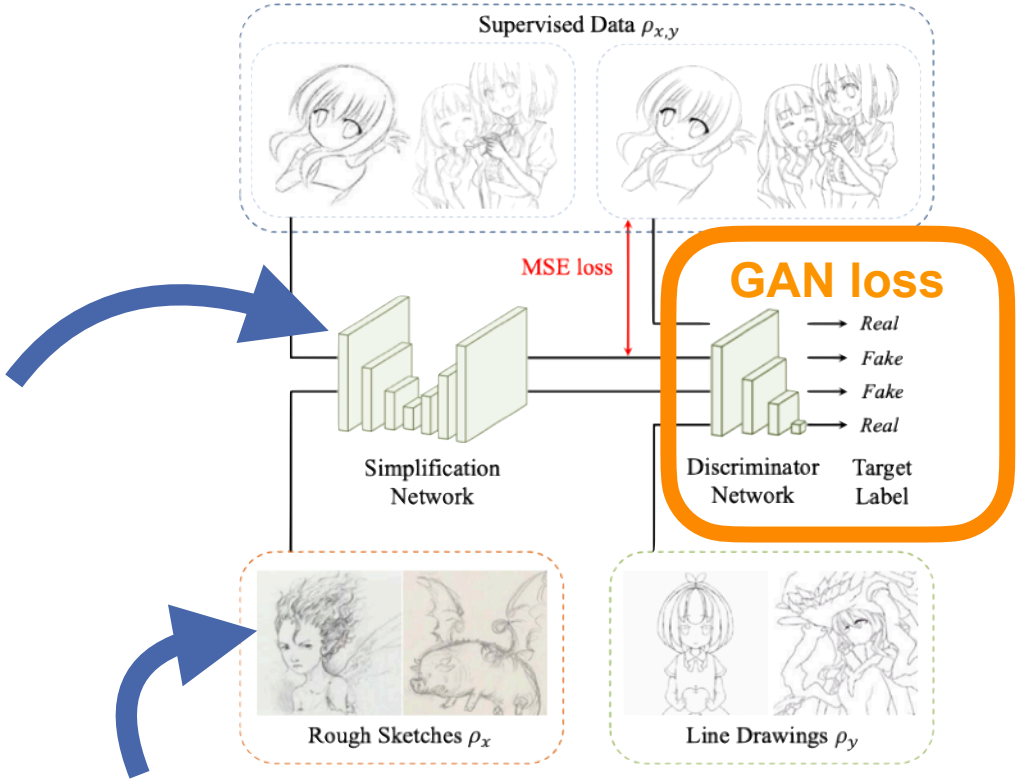


Raster rough sketch → Raster clean sketch

Raster Sketch Cleanup

Vectorization





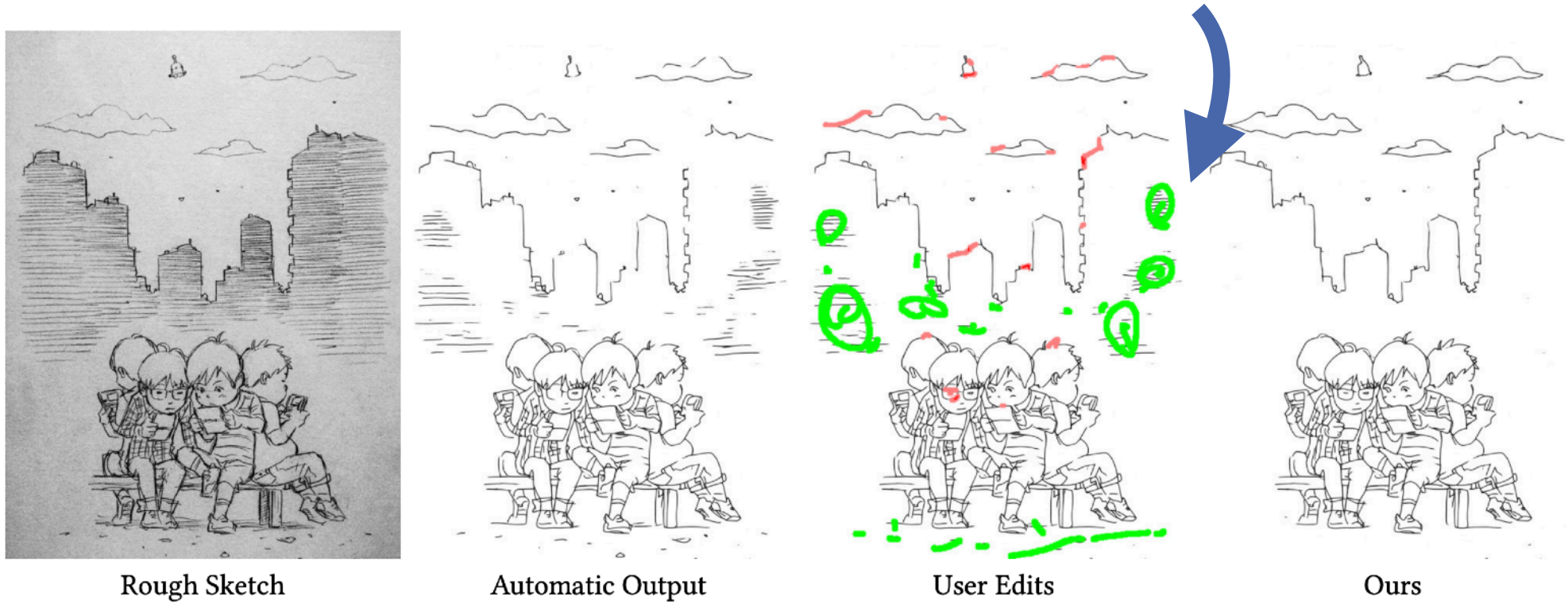
Unlabeled data

[Learning to Simplify (Simo-Serra et al) SIGGRAPH 2016]

[Mastering Sketching (Simo-Serra et al) SIGGRAPH 2018]

Raster Sketch Cleanup

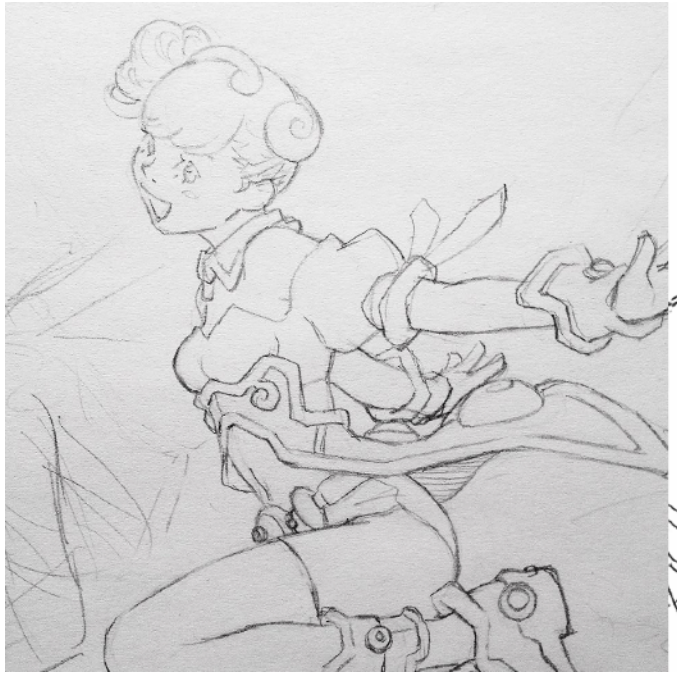
Vectorization



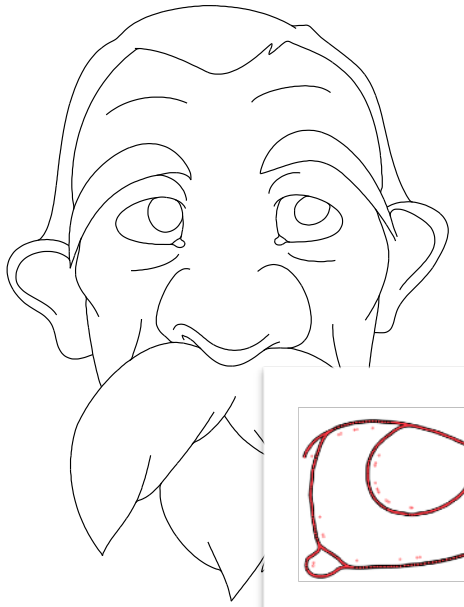
[Smart Inker (Simo-Serra et al.) SIGGRAPH 2018]

Working with Raster Sketches

Vectorization

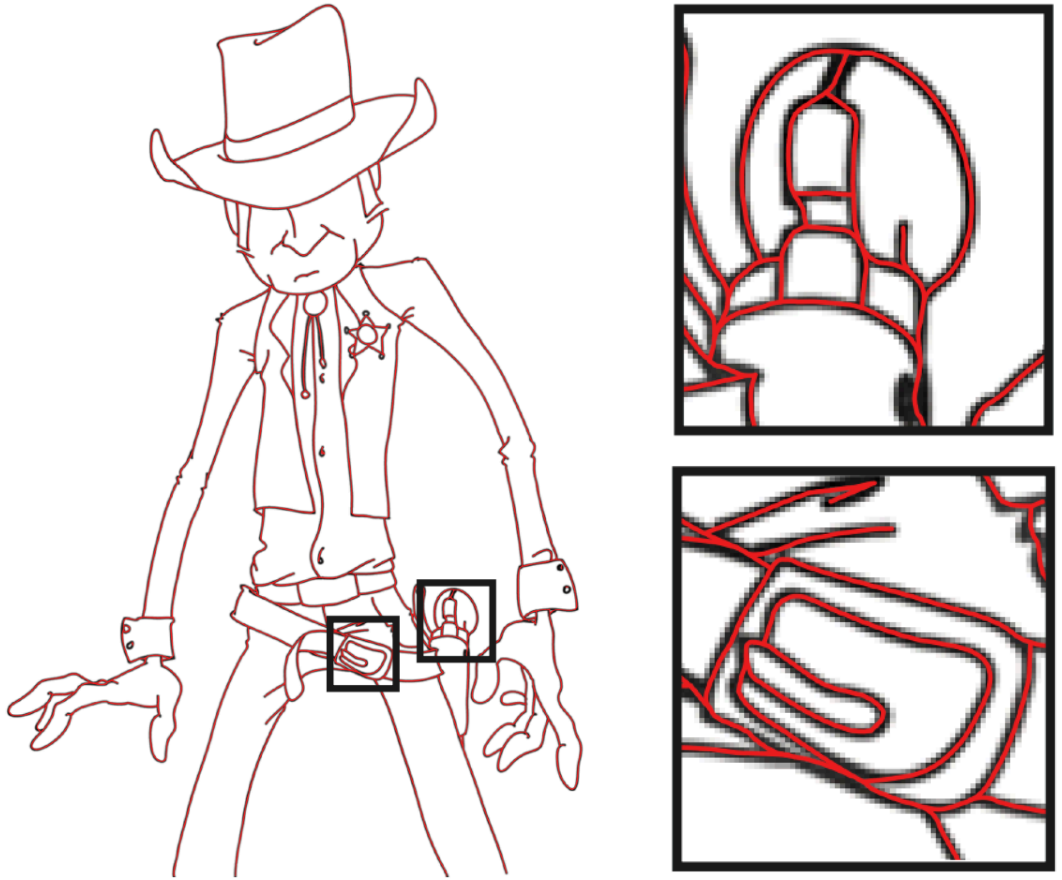


Raster rough sketch → Raster clean sketch



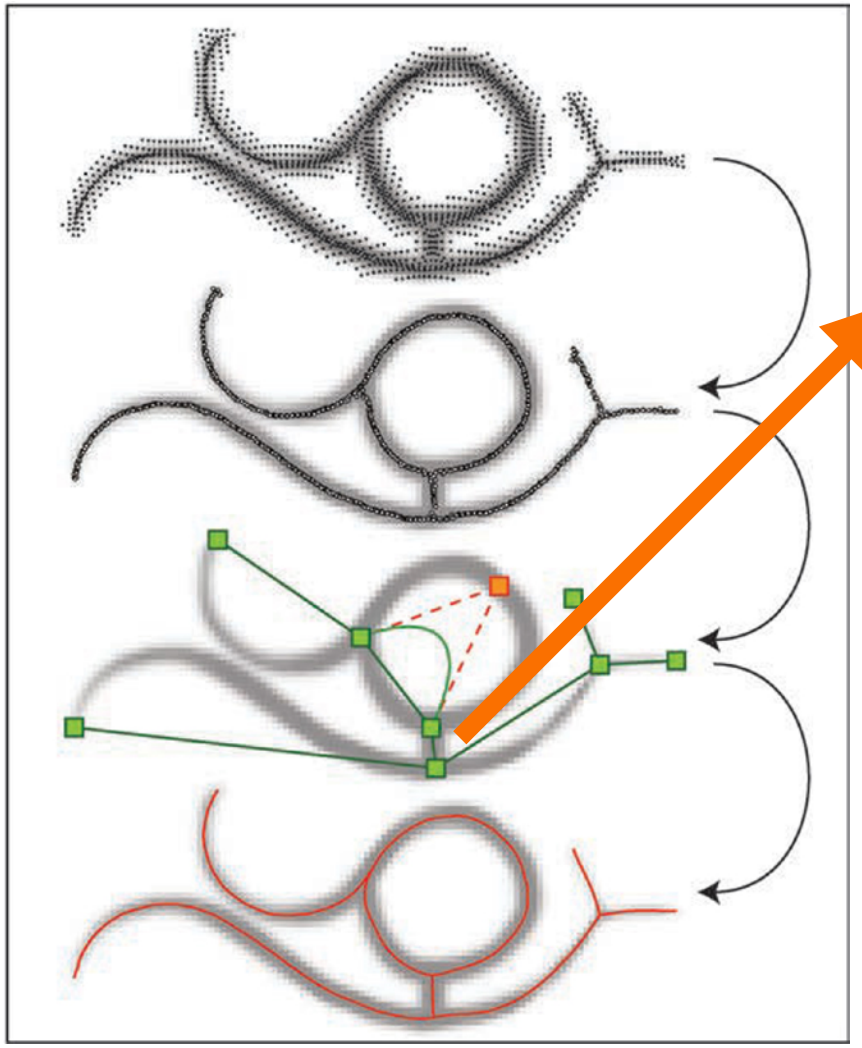
Raster sketch → Vector sketch

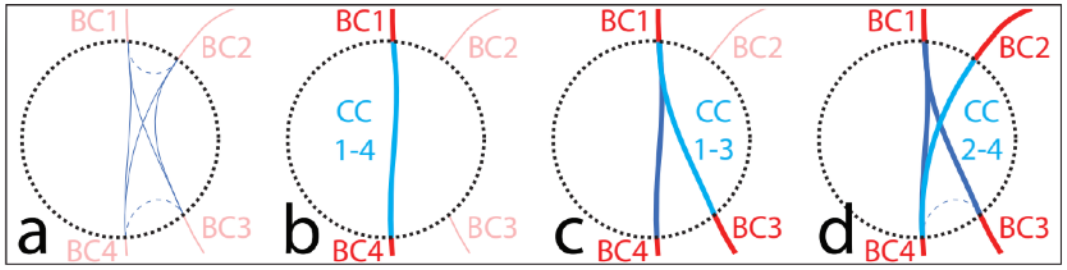
Vectorize Sketches as Graphs



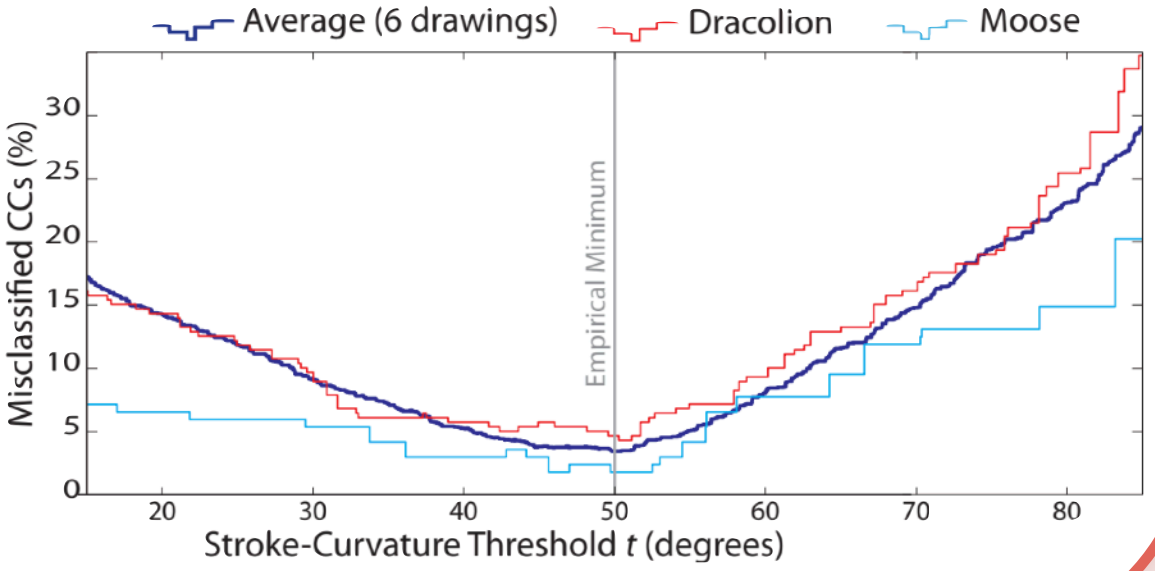
[Topology-driven vectorization of **clean** line drawings (Noris et al.) SIGGRAPH 2013]

Vectorize Sketches as Graphs



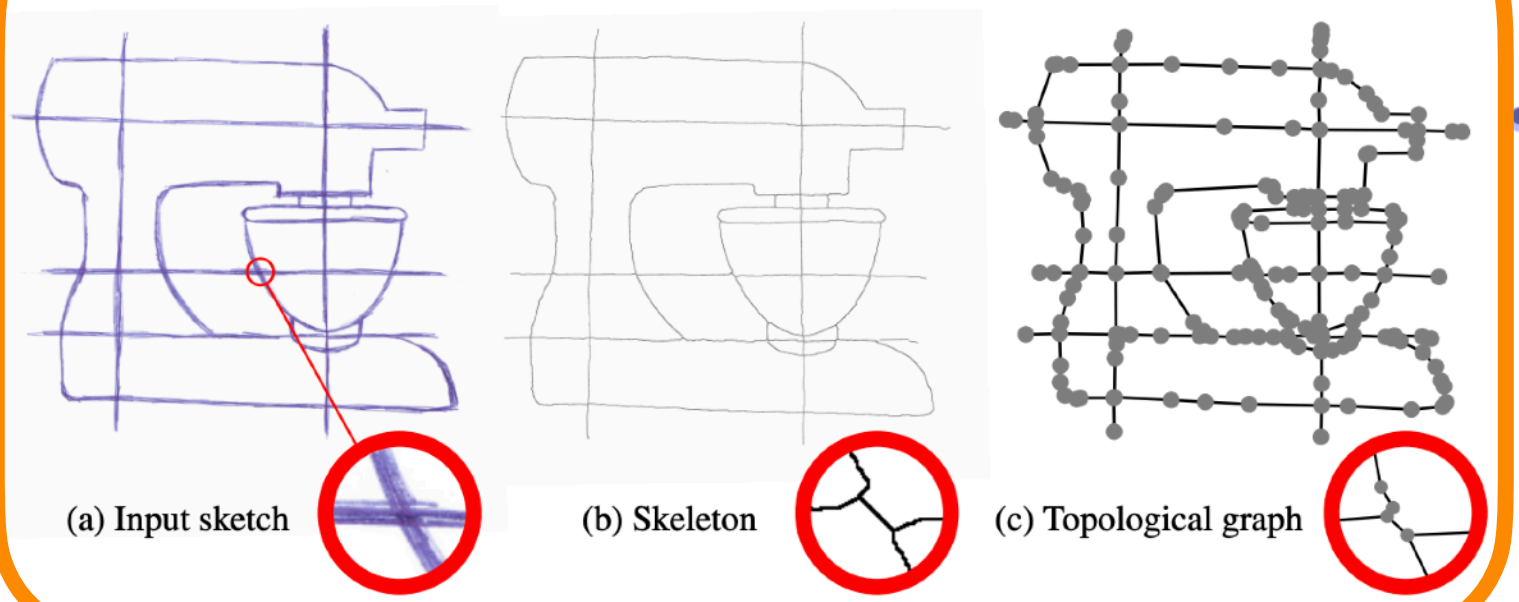


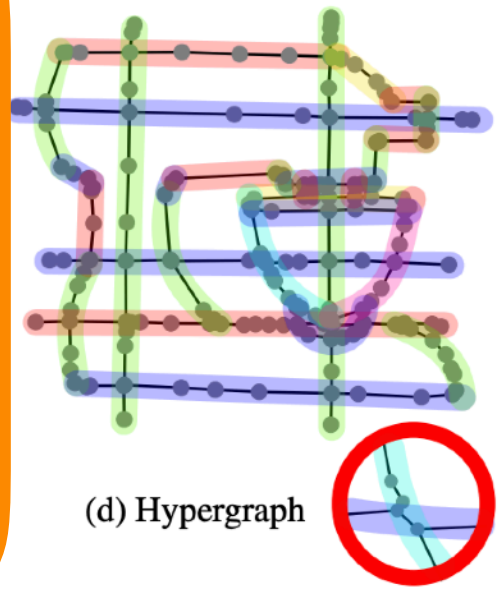
Data-based thresholding

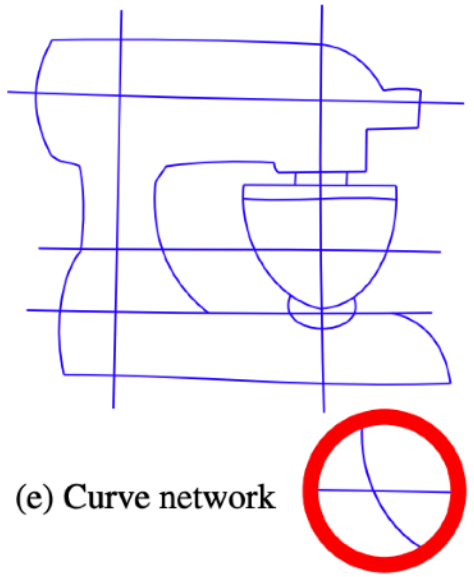


Vectorize Sketches as Graphs

Similar to [Noris 2013]

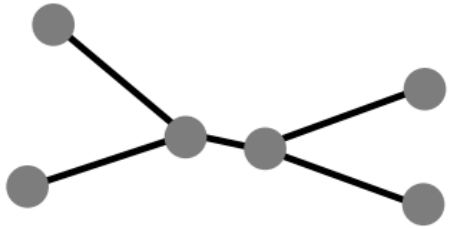




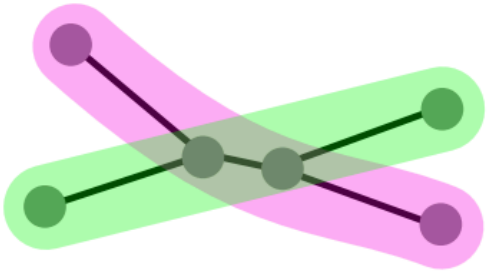


[Fidelity vs. Simplicity (Favreau et al.) SIGGRAPH 2016]

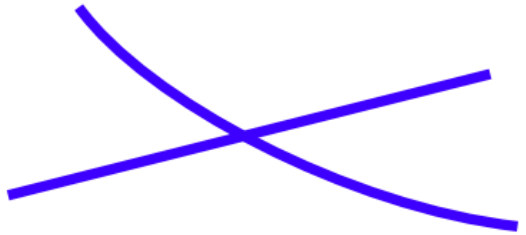
Vectorize Sketches as Graphs



(a) Topological graph



(b) Hypergraph



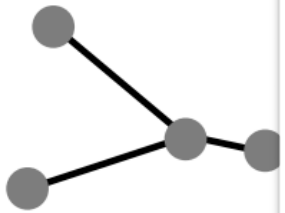
(c) Reconstructed curves

$$U(\mathbf{x}) = (1-\lambda)U_{\text{fidelity}}(\mathbf{x}) + \lambda U_{\text{simplicity}}(\mathbf{x})$$

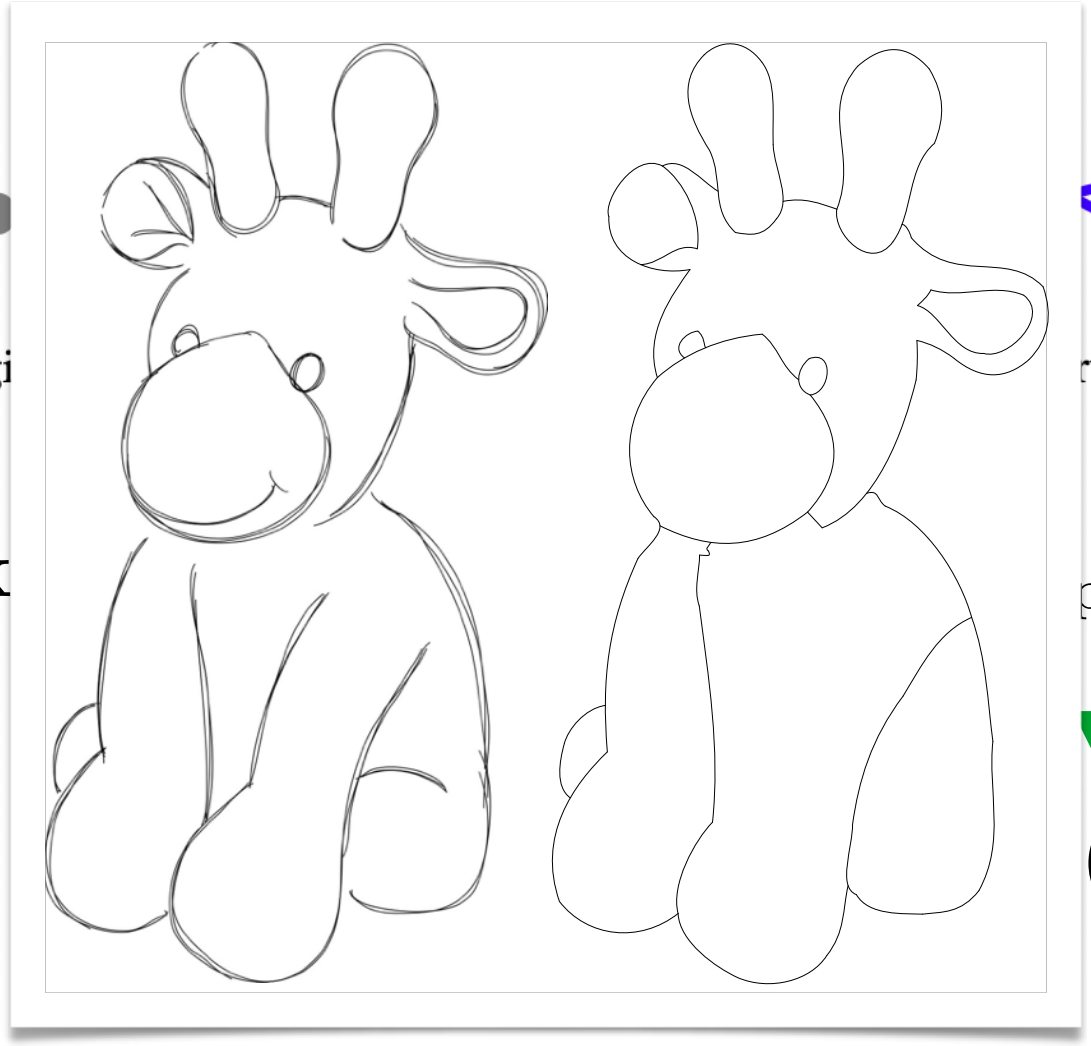
$$U_{\text{fidelity}}(\mathbf{x}) = \sum_{h \in H_{\mathbf{x}}} \epsilon(h)$$

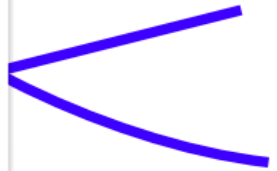
$$U_{\text{simplicity}}(\mathbf{x}) = \sum_{h \in H_{\mathbf{x}}} \left(1 + \mu \text{Deg}(B^h_{\mathbf{x}})\right)$$

Vectorize Sketches as Graphs



(a) Topologi





ructed curves

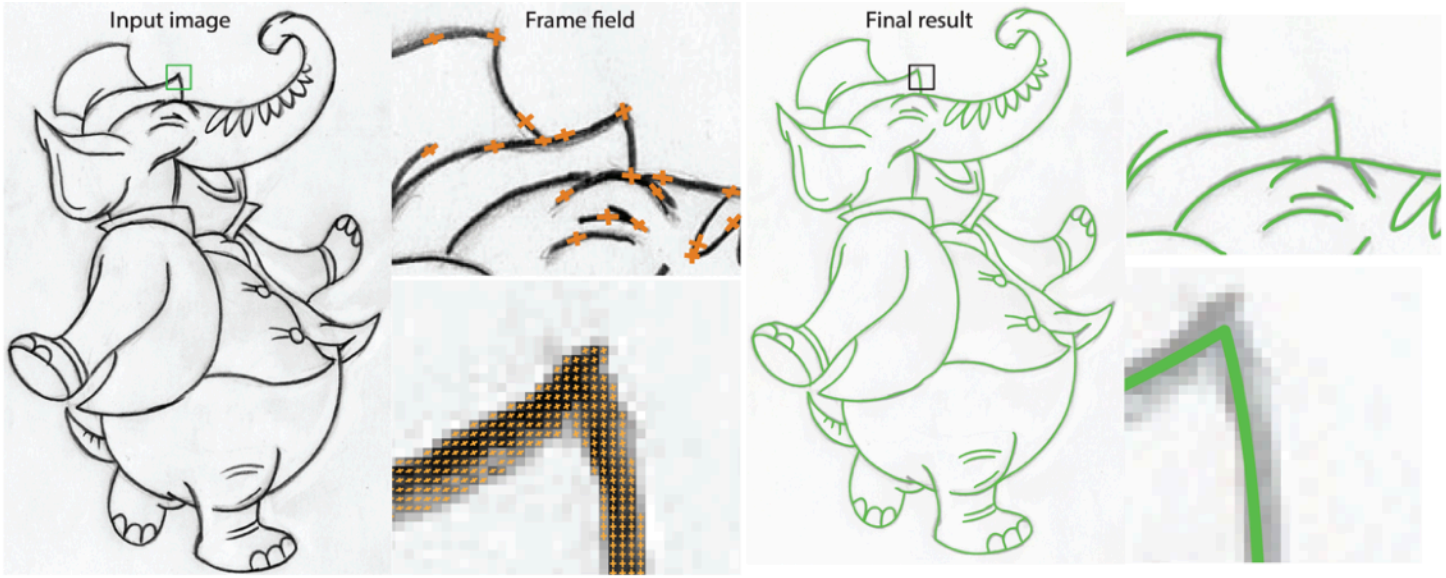
$$U(\mathbf{x}$$

$$\text{plicity}(\mathbf{x})$$

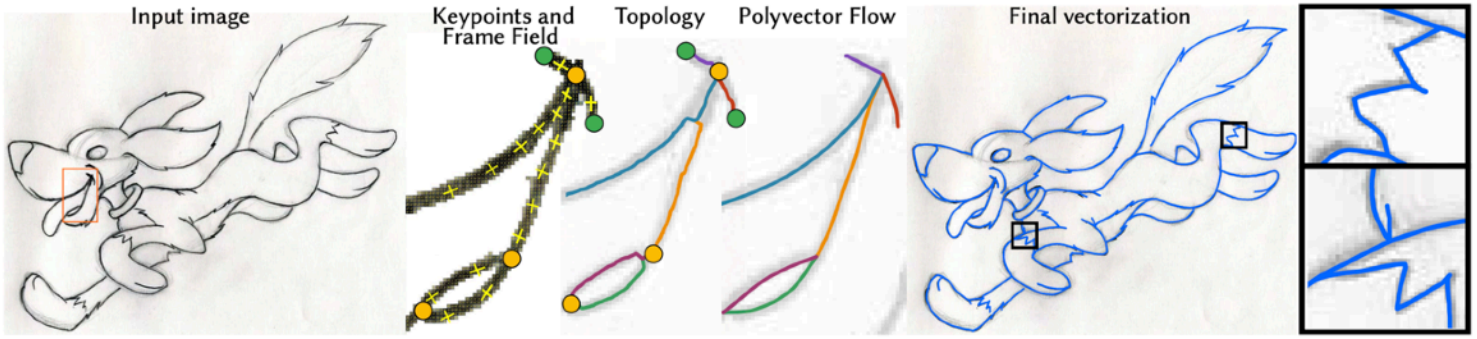
$$U_{\text{fidelity}}(\mathbf{x})$$

$$\left(1+\mu\text{Deg}(B^h_{\mathbf{x}})\right)$$

Vectorize Sketches via Frame Fields



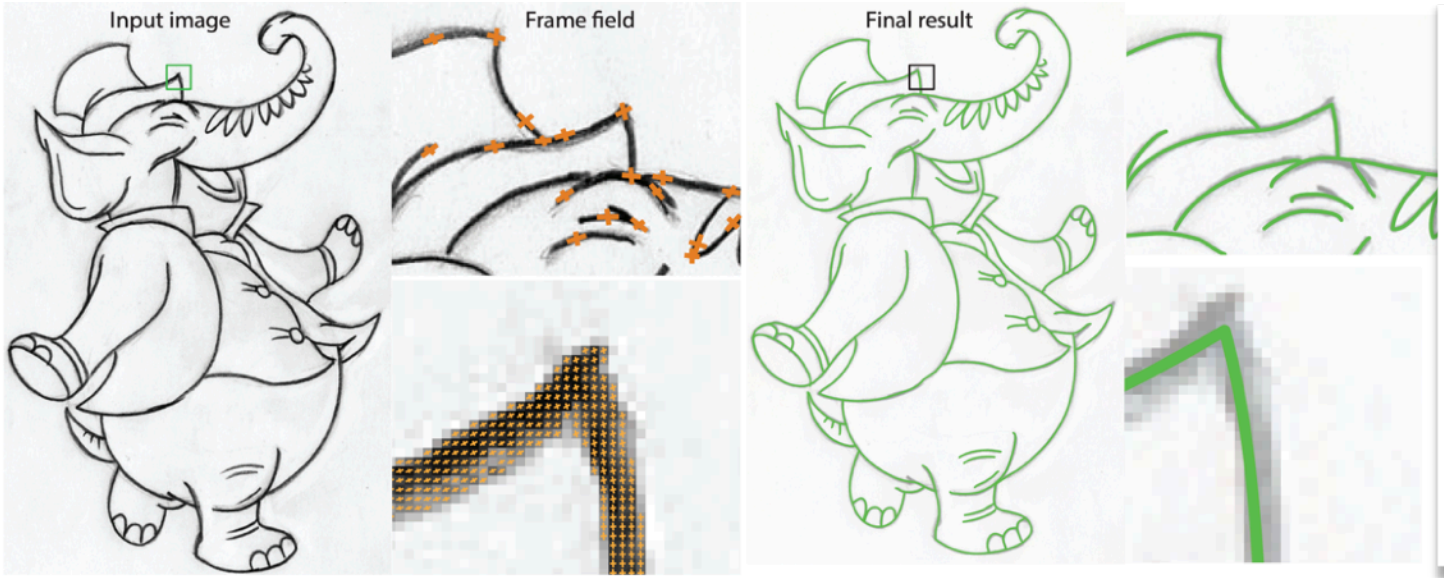
[Vectorization via PolyVector fields (Bessmeltsev and Solomon) SIGGRAPH 2019]

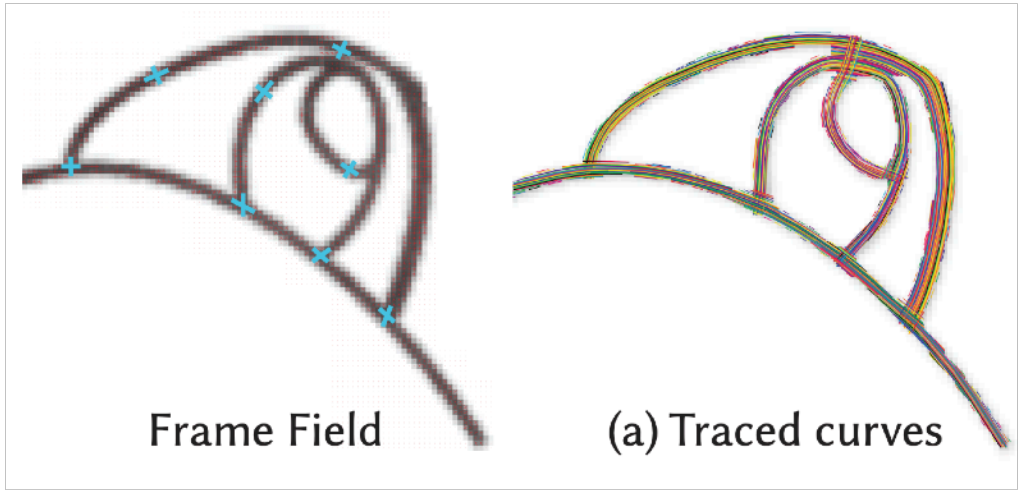


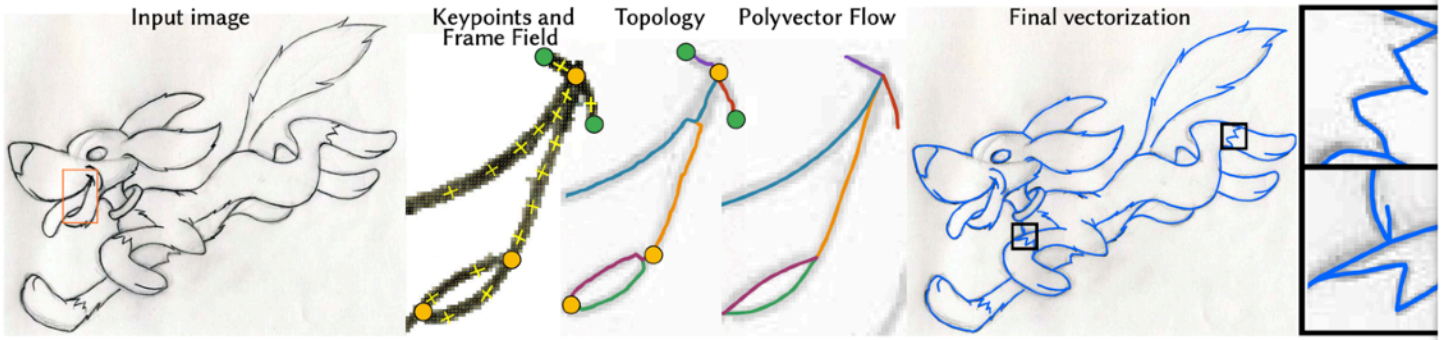
[Keypoint-driven vectorization (Puhachov et al.) SIGGRAPH 2021]

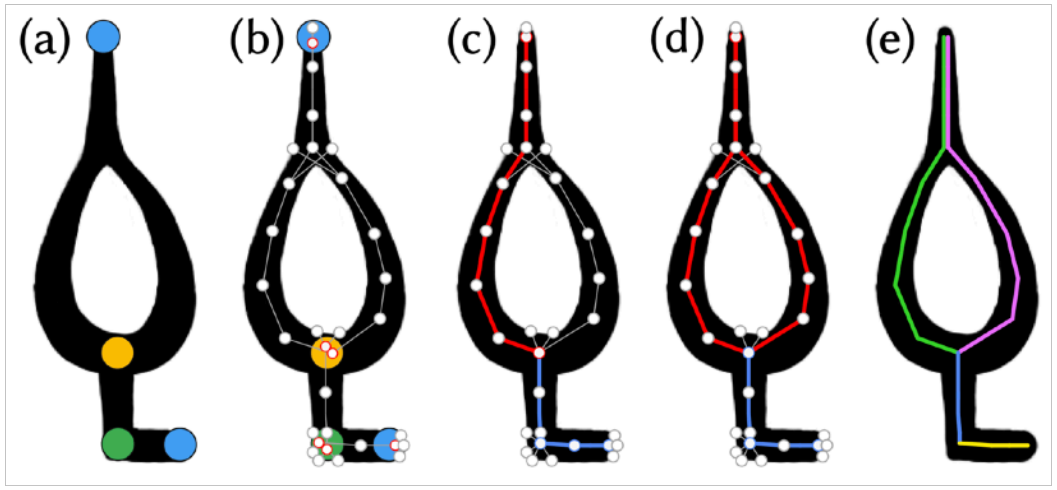
Vectorize Sketches via Frame Fields

Vectorization





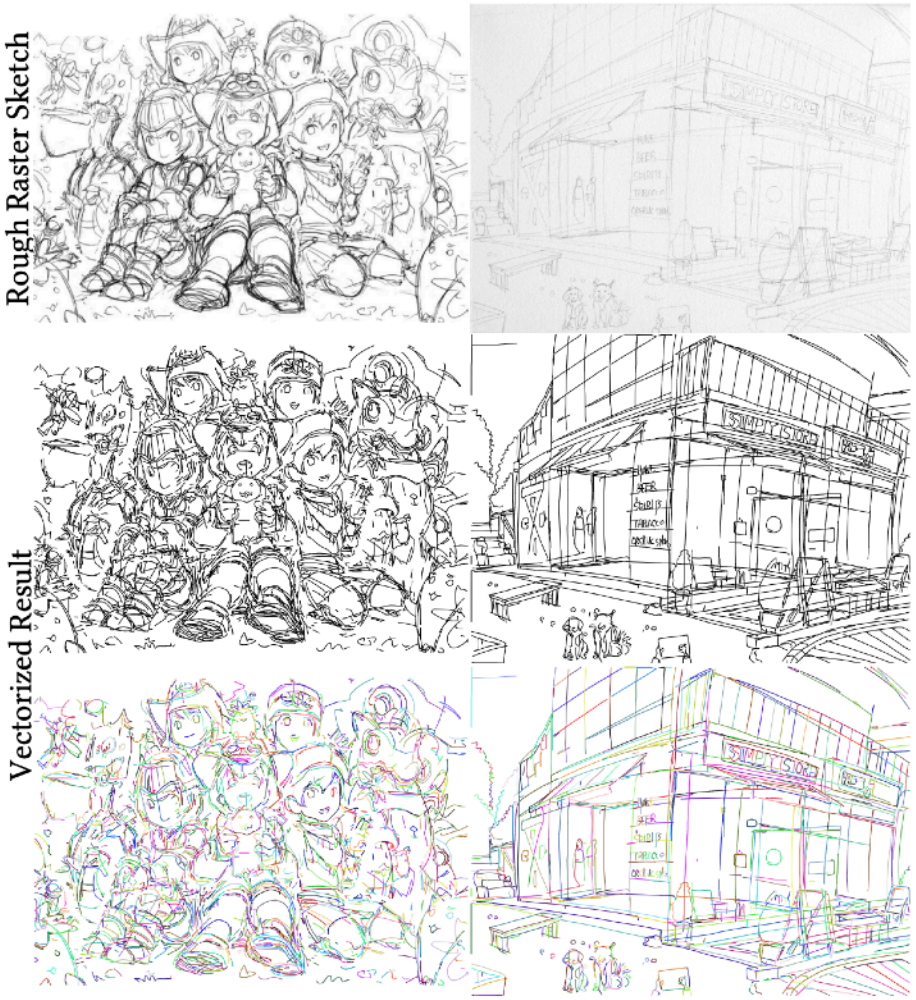


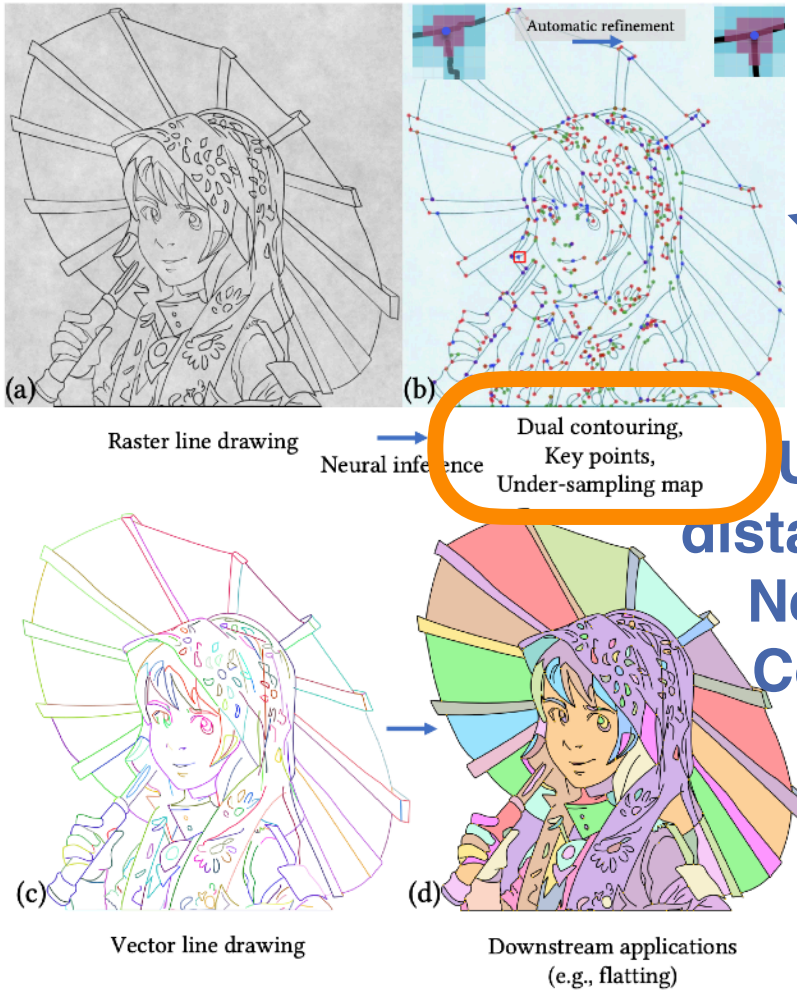


Vectorize Sketches via Dual Contouring

Vectorization

Complicated sketches in reasonable time

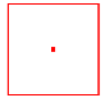




Unsigned distance fields + Neural Dual Contouring

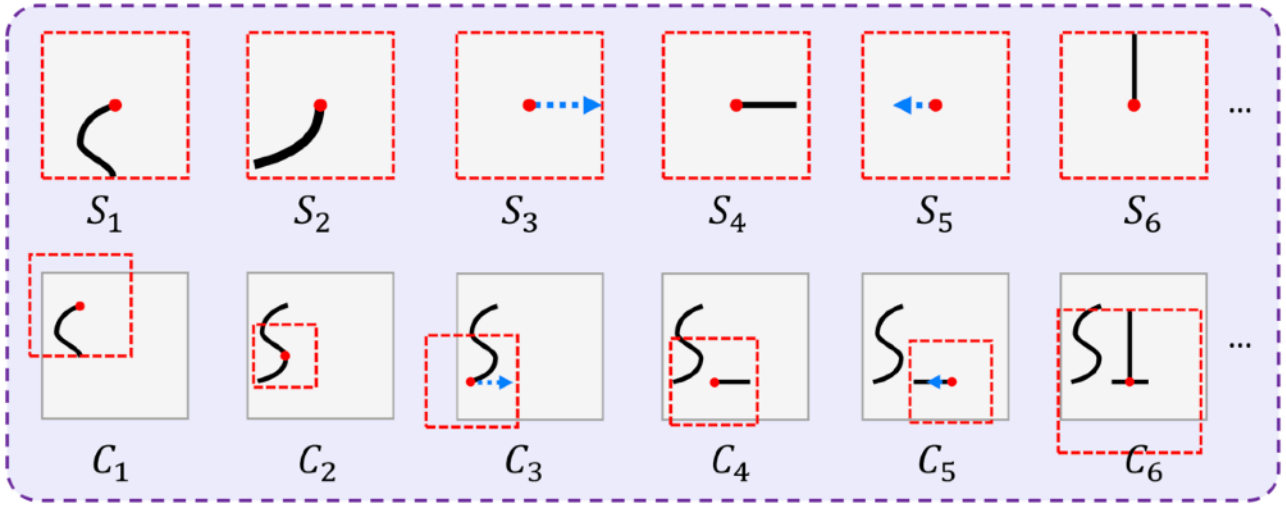
[Deep Sketch Vectorization via Implicit Surface Extraction (Yan et al.) **SIGGRAPH 2024**]

Vectorize Sketches via Tracing



"Fidelity vs Simplicity"-style loss:

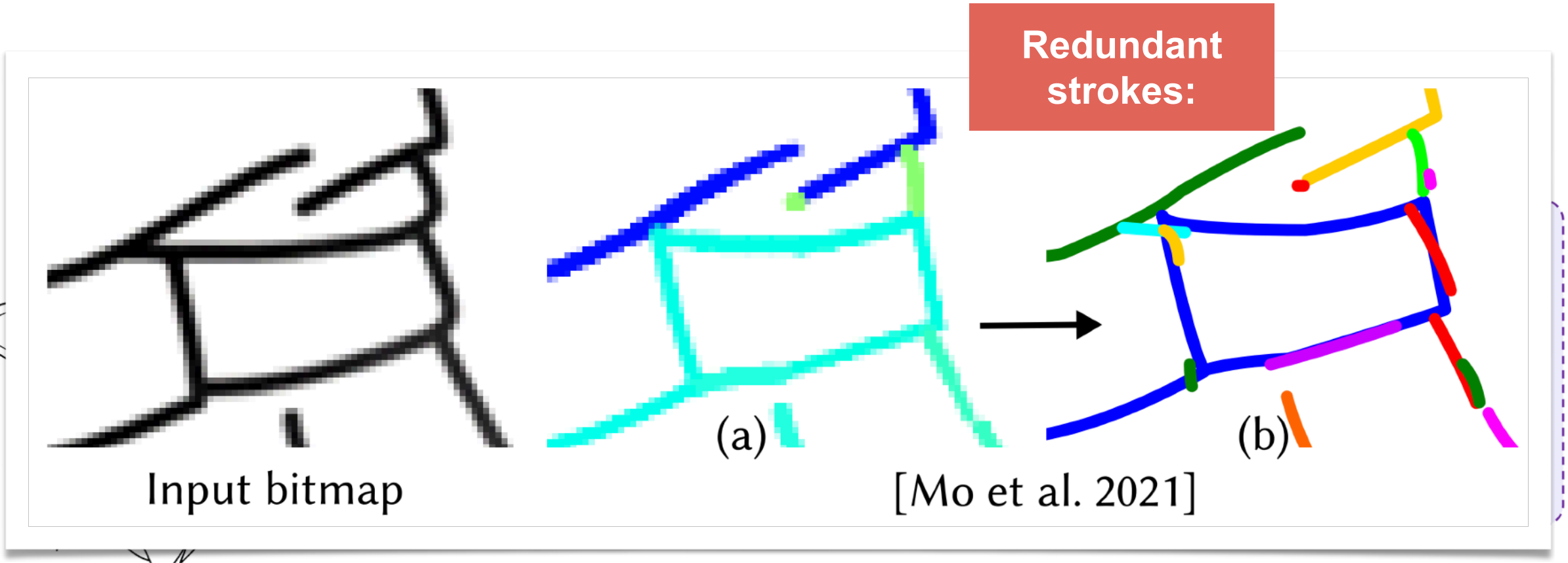
$$\mathcal{L}_{\text{total}} = \mathcal{L}_{\text{ras}} + \lambda_{\text{out}}\mathcal{L}_{\text{out}} + \lambda_{\text{reg}}\mathcal{L}_{\text{reg}}$$



[Mo et al. SIGGRAPH 2021]

Vectorize Sketches via Tracing

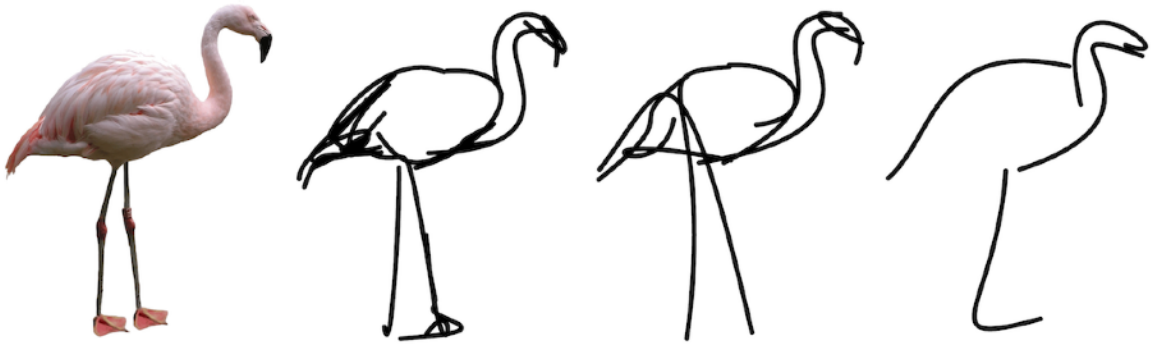
Vectorization



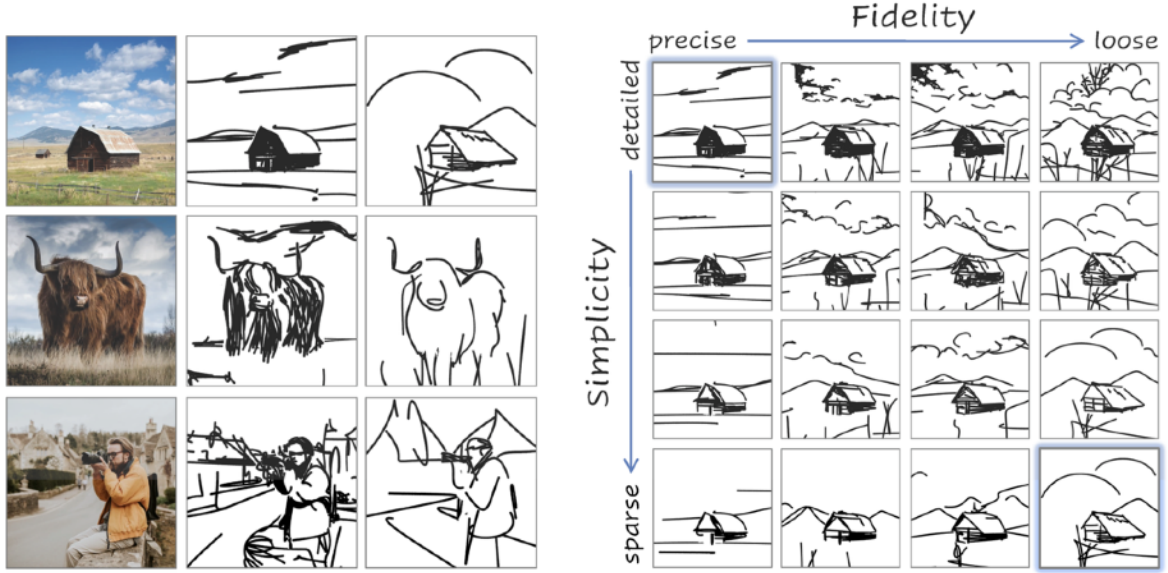
[Mo et al. SIGGRAPH 2021]

Diffusion-Model-Based Sketch Generation

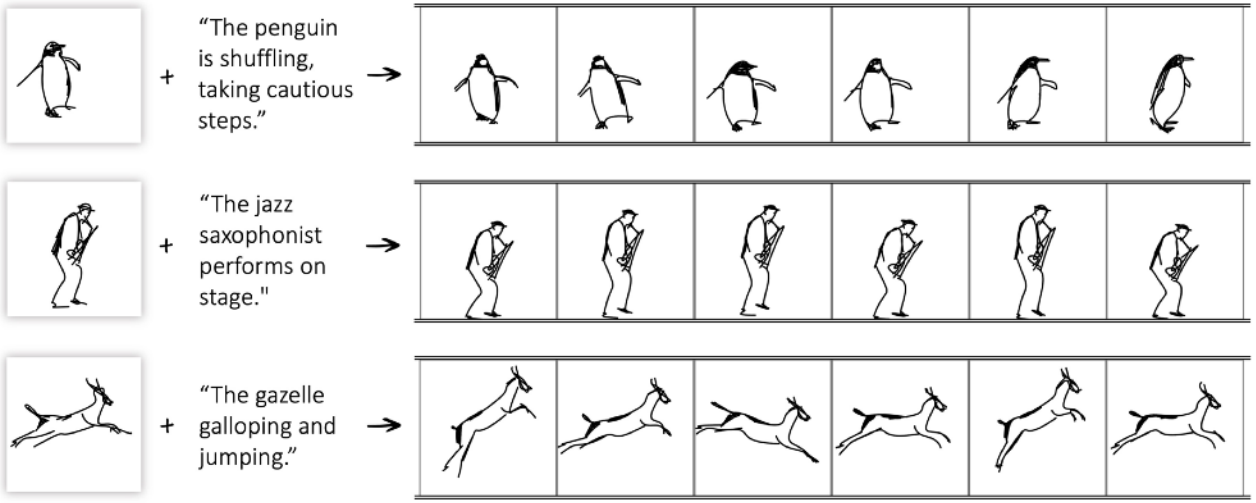
Vectorization



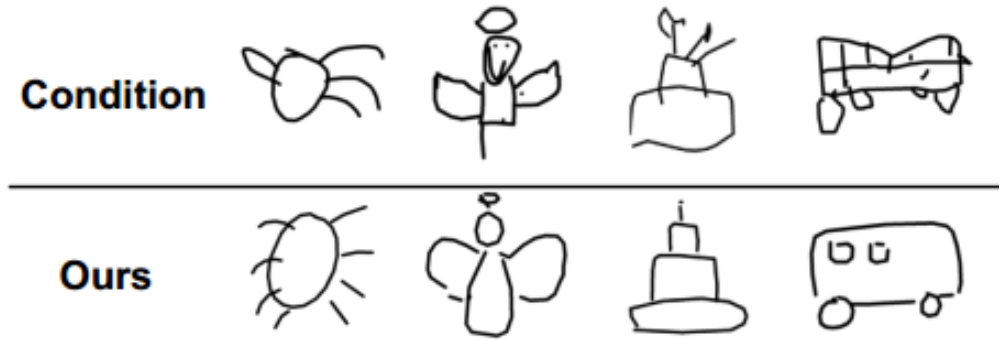
CLIPasso



CLIPascene



LiveSketch



SketchKnitter

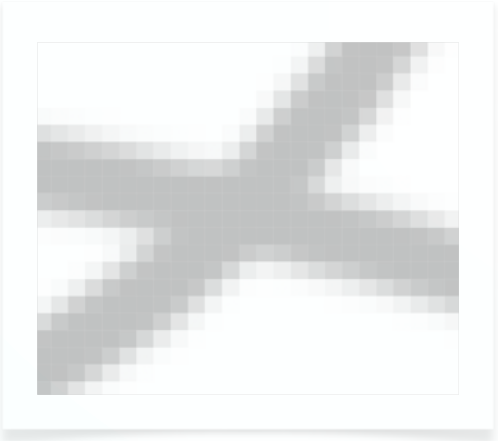
Takeaways

- **Image-to-image network**: Cleanup, keypoint prediction, etc.
- **Graph-based discrete steps** are necessary for vector outputs.
- **Few methods handle overdrawing**: [Simo-Serra et al'16, 18ab] (raster), [Favreau et al.'16], [Mo et al.'21].
- **Data is scarce**: Most learning based methods train on synthetic data or a combination of annotated and unannotated data.
- The newest method uses a bag of components → Simpler and more elegant methods in the future?

More papers:

Tracking Samples

2D Sketches

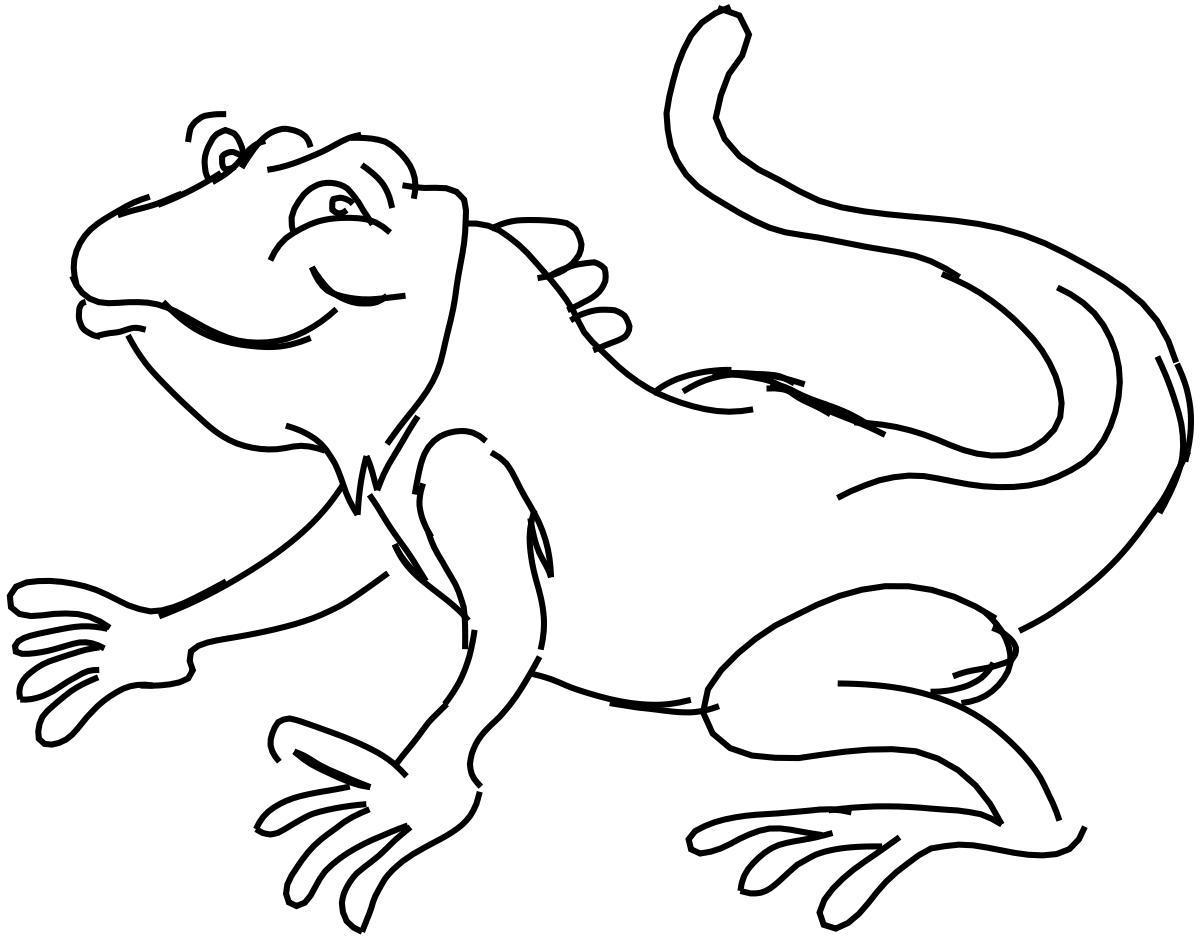


Raster Samples

Sketch Cleanup & Flat Colorization

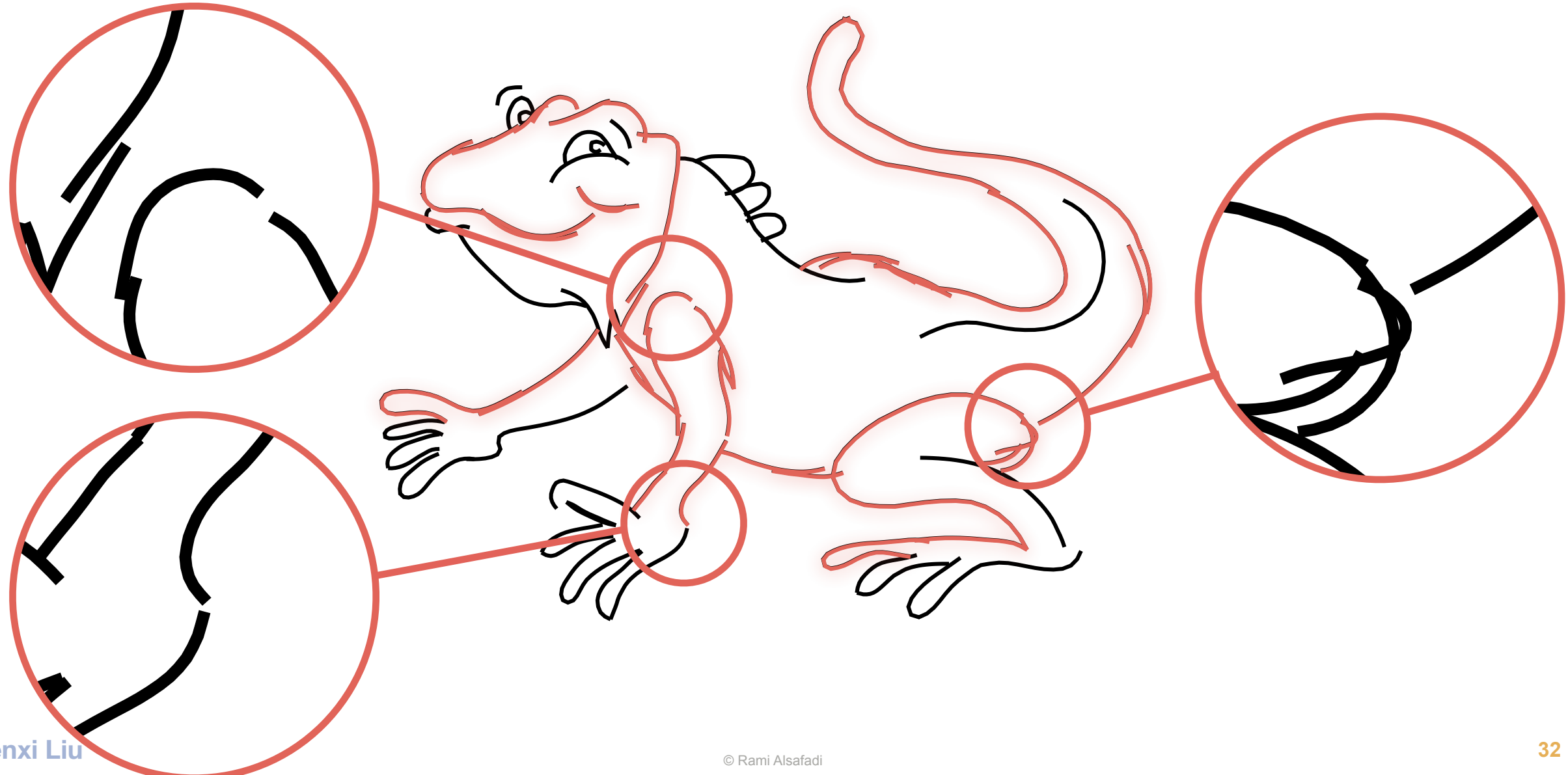
Creation Process

Typical Sketches



Typical Sketches

Sketch Cleanup

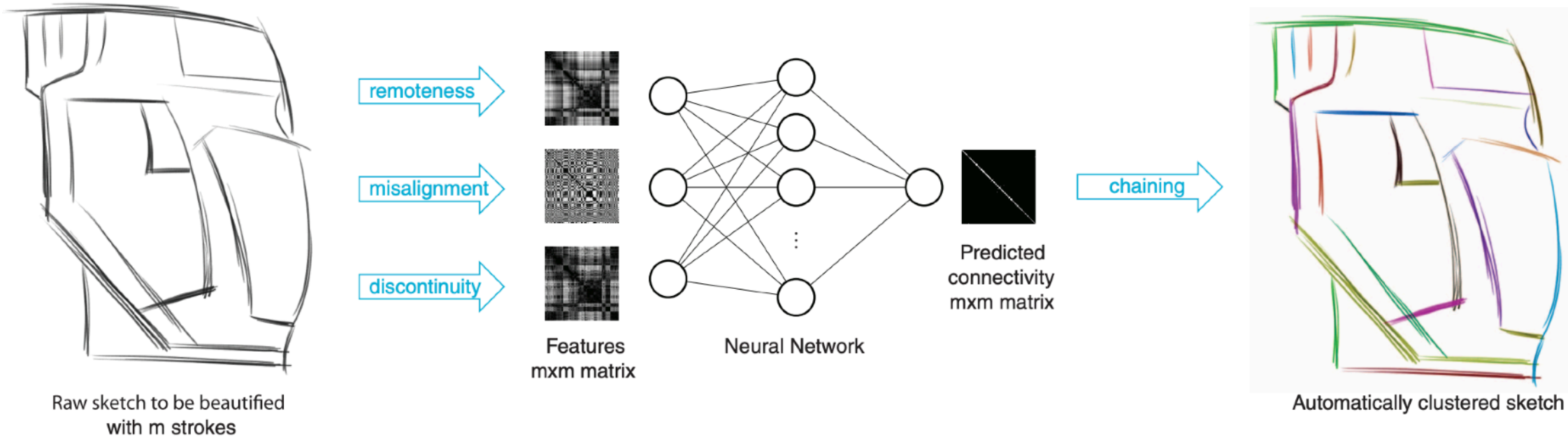


Sketch Topology: Cleanup/Simplification/Consolidation

Input **vector** sketch

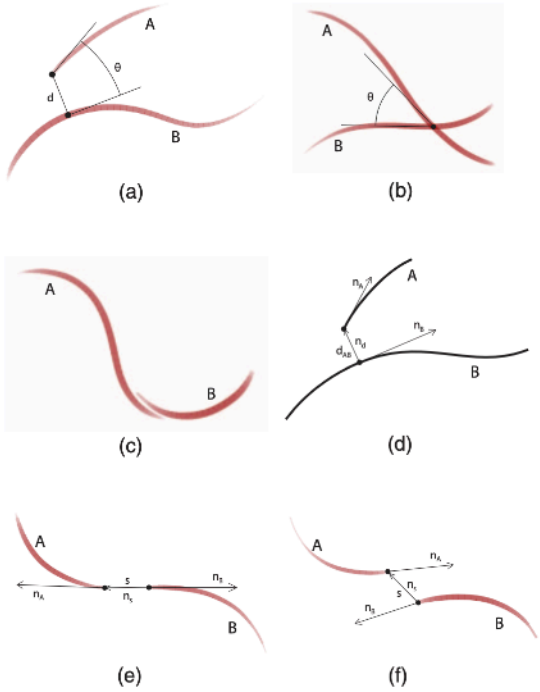
1. Clustering

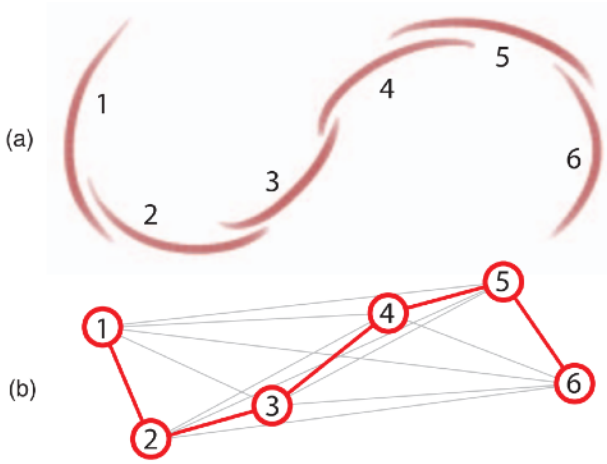
Sketch Cleanup: Clustering



[Beautification of design sketches using trainable stroke clustering and curve fitting (Orbay and Kara) TVCG 2011]

Sketch Cleanup: Clustering

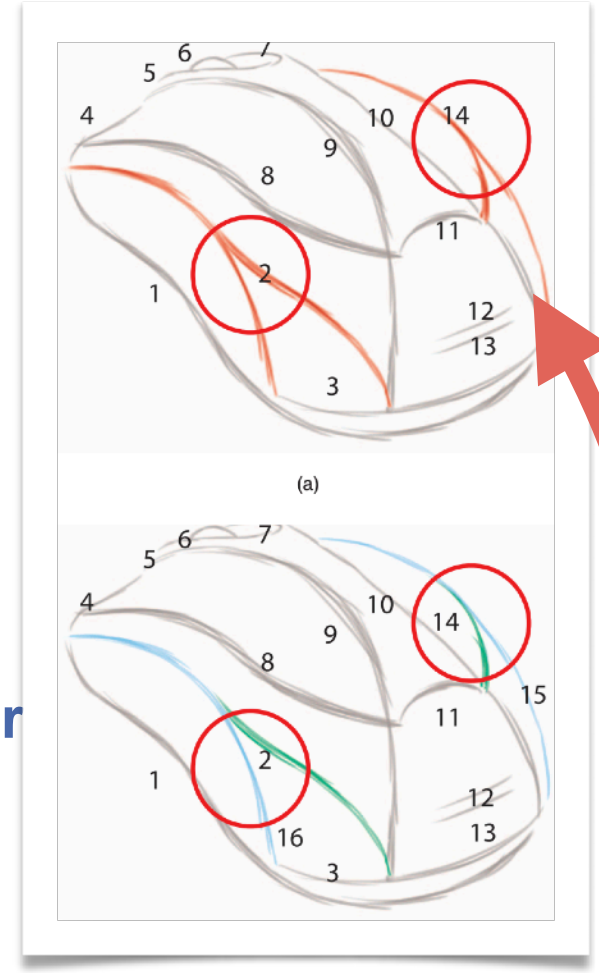




Greedily chained cluster

Classification:

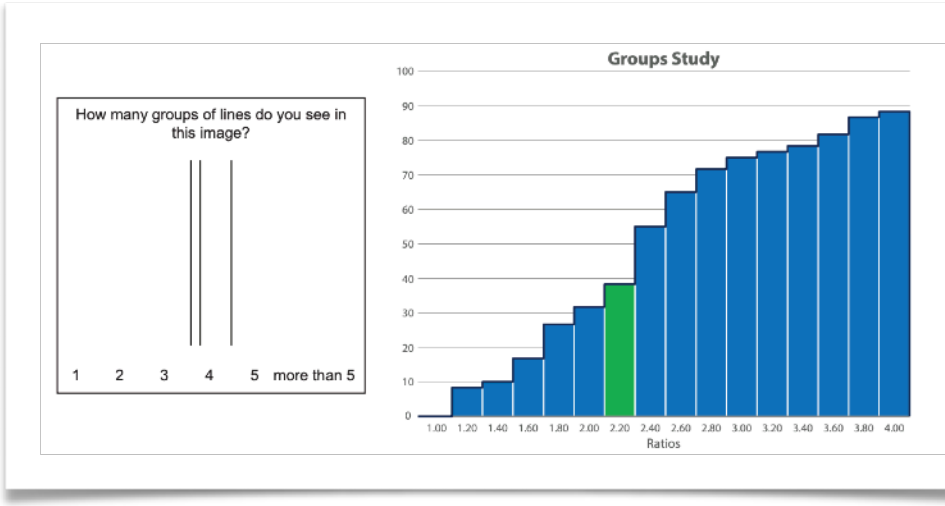
Stroke 1&2 together?



Artifact: Branching

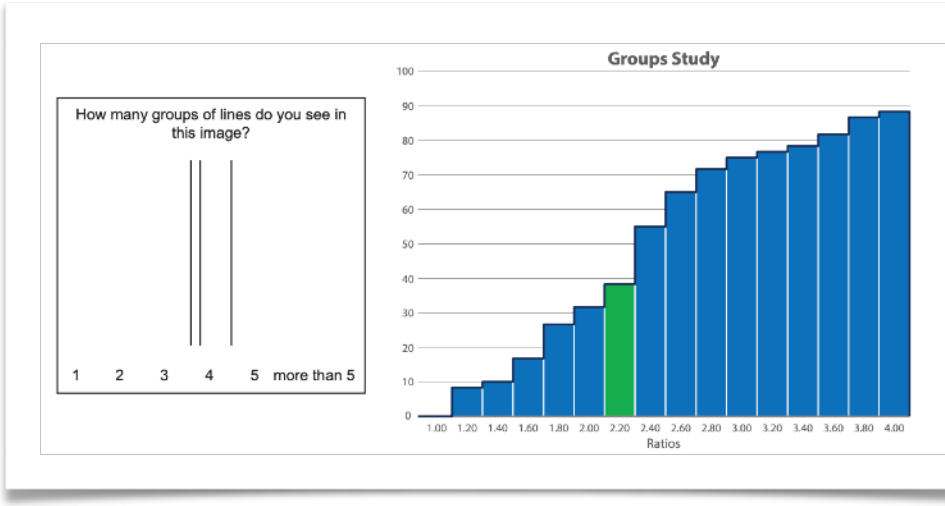
→ Separation splitting step

Sketch Cleanup: Clustering



[StrokeAggregator (Liu et al.) SIGGRAPH 2018]

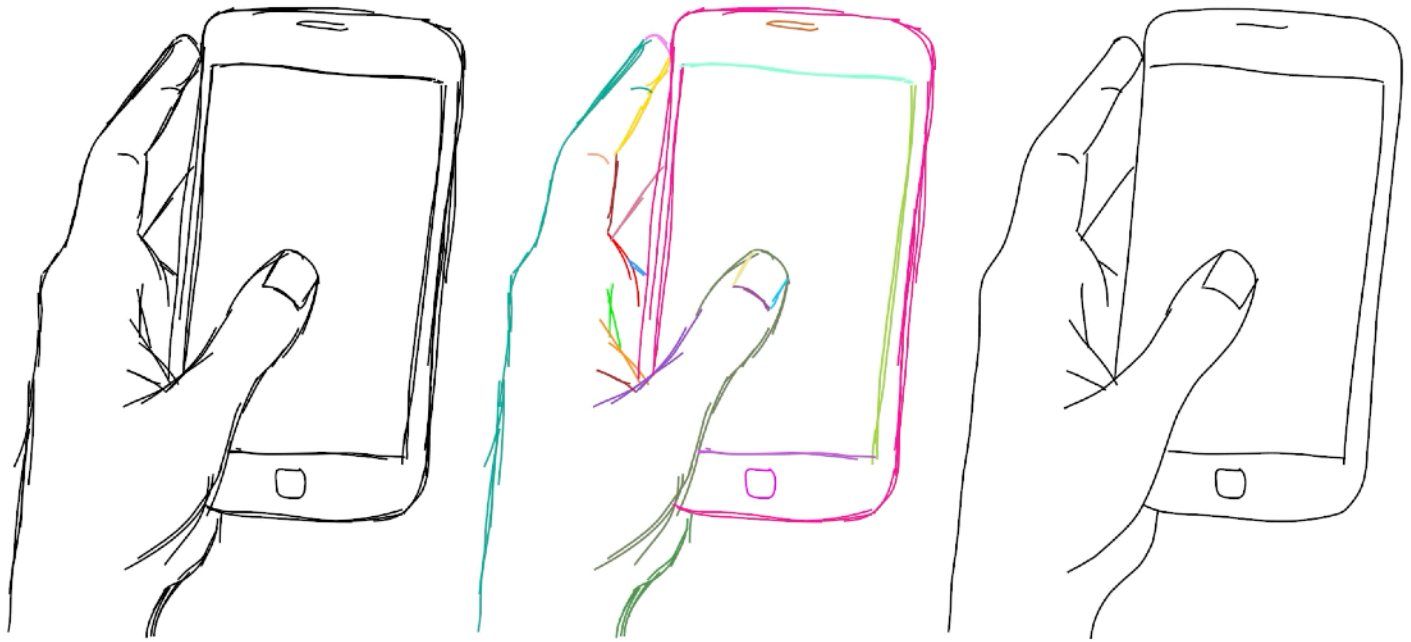
Sketch Cleanup: Clustering



[StrokeAggregator (Liu et al.) SIGGRAPH 2018]

User studies don't scale with more cues
Hard to estimate density when strokes are few…

Sketch Cleanup: Clustering



[StripMaker (Liu et al.) SIGGRAPH 2023]

Sketch Topology: Cleanup/Simplification/Consolidation

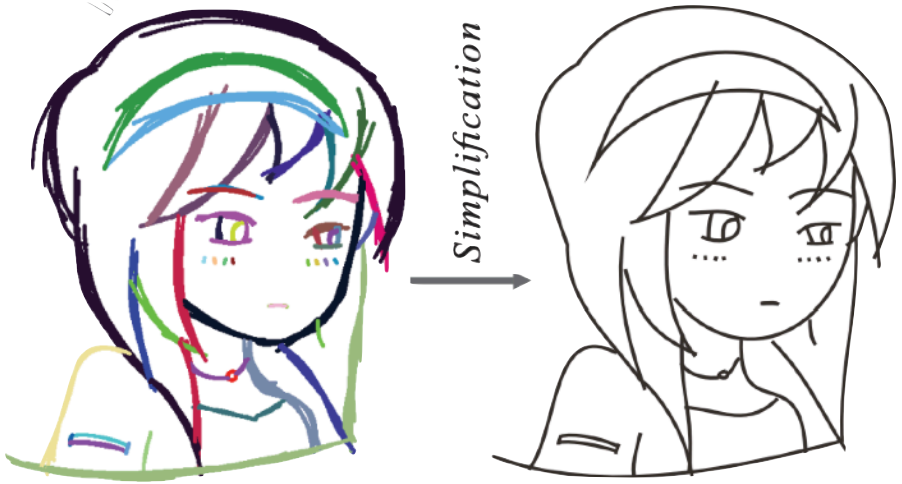
Input **vector** sketch

1. Clustering

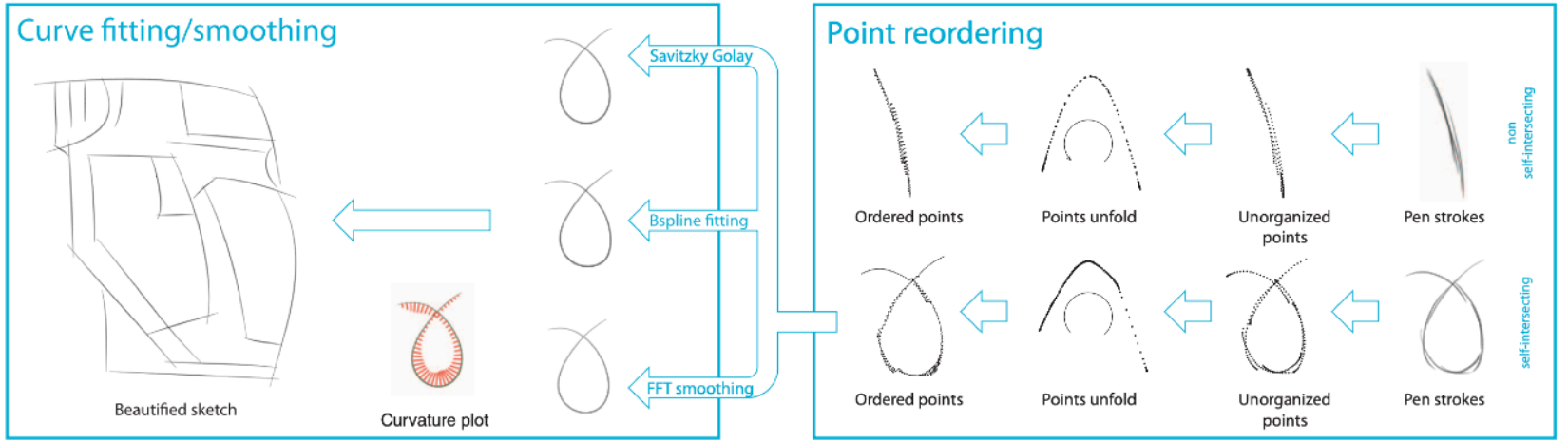
2. Fitting

Sketch Cleanup: Fitting

[Barla'05]



[Liu'15]

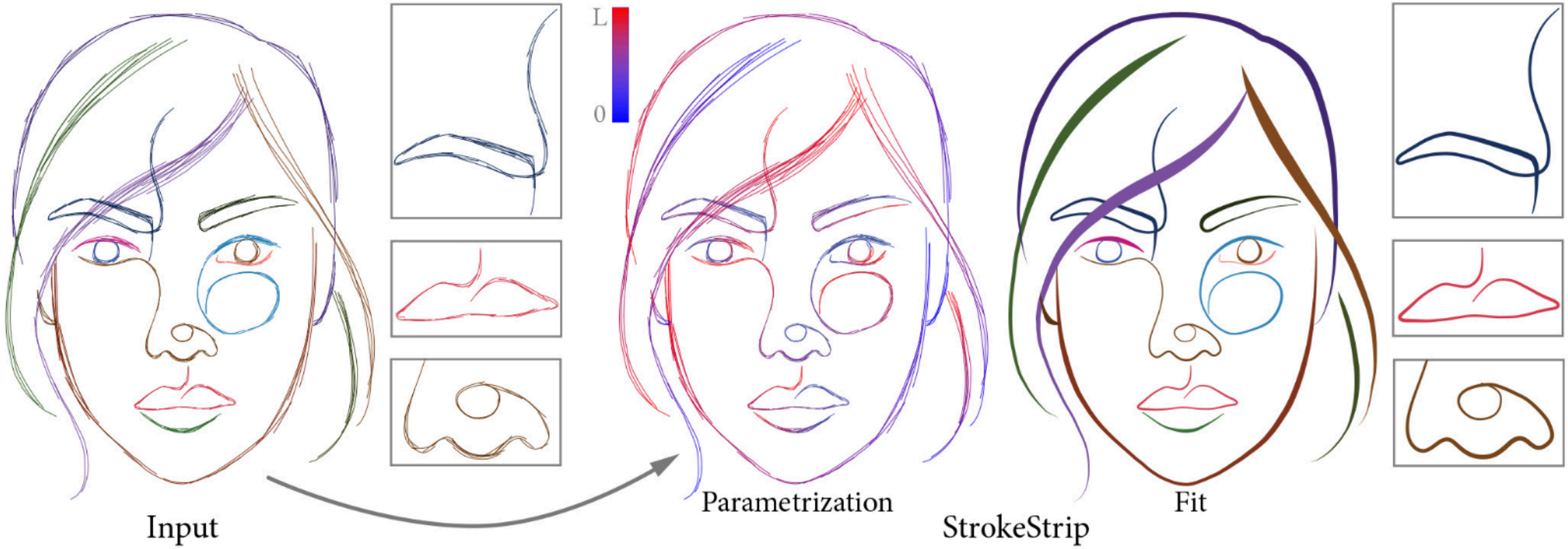


[Orbay and Kara'11]

Position-based

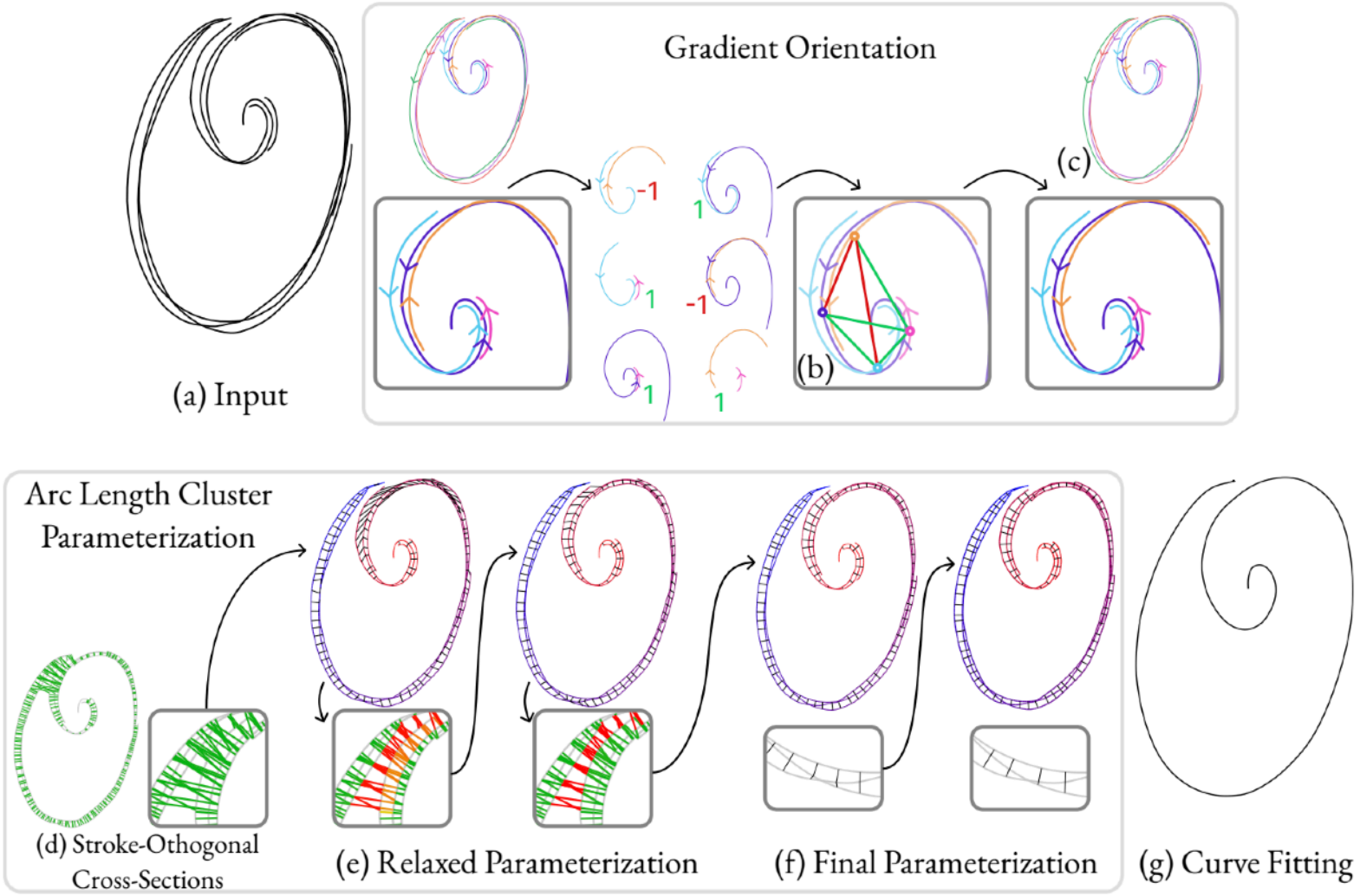
Tangent-based

Sketch Cleanup: Fitting

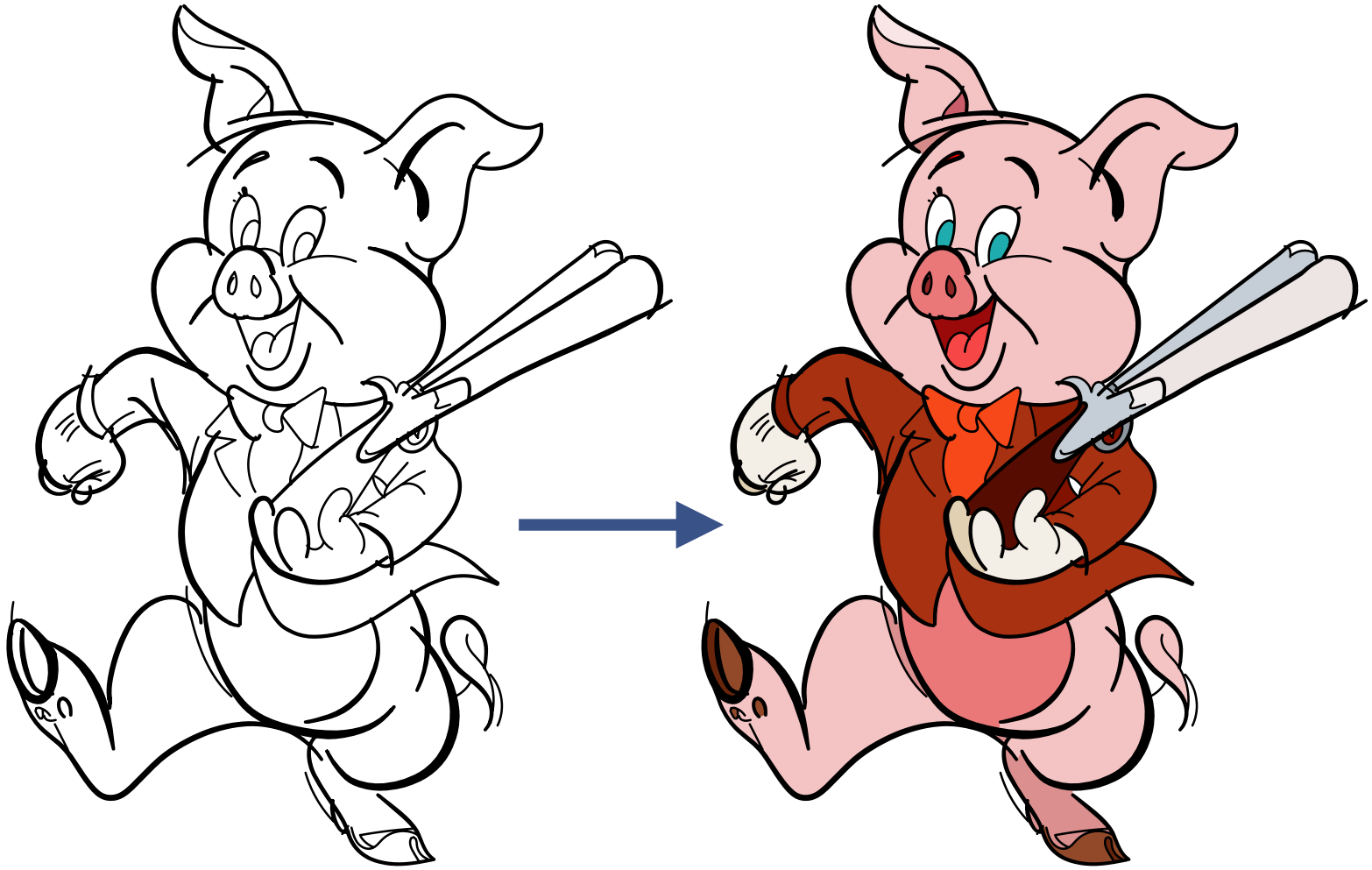


[StrokeStrip (Van Mossel et al.) SIGGRAPH 2021]

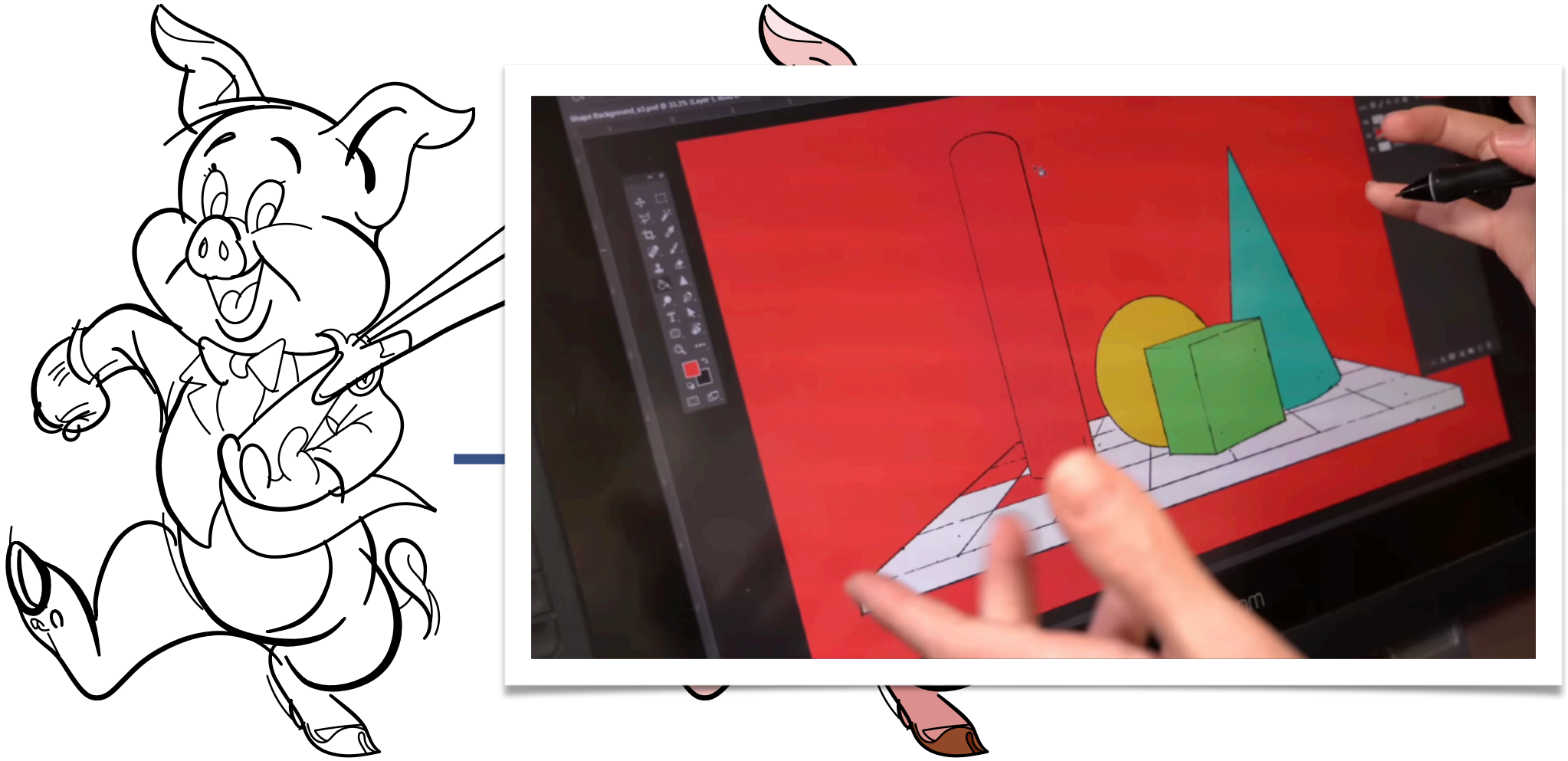
Sketch Cleanup: Fitting



Sketch Topology: Flat Colorization/Junction Reconstruction

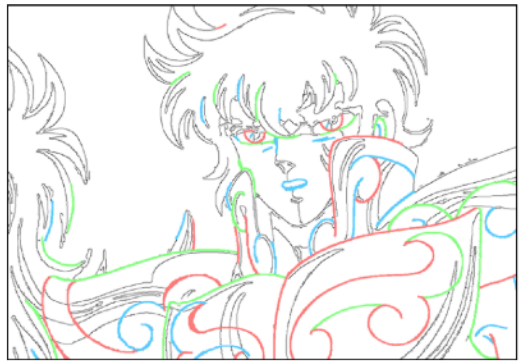


Sketch Topology: Flat Colorization/Junction Reconstruction



Sketch Flatting: Region Filling

Flat Colorization



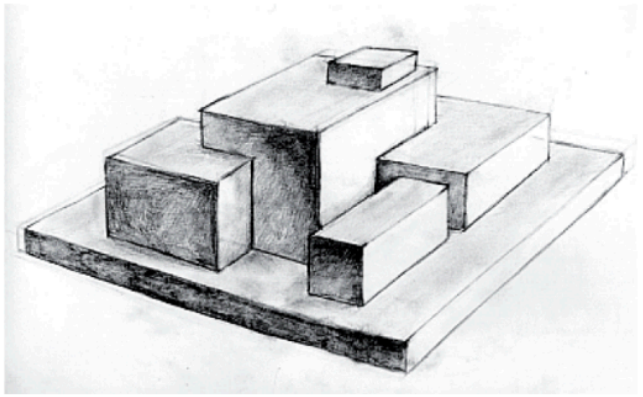
(a) Segmentation mask

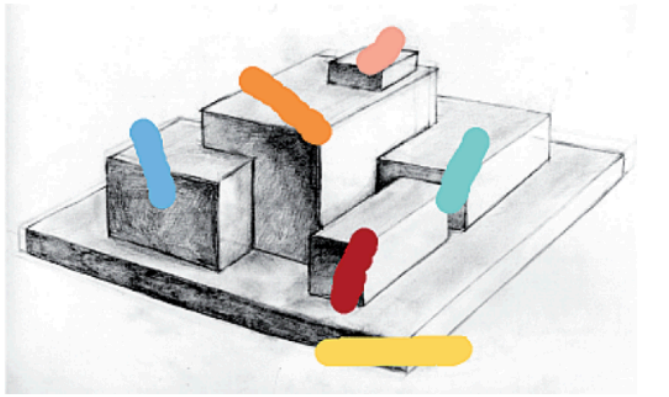
(b) Trapped-ball segmentation

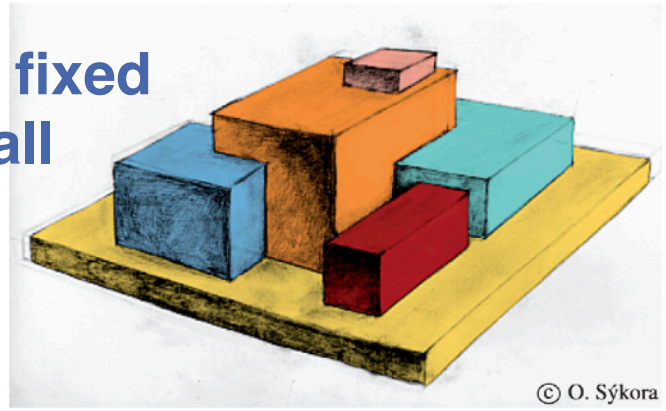
(c) Our segmentation result

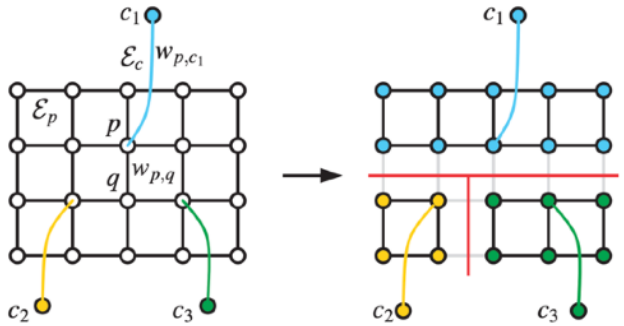
Move this fixed size ball

[Zhang et al. TVCG 2009]







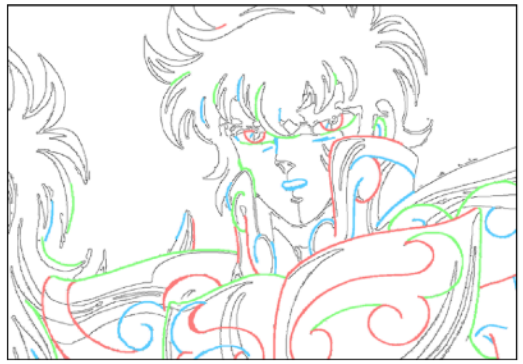


Multiway Graph Cut

[Lazybrush (Sýkora et al.) Eurographics 2009]

Sketch Flatting: Region Filling

Flat Colorization



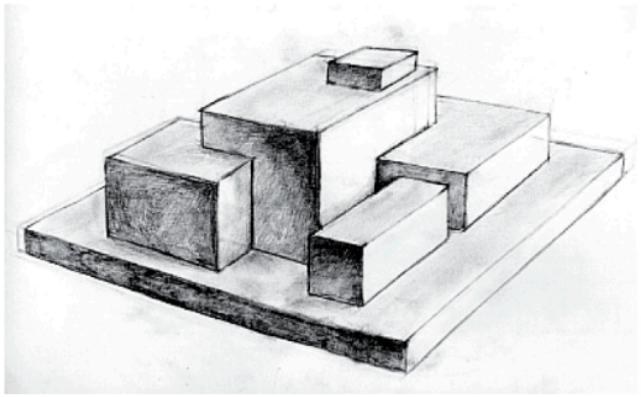
(a) Segmentation mask

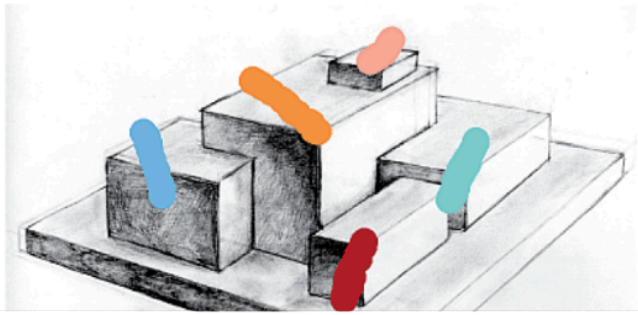
(b) Trapped-ball segmentation

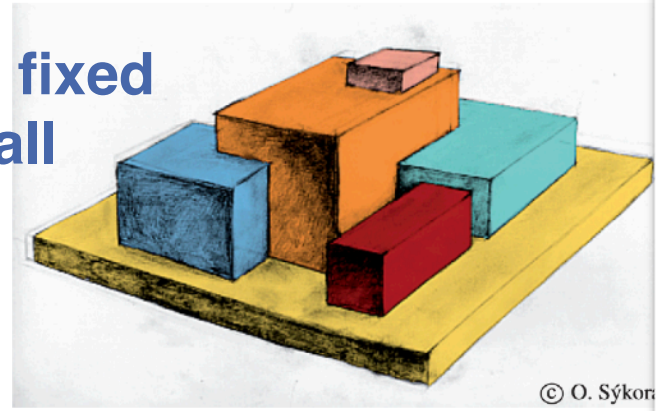
(c) Our segmentation result

Move this fixed size ball

[Zhang et al. TVCG 2009]







LAZYBRUSH
TVPaint plugin for quick lineart coloring

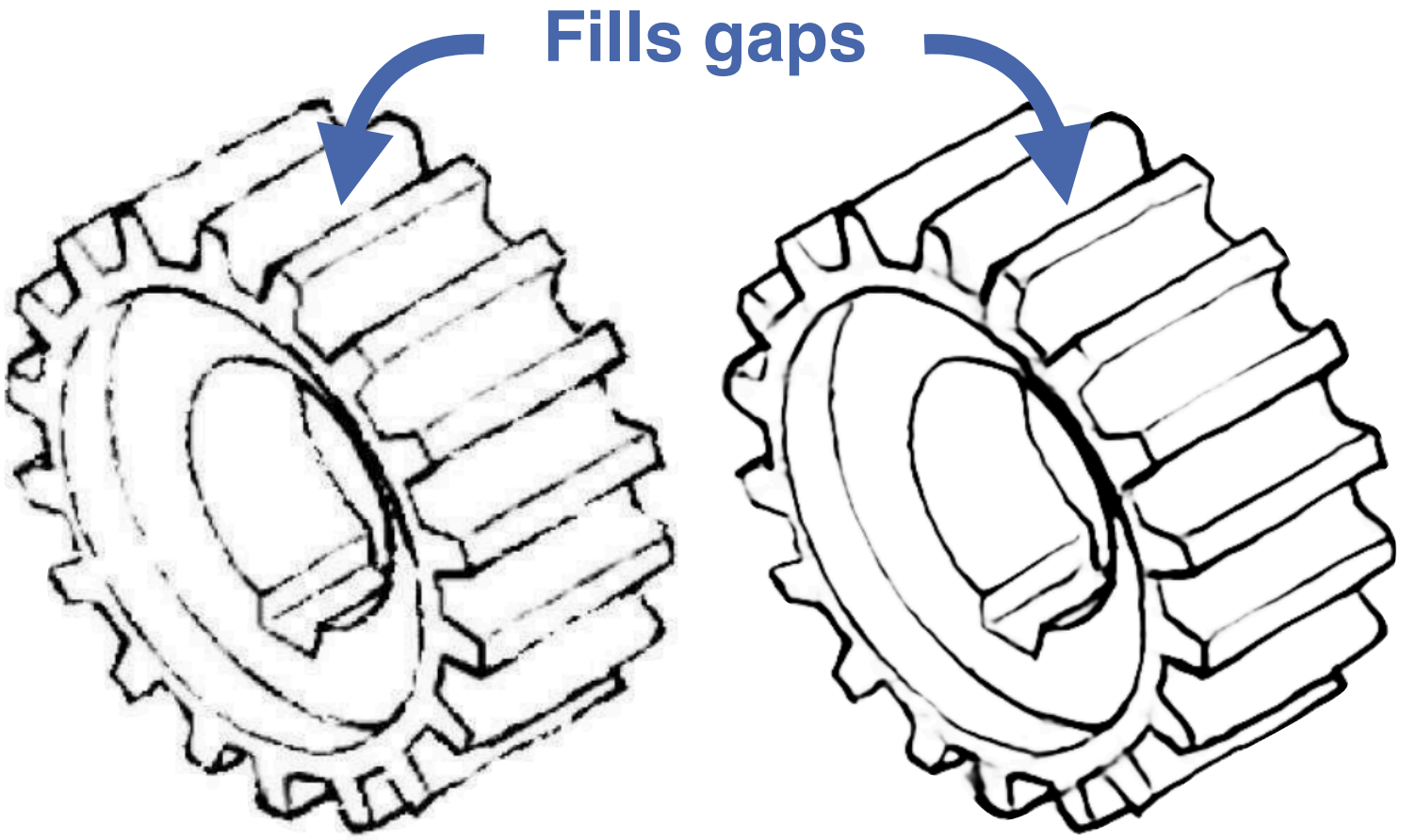
TVPaint animation 11

SKETCH COLOR

KRITA

[Lazybrush (Sýkora et al.) Eurographics 2009]

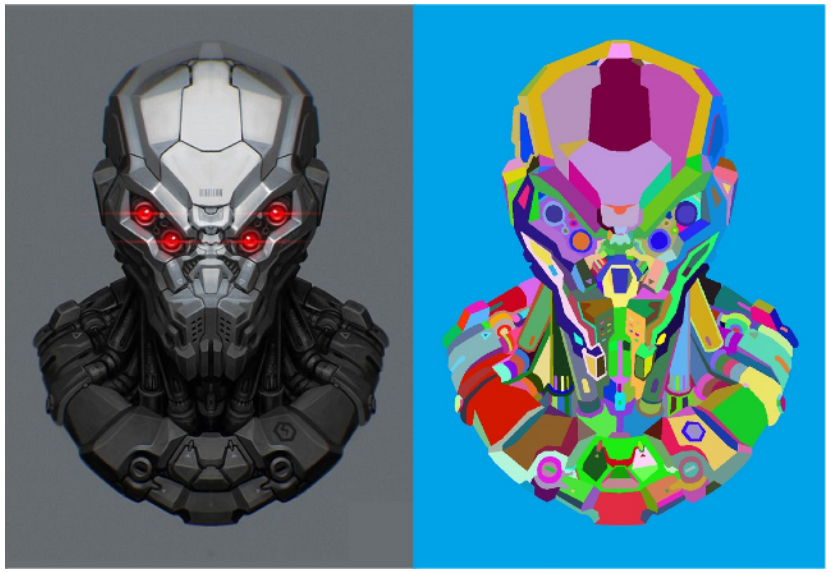
Sketch Flatting: End-to-End

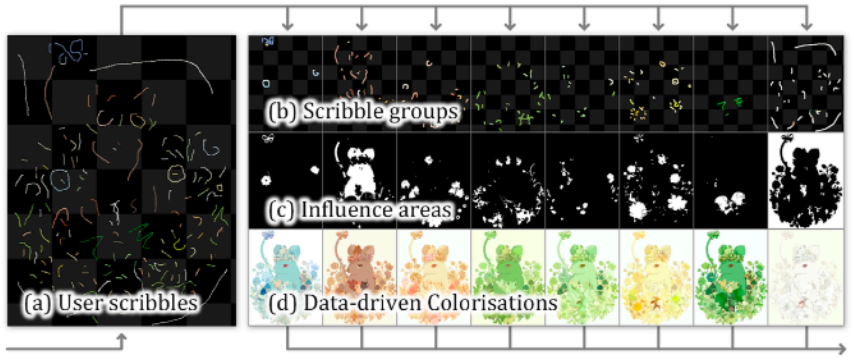


[Sasaki et al. CVPR 2017]

Sketch Flatting: End-to-End

Flat Colorization





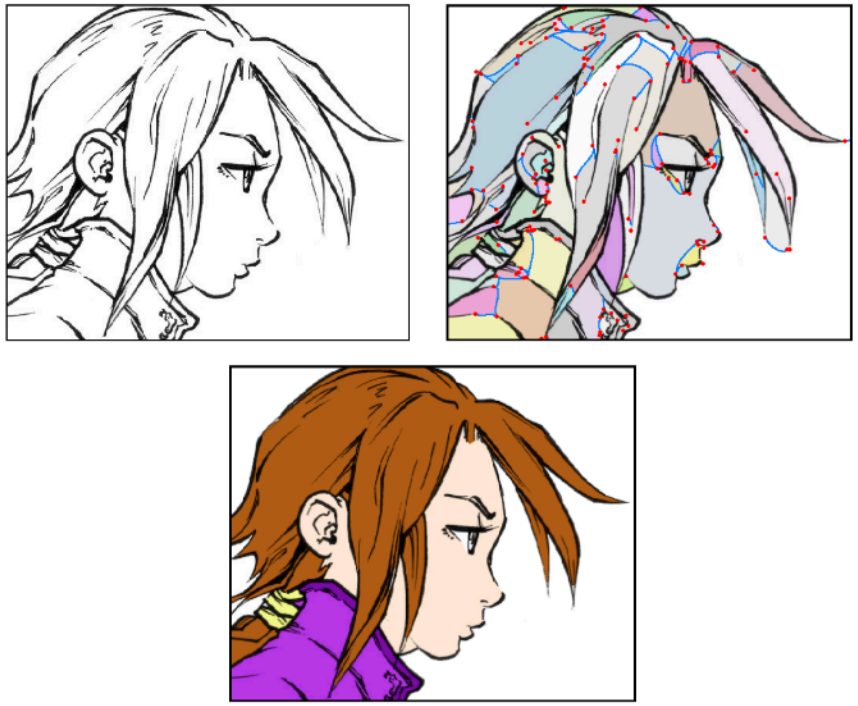
Dataset

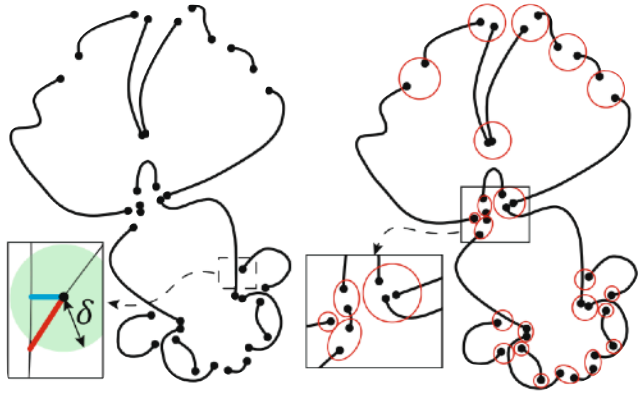
- [Danbooregion (Zhang et al.) ECCV 2020]

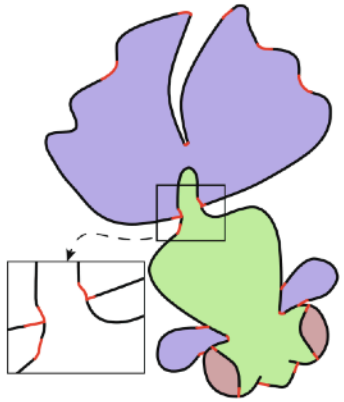
Neural Networks

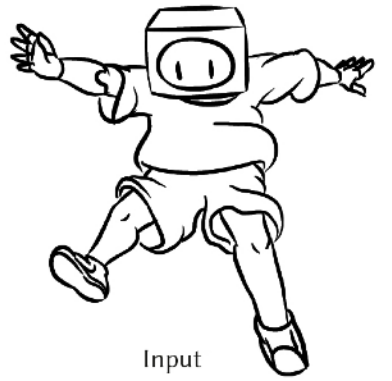
- [Zhang et al. CVPR 2021]

Sketch Flatting: Junction Connection









Endpoint Extension

- [Fourey et al. Eurographics 2018]

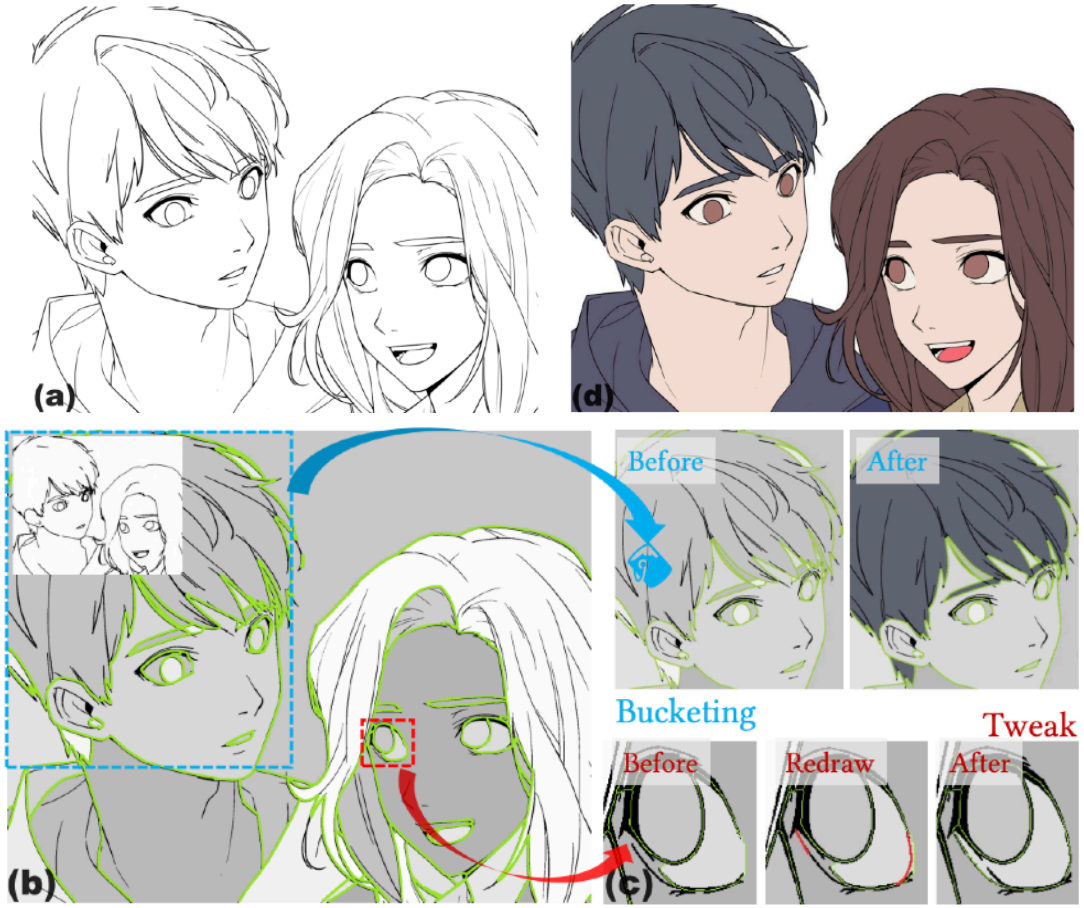
Endpoint Clustering

- [Jiang et al. The Visual Computer 2021]

Junction Classification

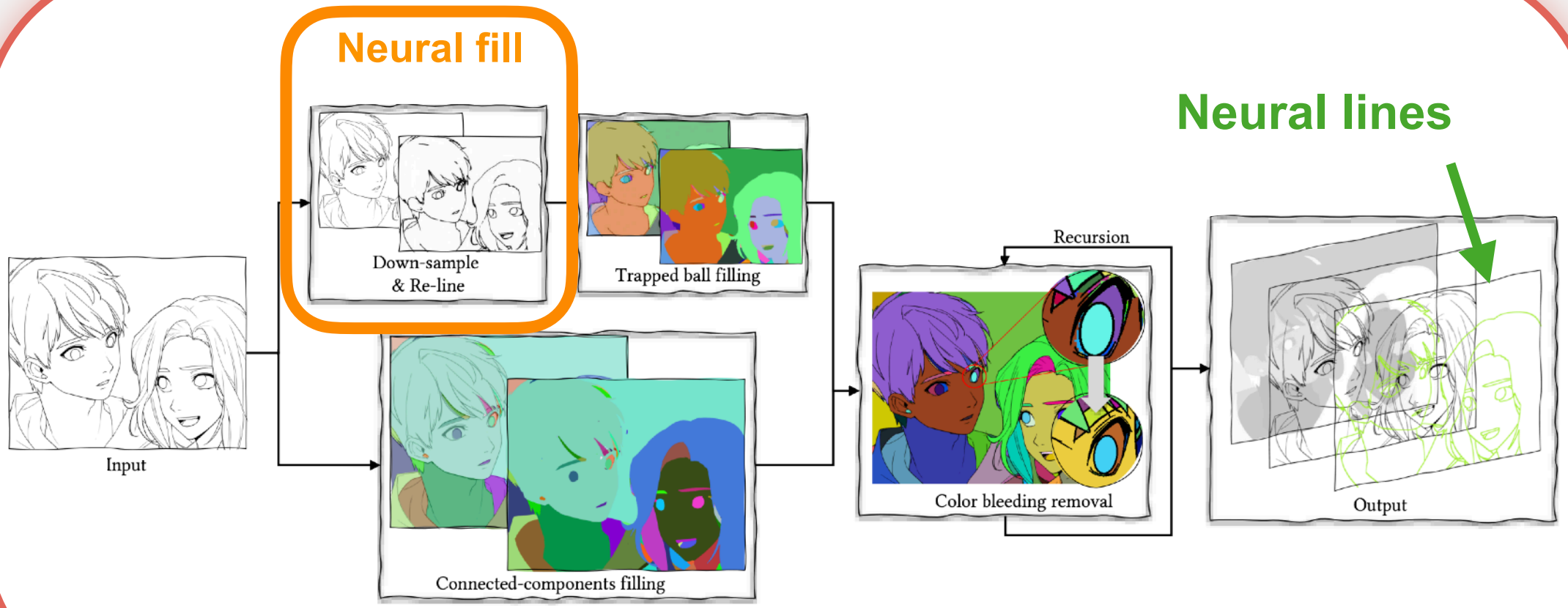
- [Yin et al. SIGGRAPH 2022]

Sketch Flatting: Hybrid



[FlatMagic (Yan et al.) CHI 2022]

Sketch Flatting: Hybrid

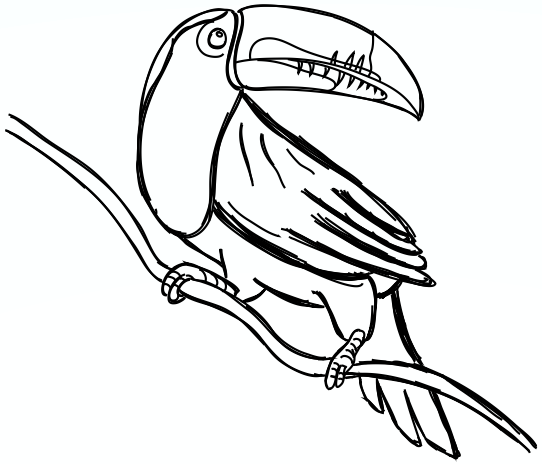


Takeaways

- **Raster vs Vector:** the majority of commercial tools are raster based making it easier for raster methods to get tech-transfered.
- **[A Benchmark for Rough Sketch Cleanup (Yan et al.) SIGGRAPH Asia 2020]**:
  - Ignoring “varying thickness and weight”, “non-shape strokes”, “global context”.
  - Junctions: “professional artists **have trouble creating** topologically accurate junctions”.

More papers:

Tracking Samples



2D Sketches

Raster Samples

3D Sketches

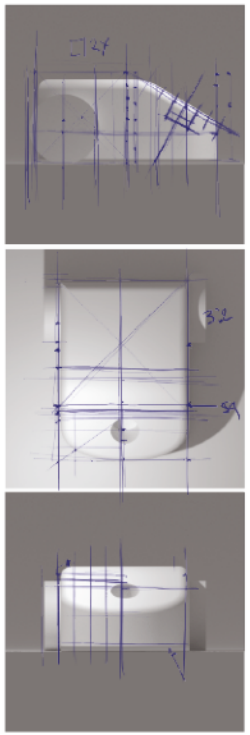
Sketch Lifting

Creation Process

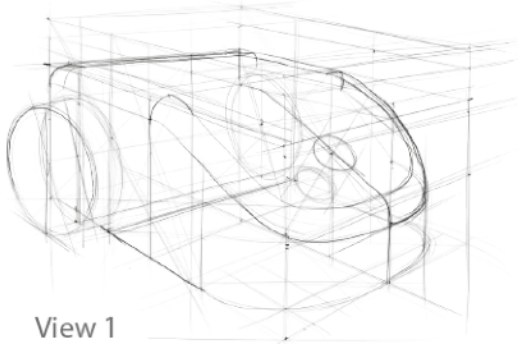
Sketch Lifting

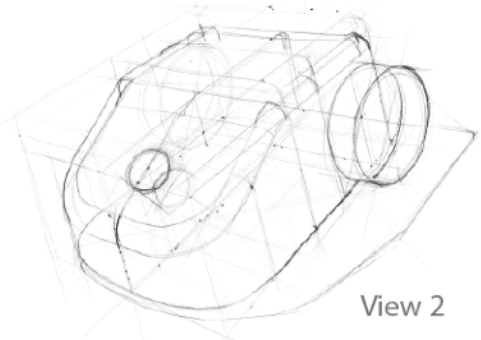
Sketching interface available

Professional CC0 sketches!

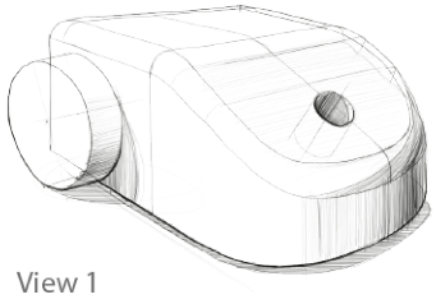


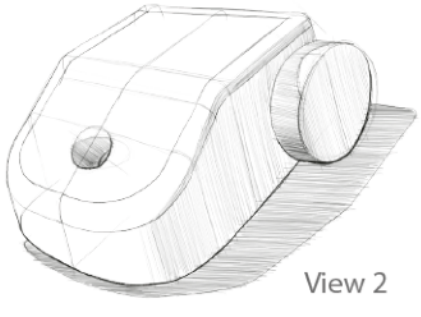
a. Orthographic views with designer measurements



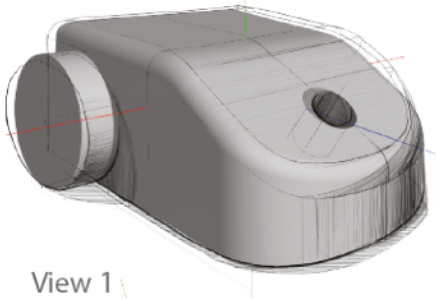


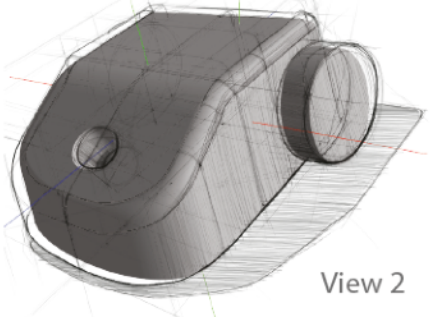
b. Concept sketch



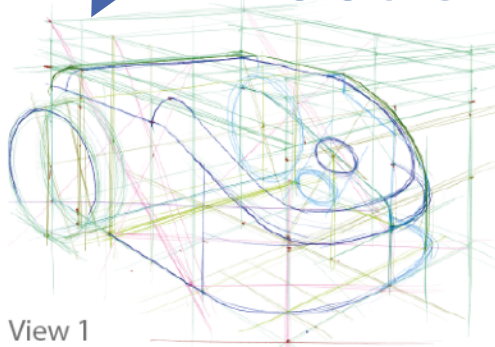


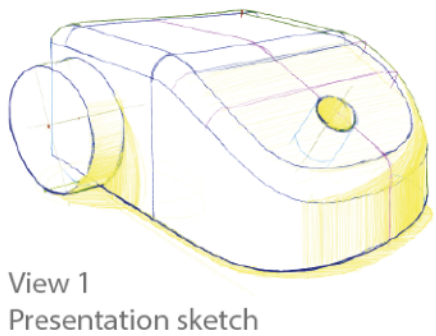
c. Presentation sketch





d. Registered 3D model





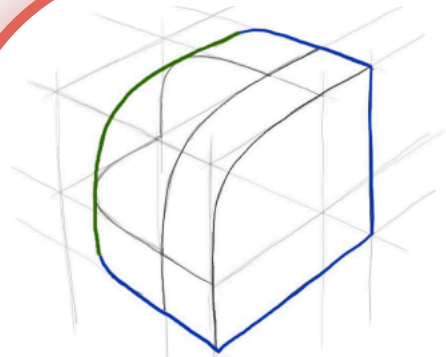
e. Stroke labeling

Descriptive lines:
smooth silhouette
ridge visible,
ridge occluded ,
valley visible,
valley occluded,
descriptive
cross-section

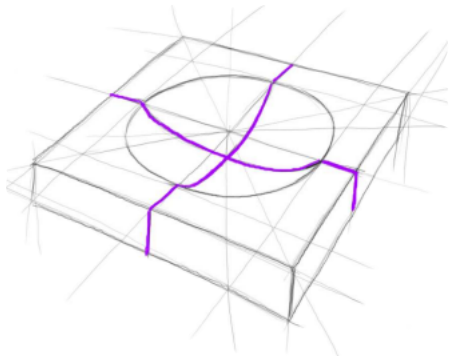
Construction lines
scaffold,
axis,
surfacing
cross-section,
projection line,
mirroring,
divide rectangle,
multiply rectangle
hatching,
shadow ,
tick ...

[OpenSketch (Gryaditskaya et al.) SIGGRAPH Asia 2019]

Sketch Lifting

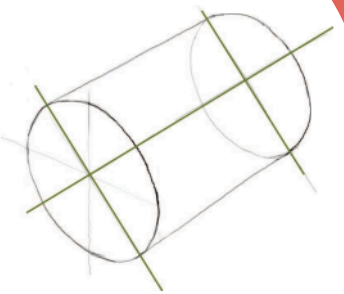


Silhouette: smooth, ridge

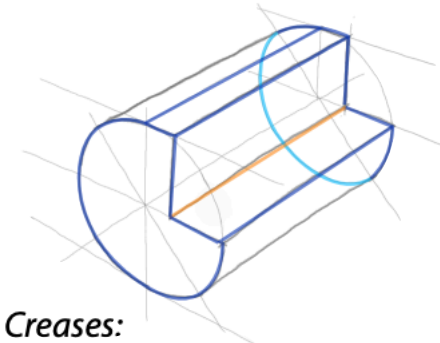


Discriptive cross-section

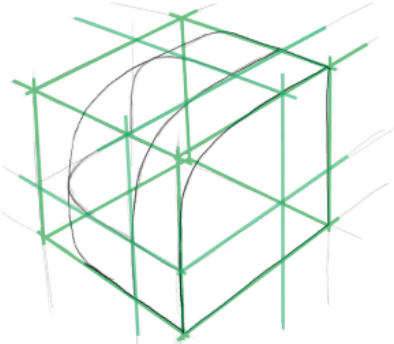
Global context: vanishing points



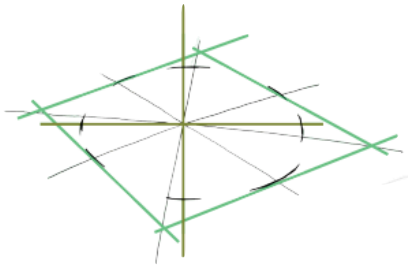
Local context: axis



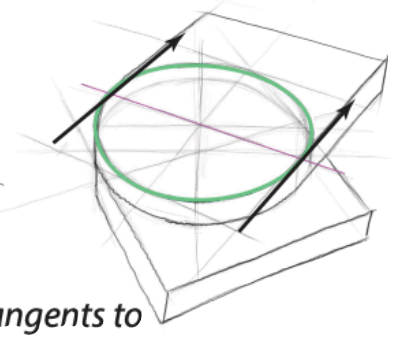
Creases:
ridges (occluded), valleys



a. Scaffolds



b. A square
for an ellipse

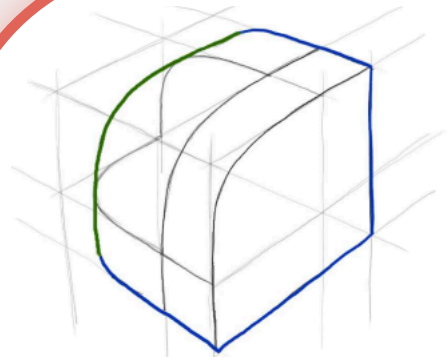


c. Tangents to
an ellipse for a square

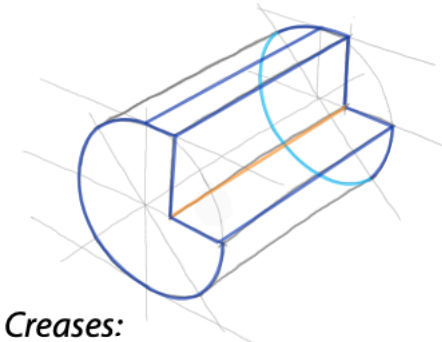
Descriptive Lines

Construction Lines

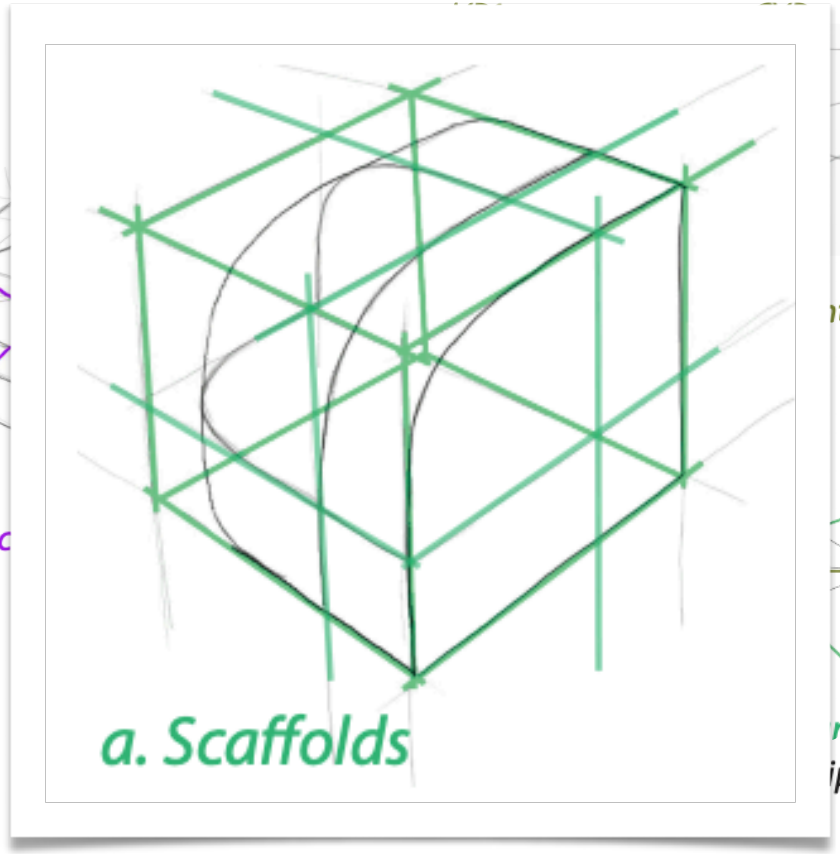
Sketch Lifting

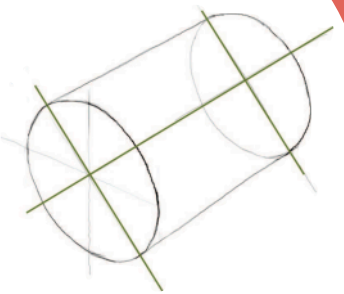


Silhouette: *smooth*, *ridge*

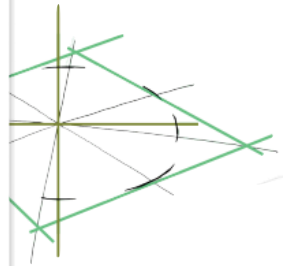


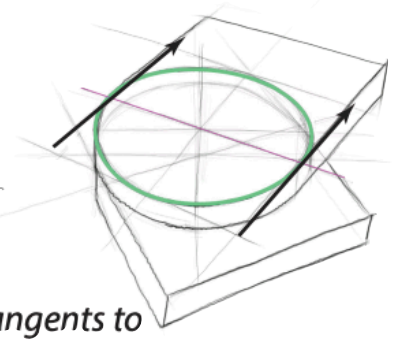
Creases:
ridges (occluded), *valleys*





Local context: *axis*

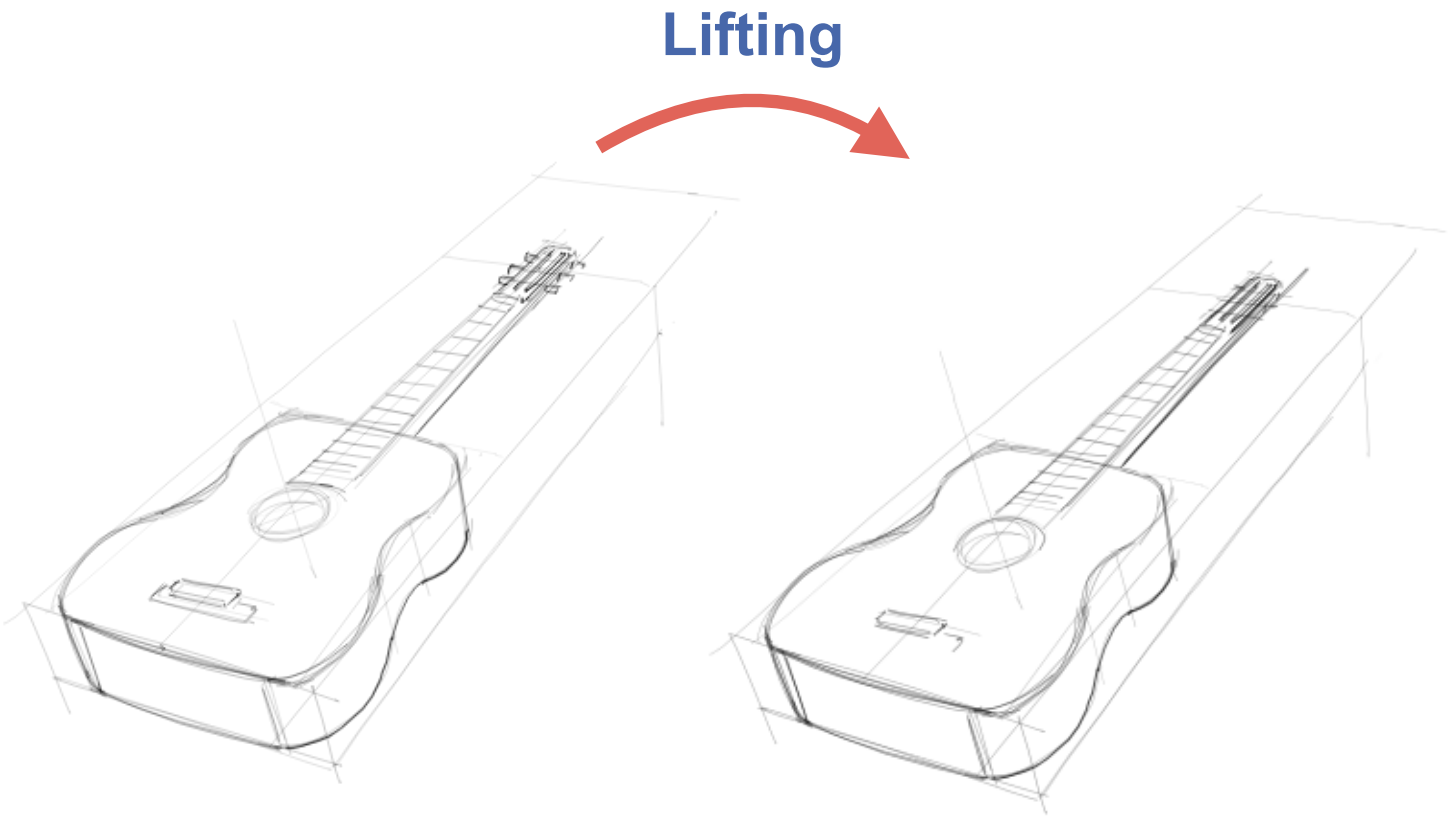




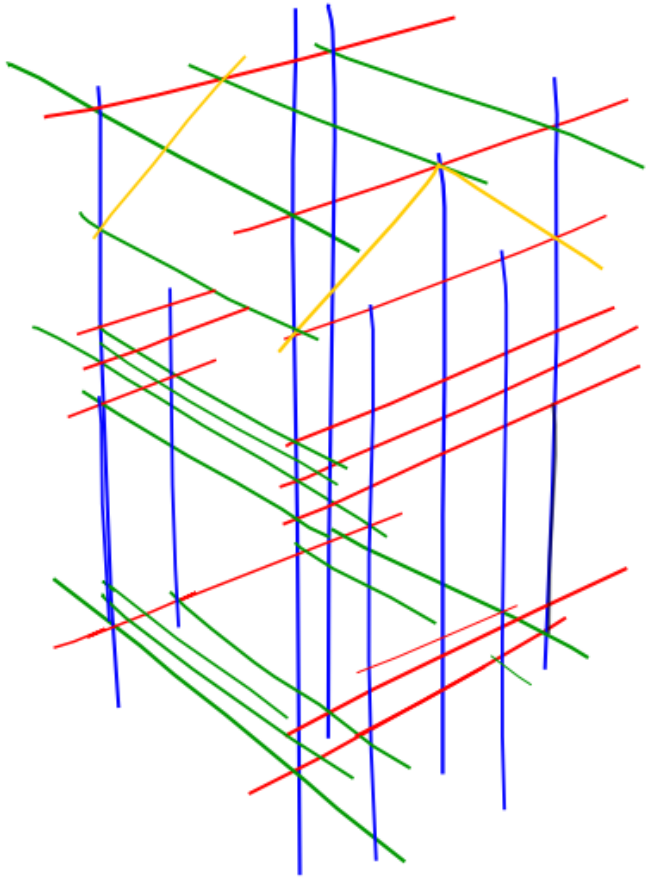
c. Tangents to
an *ellipse* for a square

Descriptive Lines **Construction Lines**

Sketch Lifting

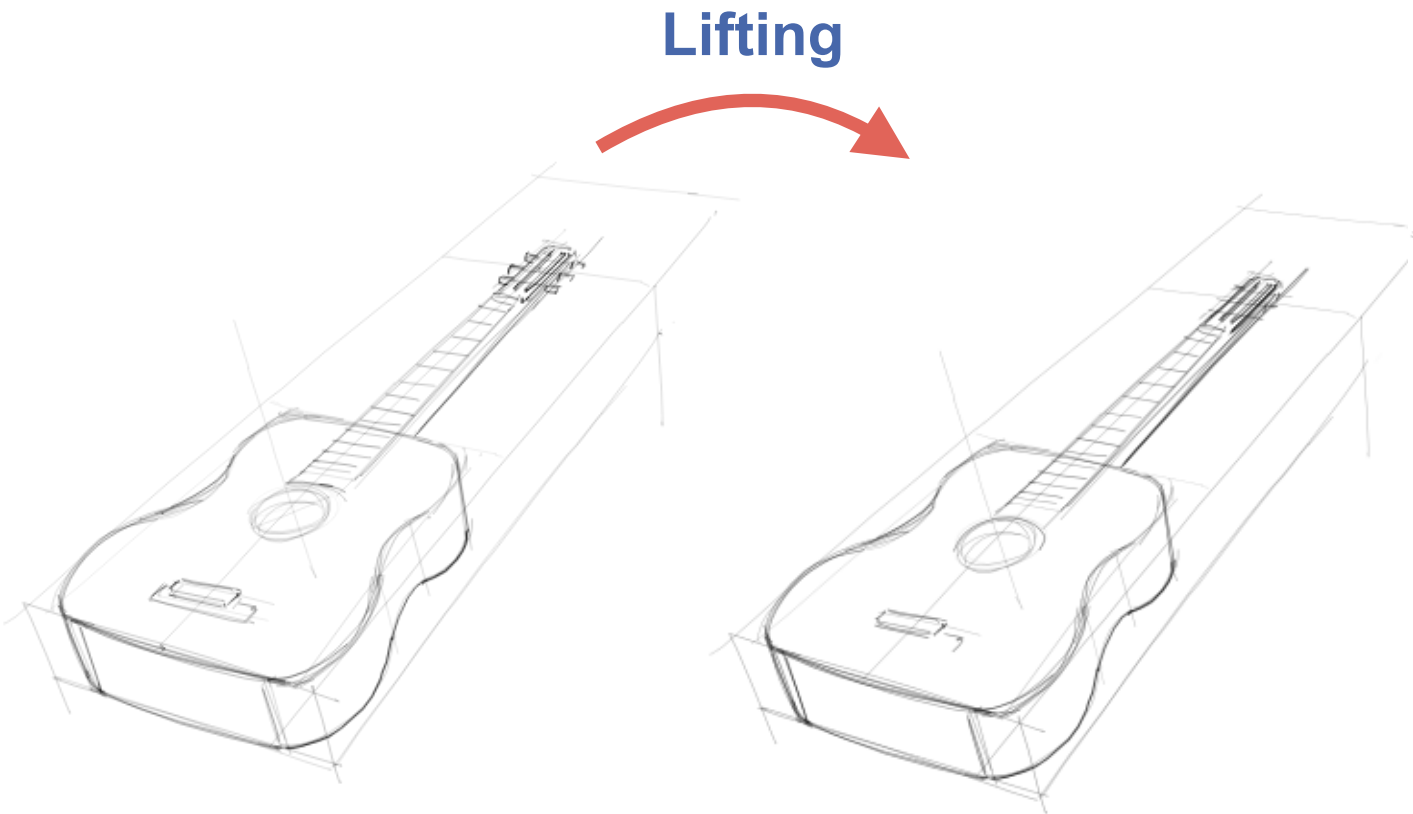


[Gryaditskaya et al. SIGGRAPH Asia 2020]

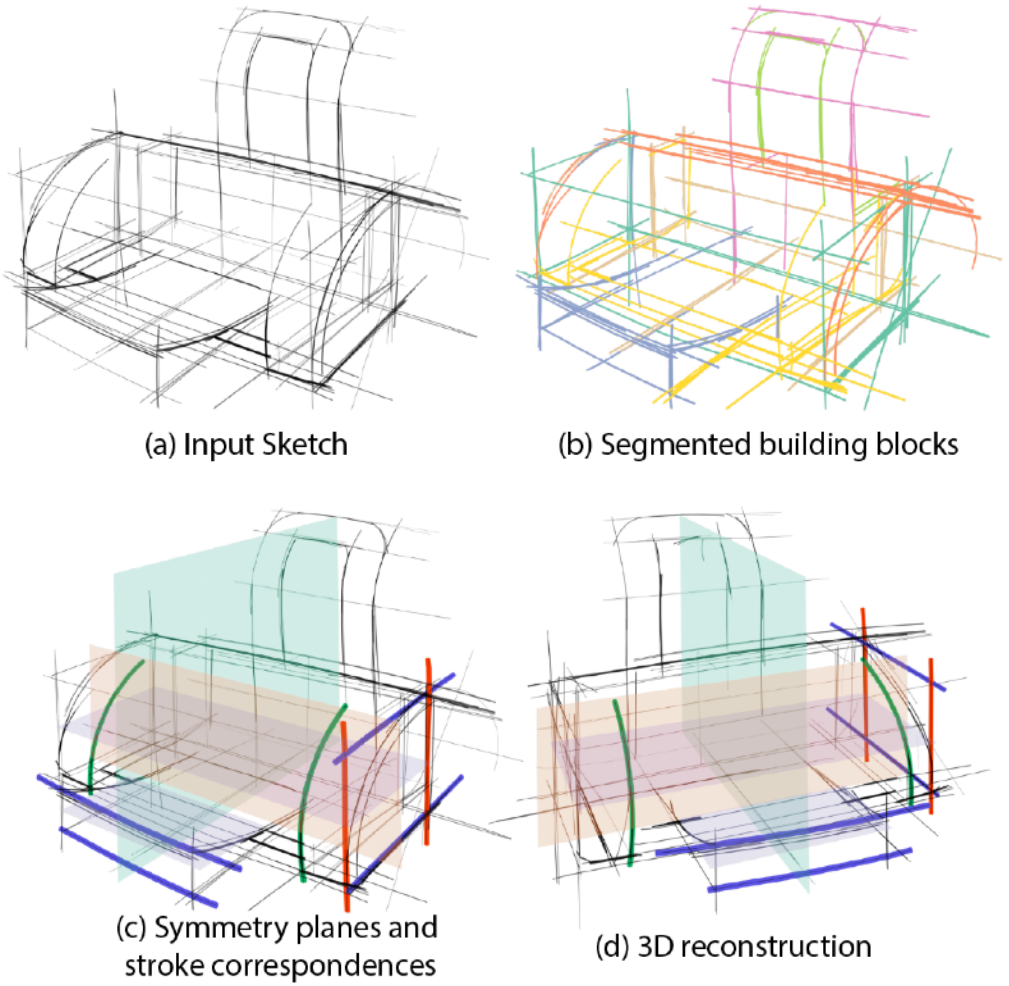


Axis-aligned constructive lines

Sketch Lifting



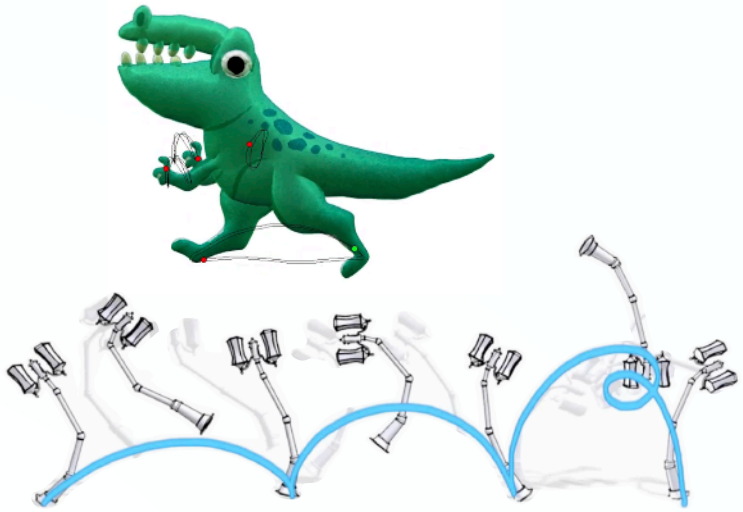
[Gryaditskaya et al. SIGGRAPH Asia 2020]



[Hähnlein et al. SIGGRAPH 2022]

Tracking Samples

2D Sketches



Models & Animations

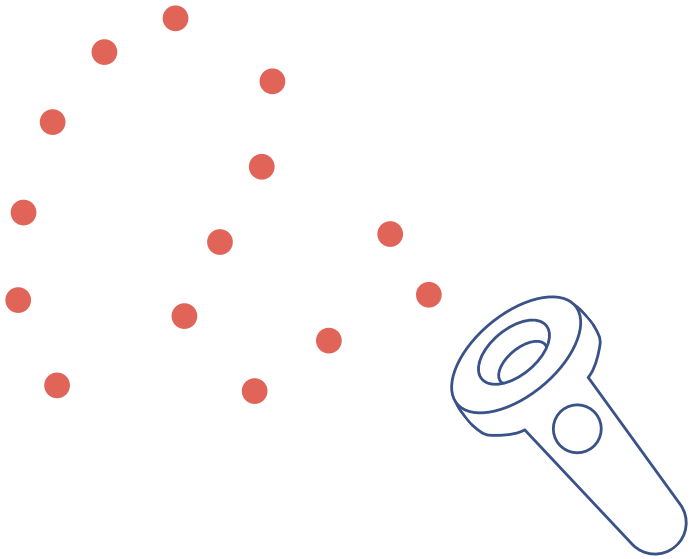
Raster Samples

3D Sketches

Sketch Surfacing

Creation Process

3D Sketches

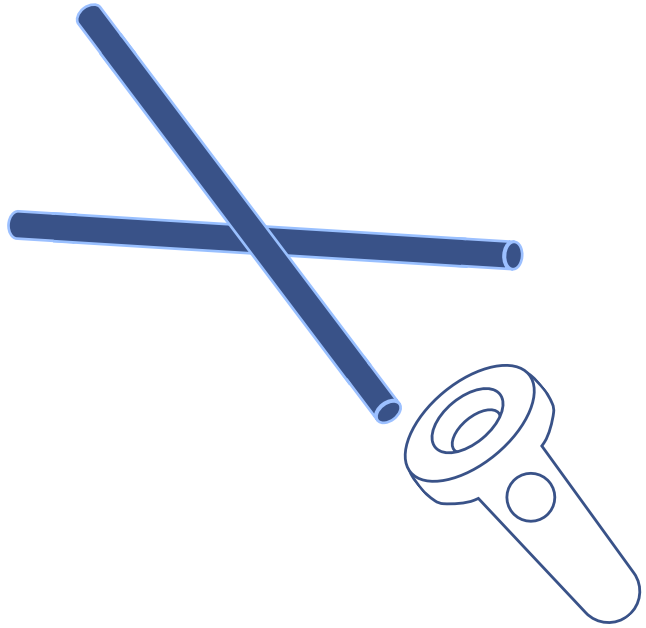


Samples

- No connectivity
- Inconsistently oriented normals

Ribbons

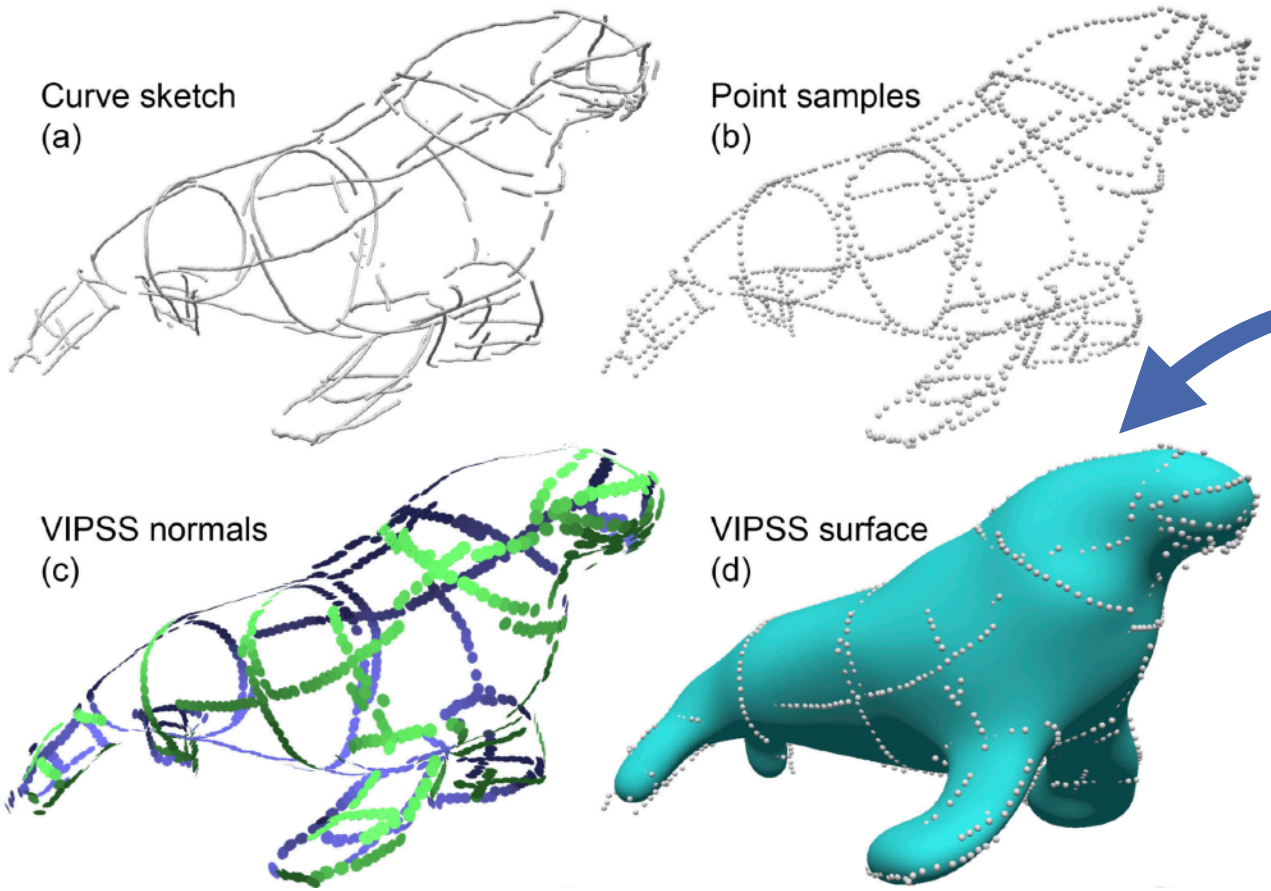
- With connectivity
- Inconsistently oriented normals
- Hidden parts



Tubes

- With connectivity
- No normals
- Can be lifted sketches

Surface Reconstruction from 3D Samples

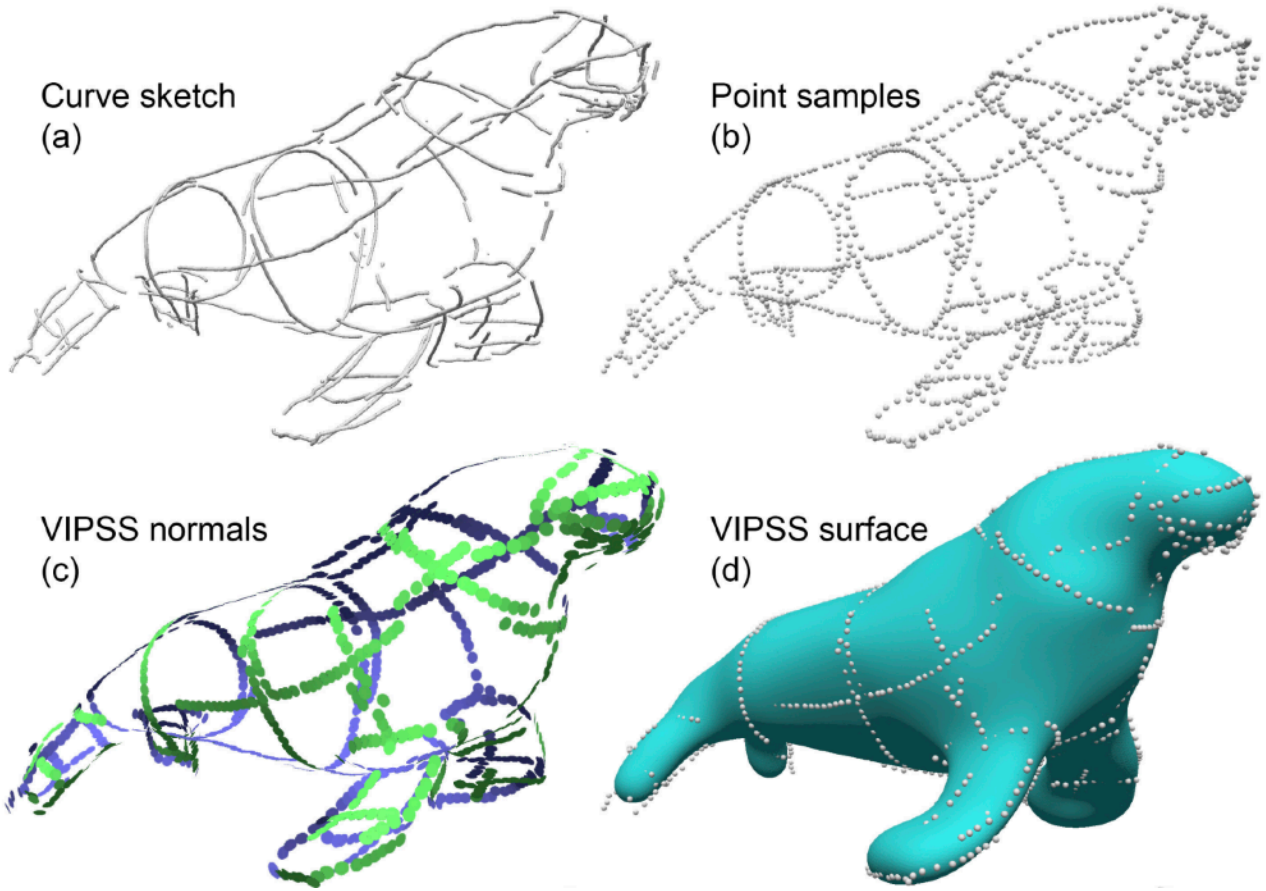


Implicit method that also orients

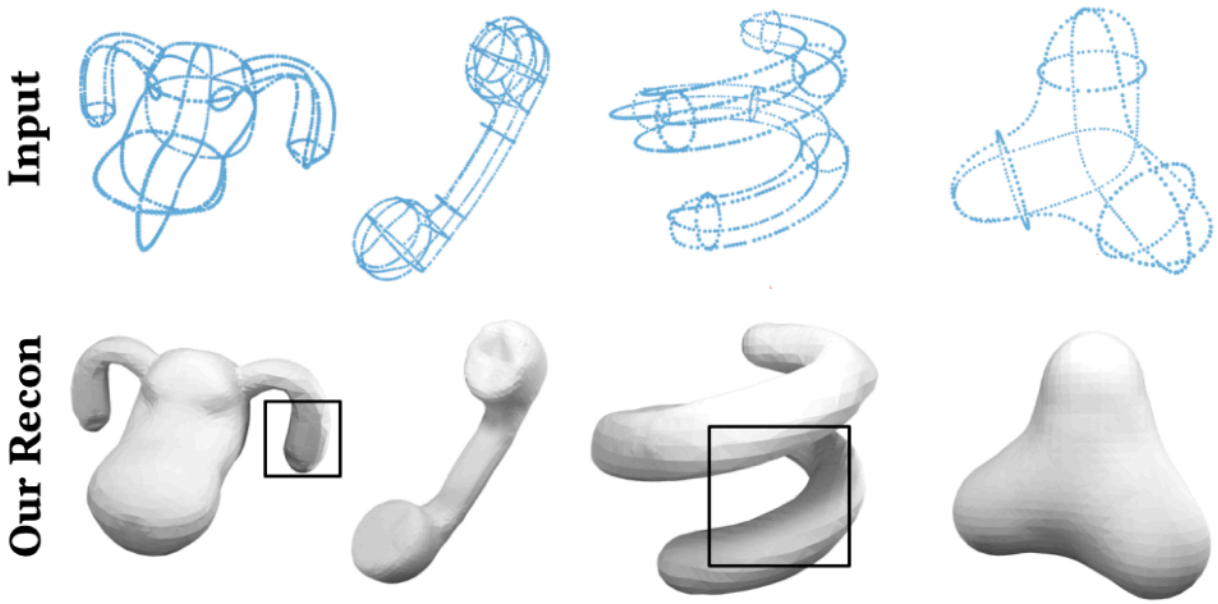
[VIPSS (Huang et al.) SIGGRAPH 2019]

Surface Reconstruction from 3D Samples

Sketch Surfacing



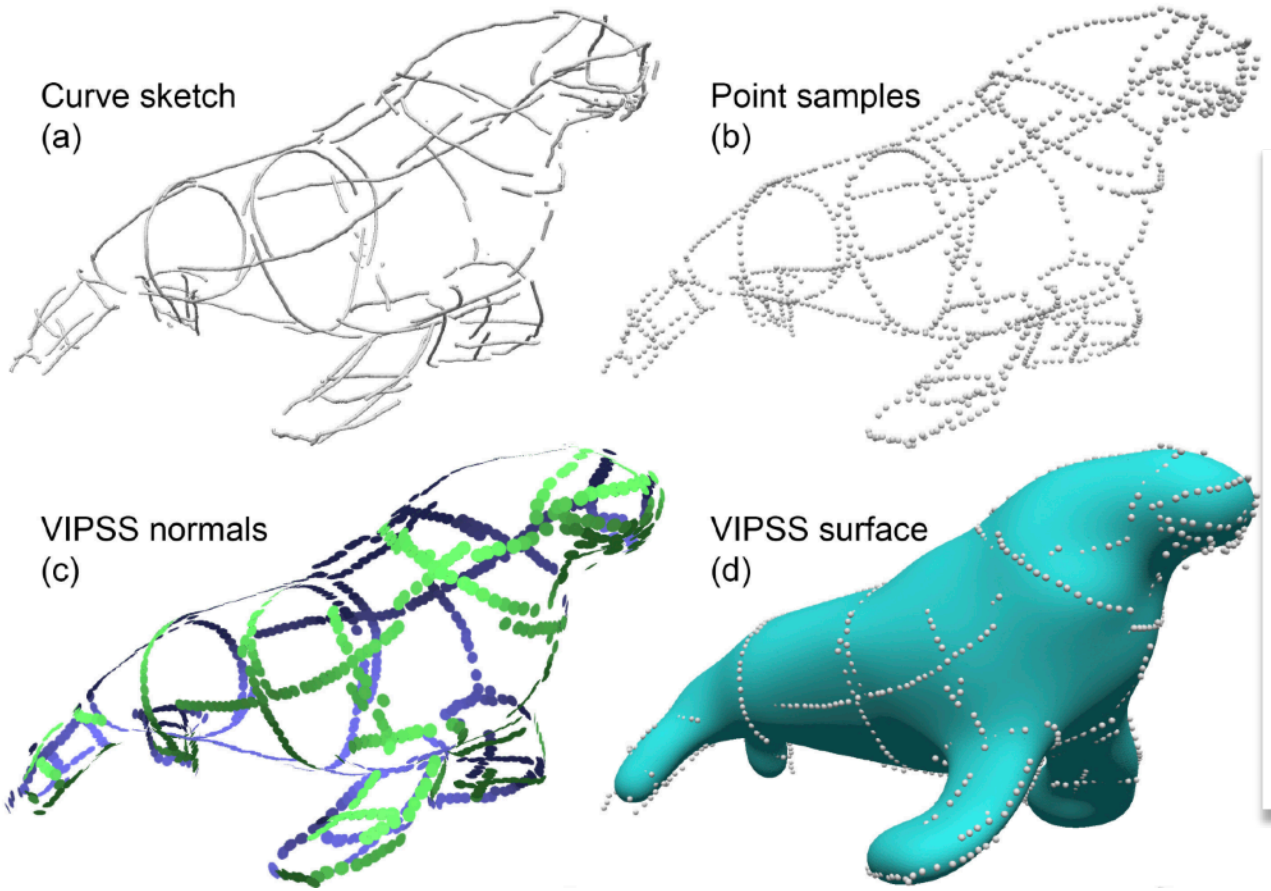
[VIPSS (Huang et al.) SIGGRAPH 2019]



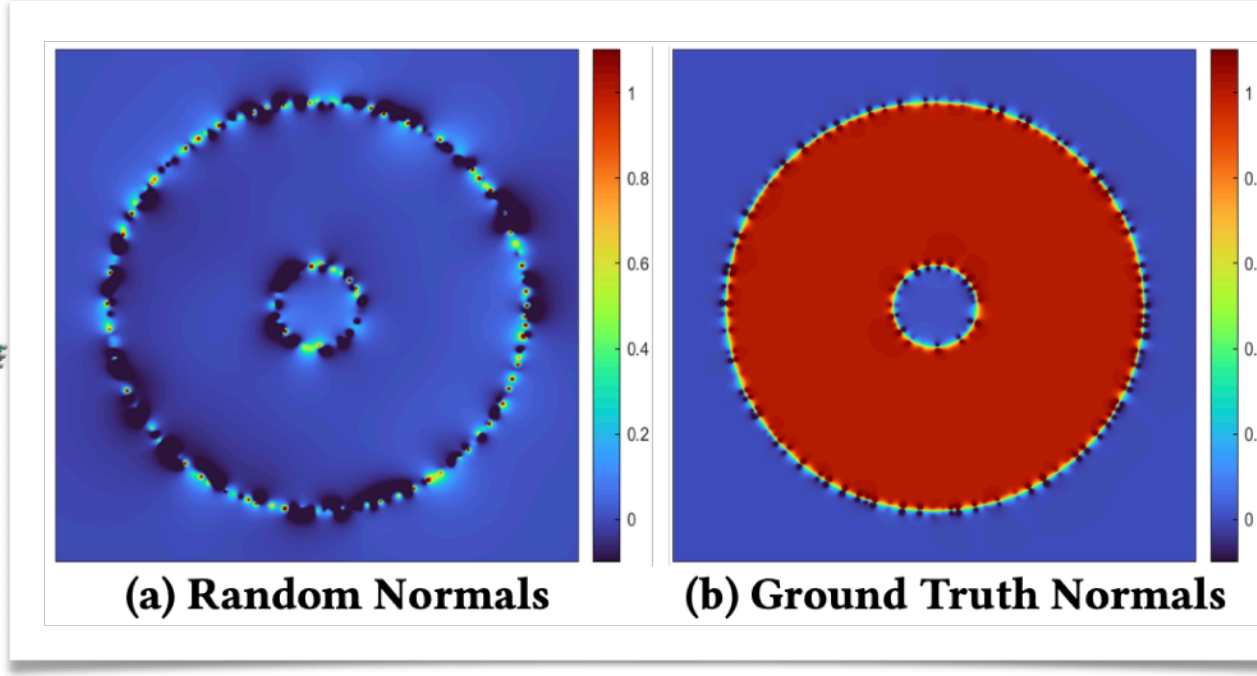
[Xu et al. SIGGRAPH 2023]

Surface Reconstruction from 3D Samples

Sketch Surfacing



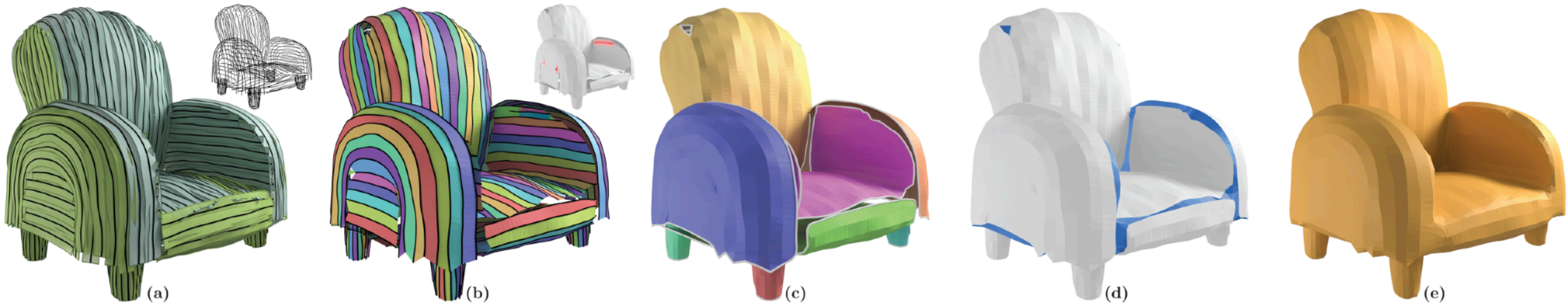
[VIPSS (Huang et al.) SIGGRAPH 2019]



[Xu et al. SIGGRAPH 2023]

Surface Reconstruction from 3D Ribbons

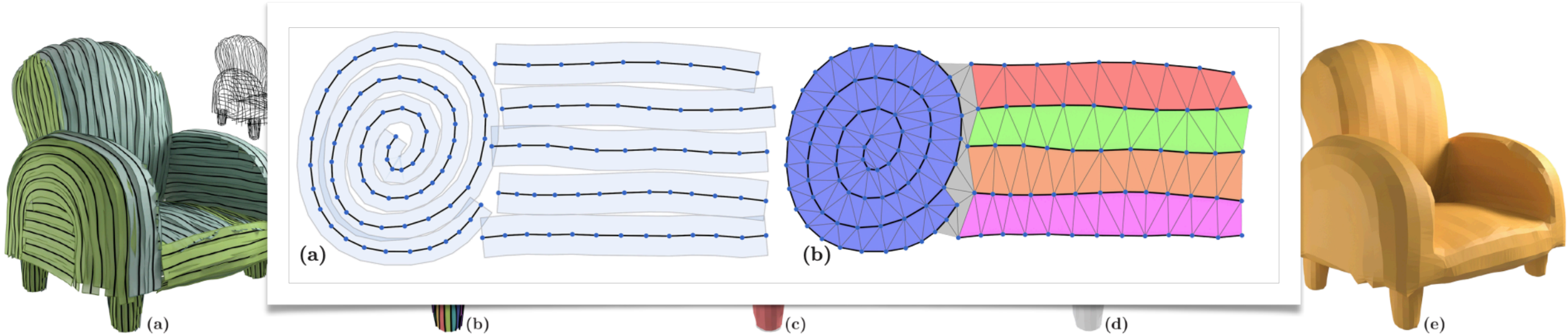
Sketch Surfacing



[SurfaceBrush (Rosales et al.) SIGGRAPH 2019]

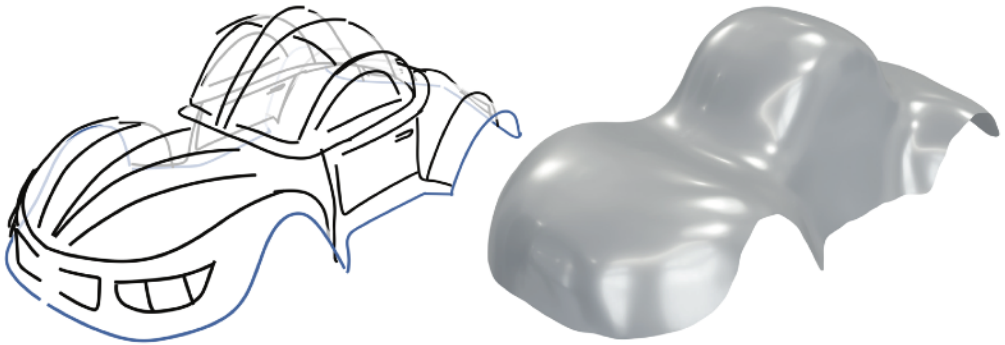
Surface Reconstruction from 3D Ribbons

Sketch Surfacing



[SurfaceBrush (Rosales et al.) SIGGRAPH 2019]

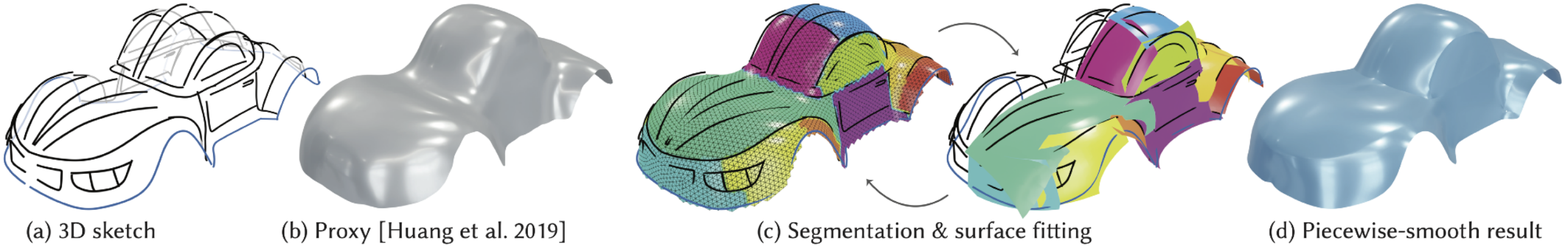
Surface Reconstruction from 3D Tubes



(a) 3D sketch (b) Proxy [Huang et al. 2019]

[Piecewise-smooth surface fitting onto unstructured 3D sketches (Yu et al.) SIGGRAPH 2022]

Surface Reconstruction from 3D Tubes



(a) 3D sketch (b) Proxy [Huang et al. 2019] (c) Segmentation & surface fitting (d) Piecewise-smooth result

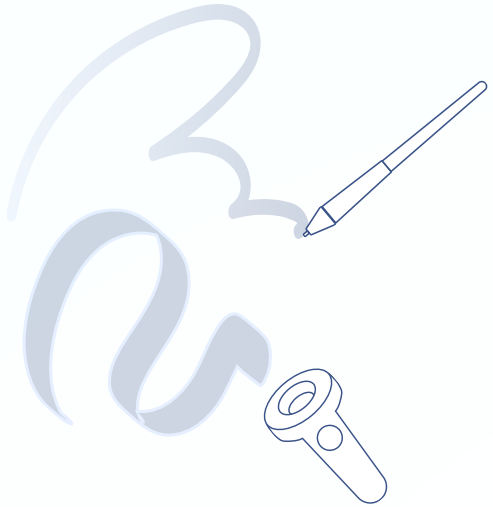
Initial mesh from VIPSS

[Piecewise-smooth surface fitting onto unstructured 3D sketches (Yu et al.) SIGGRAPH 2022]

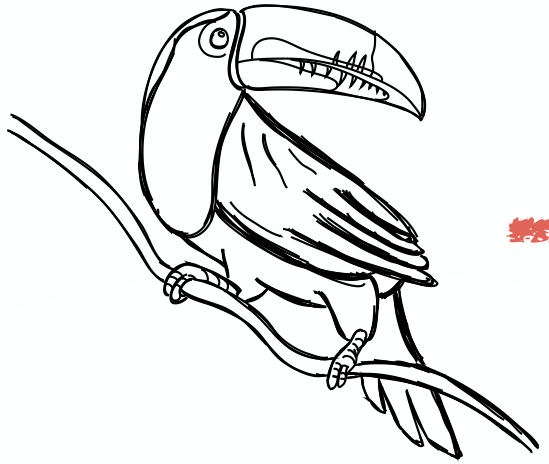
Takeaways

- Sketch lifting is an ill-conditioned problem that requires priors. Using domain-specific priors can reduce the complexity.
- Surface reconstruction from 3D sketches shares many common points as the standard surface reconstruction but also with its own characteristics and challenges.

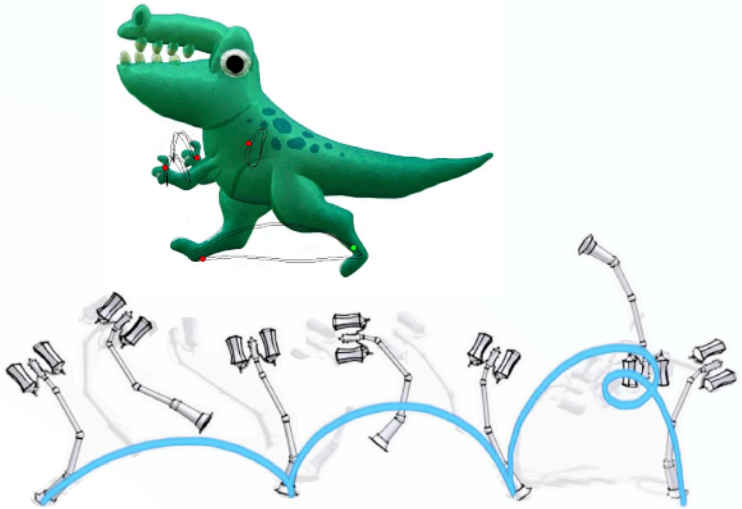
More papers:



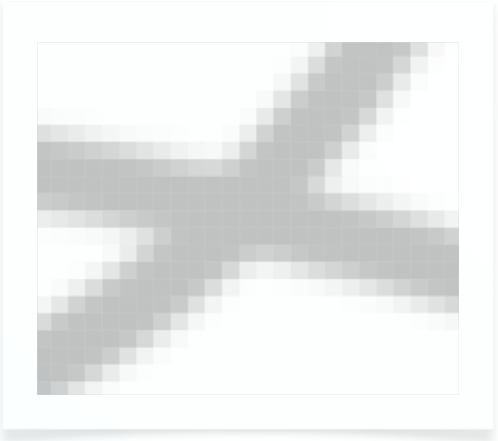
Tracking Samples



2D Sketches



Models & Animations



Raster Samples

3D Sketches

Sketch-Based Modeling & Animation

Creation Process

3D Modeling and Animation are Time-Consuming

Modeling

Editing

Posing & Animating

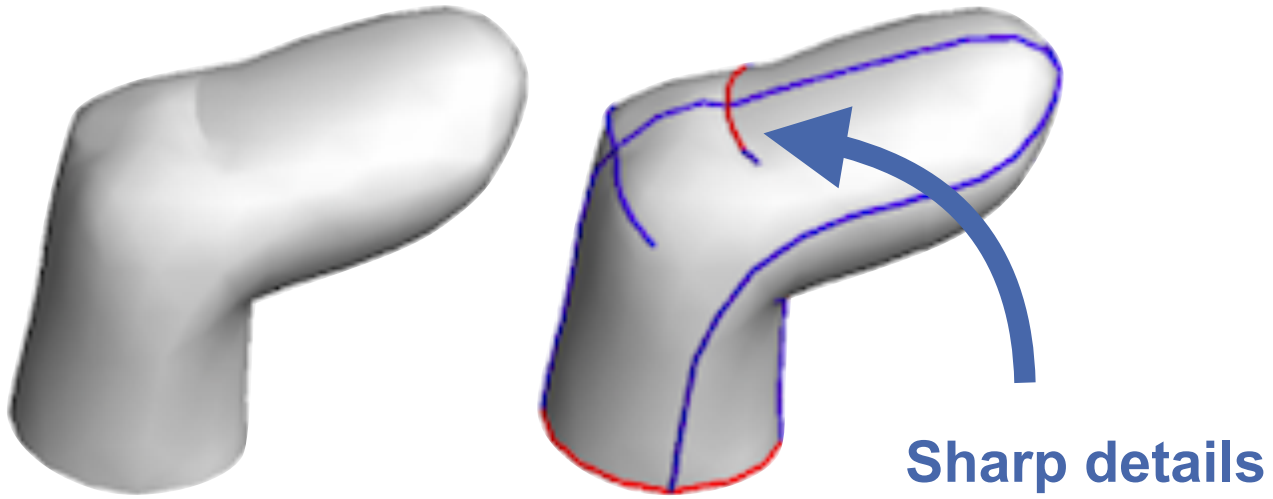
Sketch-Based Approaches

- Intuitive and expressive
- Novice friendly
- Easy to communicate

Sketch-Based Modeling: Organic Shapes

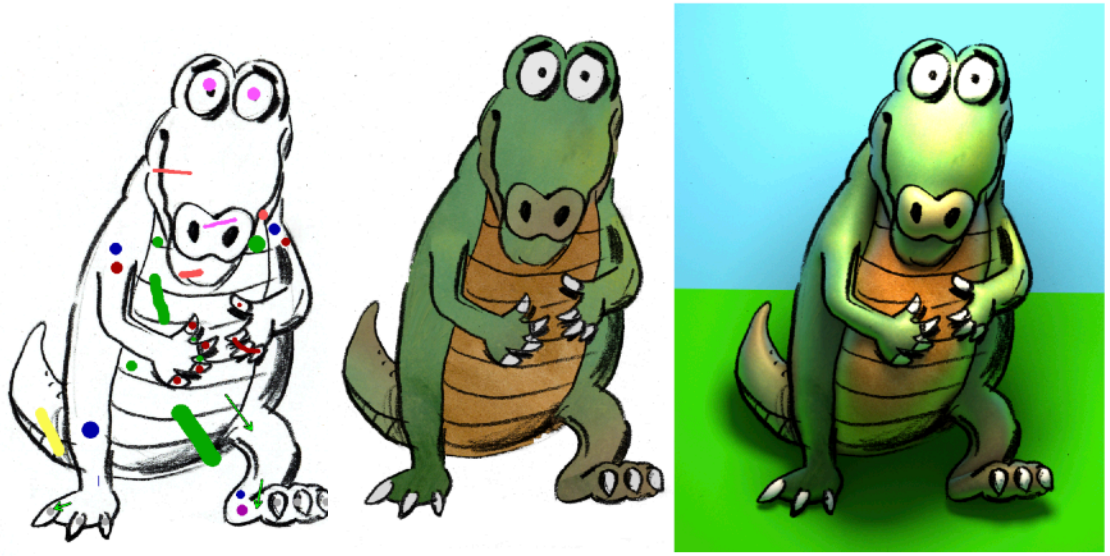
[Teddy (Igarashi et al.) SIGGRAPH 1999]

Sketch-Based Modeling: Organic Shapes

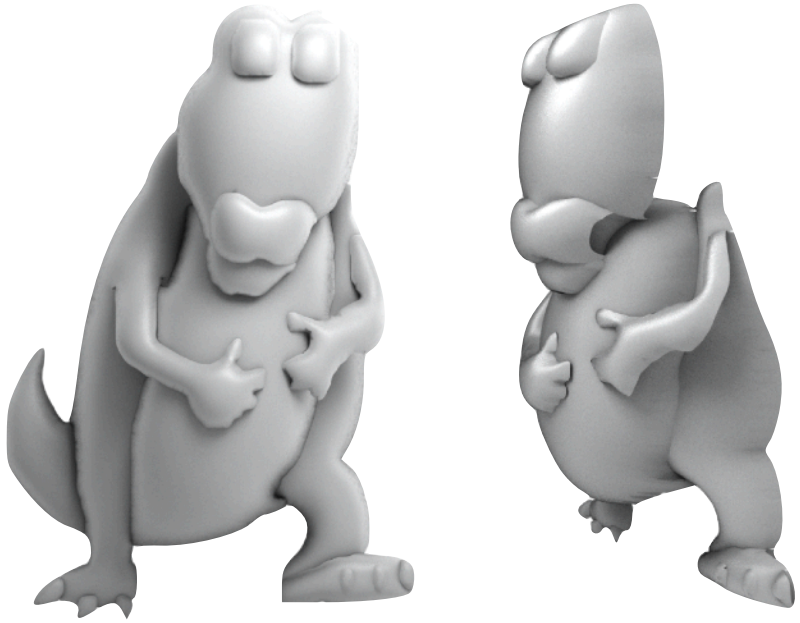


[Fibermesh (Nealen et al.) SIGGRAPH 2007]

Sketch-Based Modeling: Organic Shapes

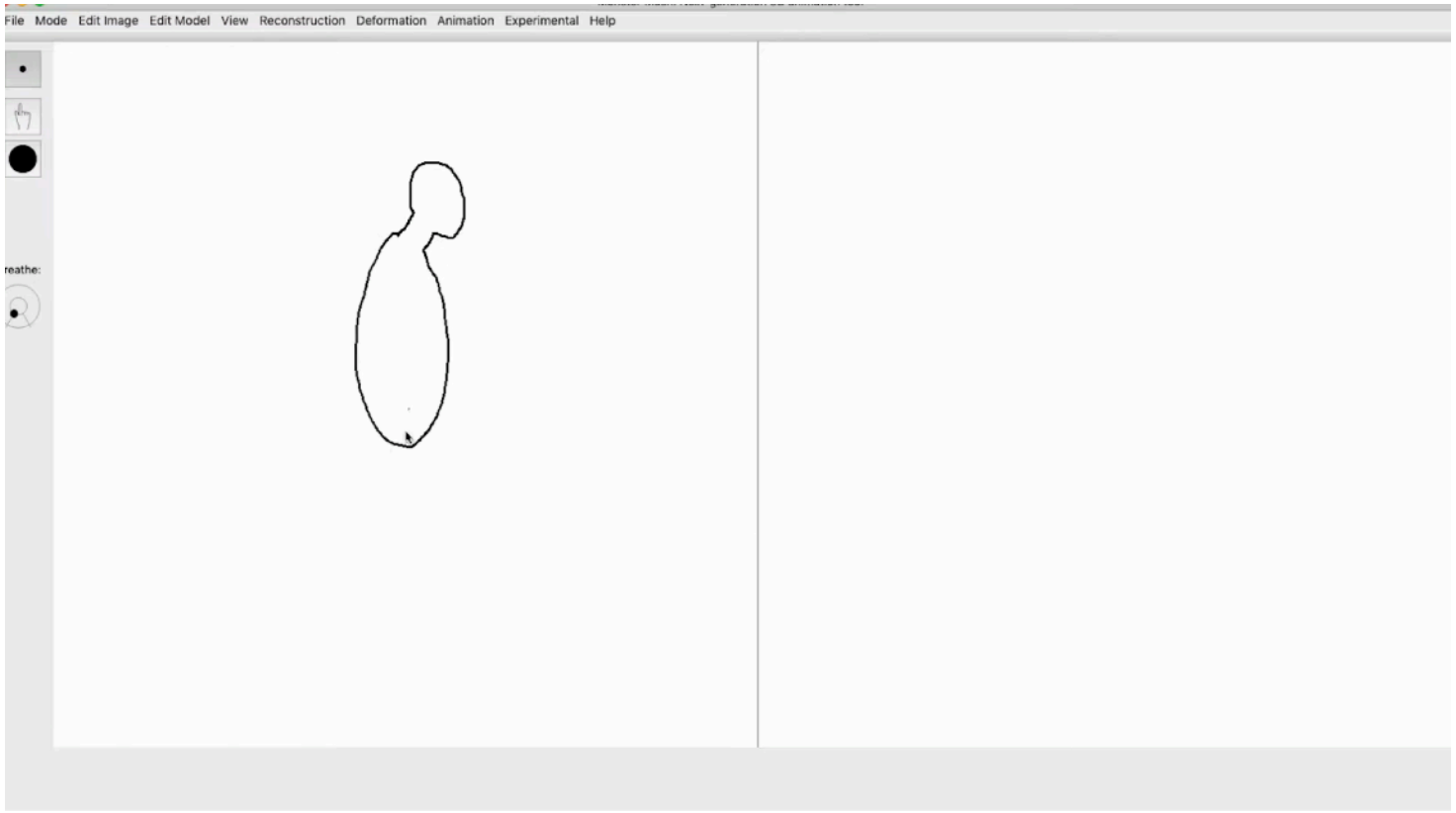


Sketch + Annotation → Bas-Relief Mesh



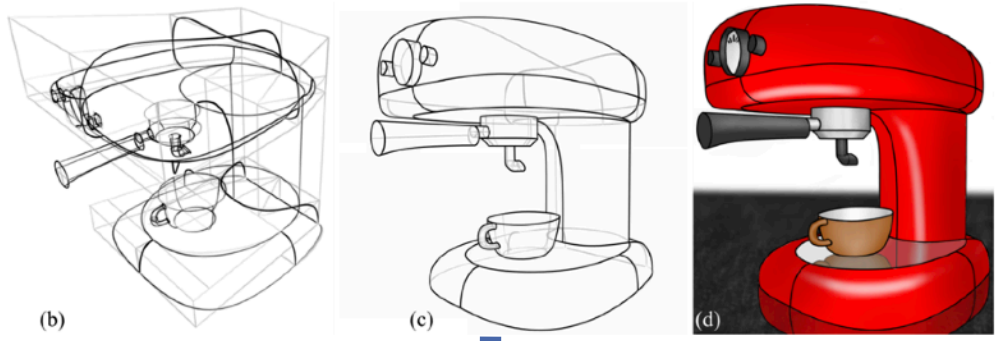
[Ink-and-ray (Sýkora et al.) SIGGRAPH 2014]

Sketch-Based Modeling: Organic Shapes

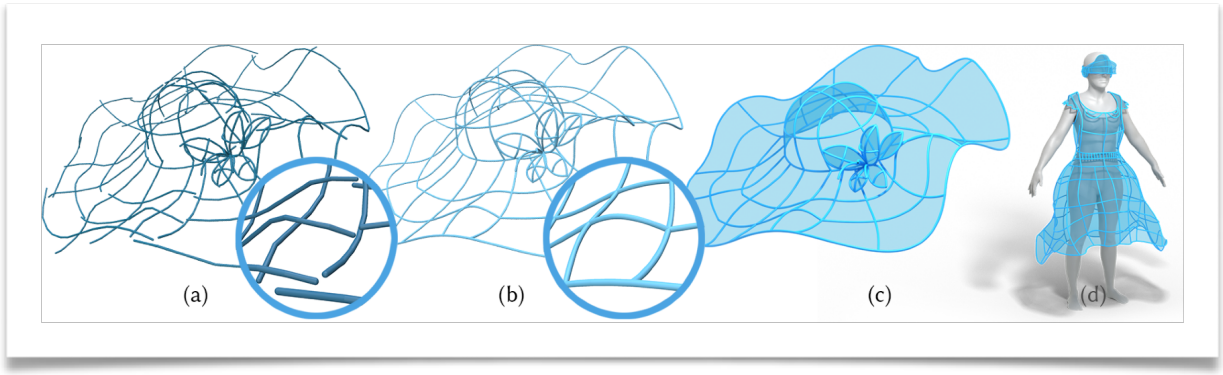


[Monster mash (Dvorožňák et al.) SIGGRAPH Asia 2020]

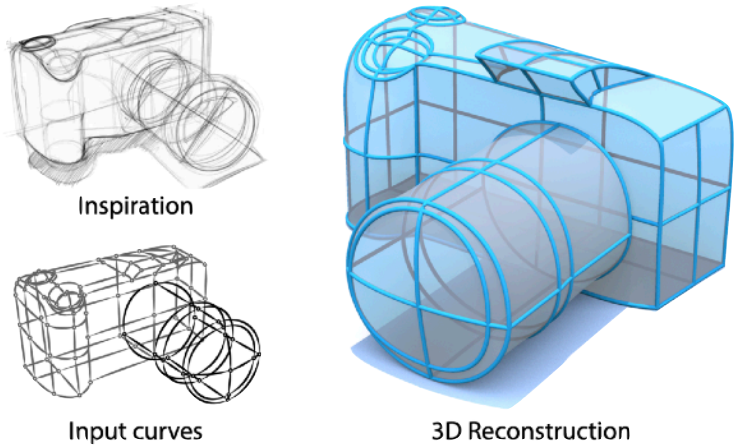
Sketch-Based Modeling: Geometric & CAD Models



[Schmidt SIGGRAPH'09]



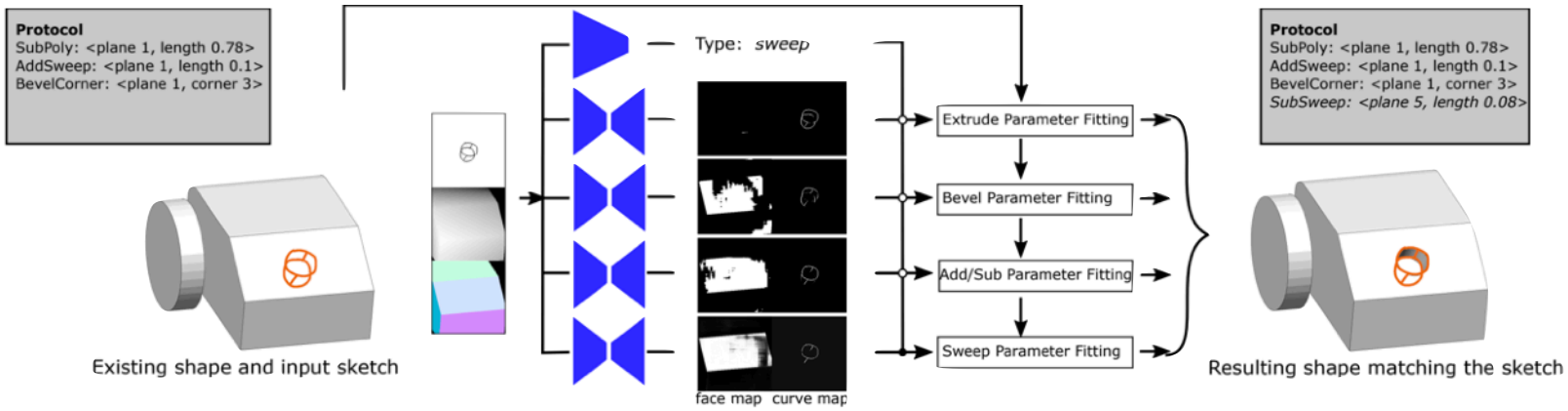
Scaffold requirement relaxed



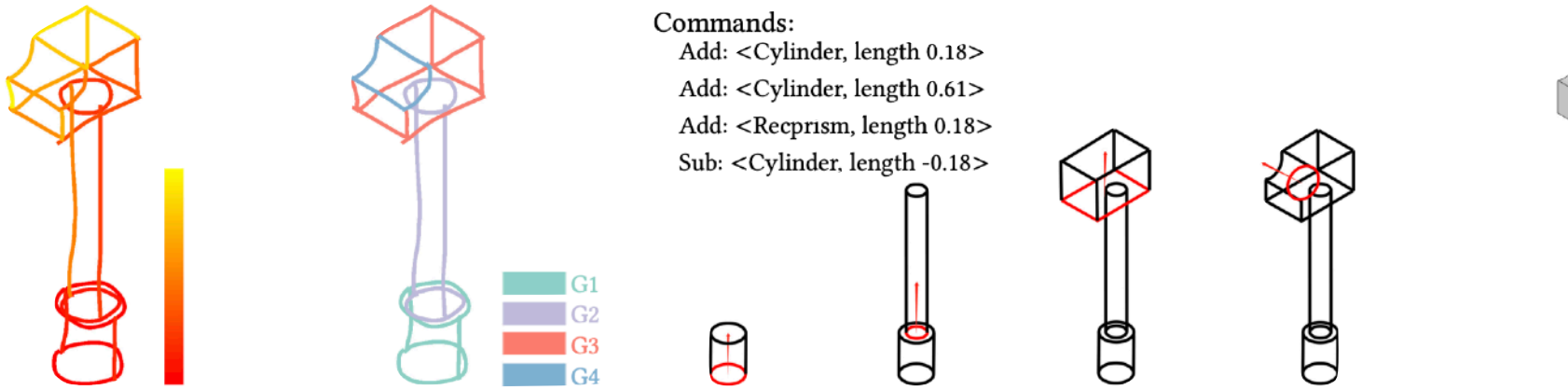
[Xu SIGGRAPH'14]

Surfacing Curve Networks

Sketch-Based Modeling: Geometric & CAD Models



[Li SIGGRAPH Asia'20]



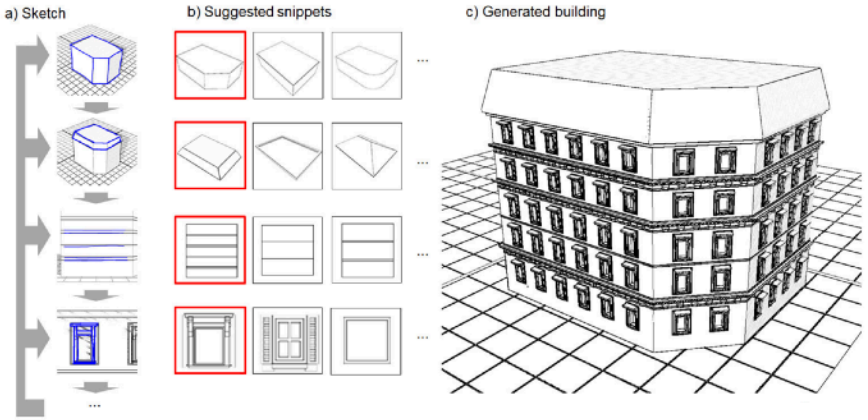
[Li SIGGRAPH'22]

CAD Modeling

Sketch-Based Modeling: Domain Specific

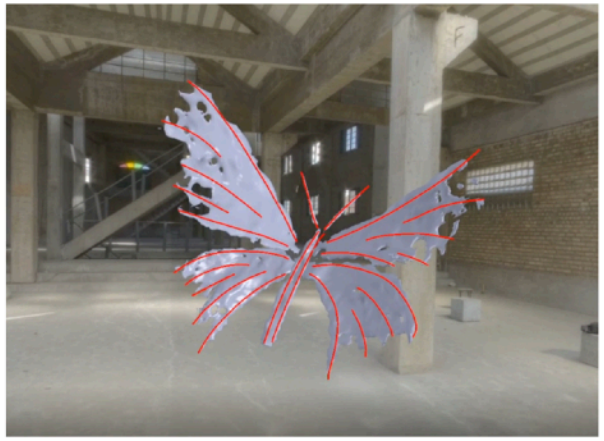
Layered 3D Models

[De Paoli SIGGRAPH'15]



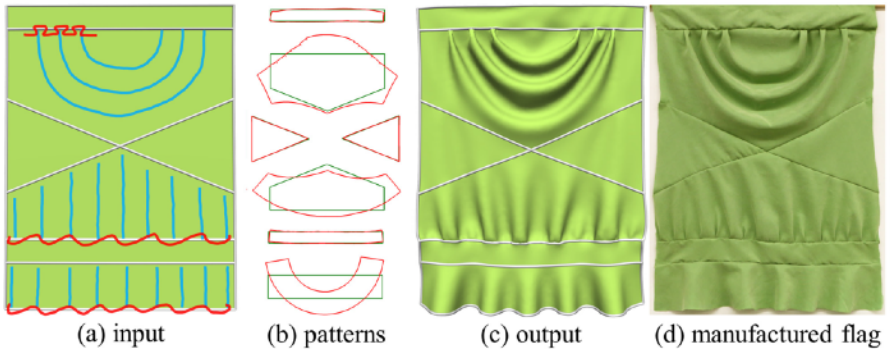
Building Models

[Nishida SIGGRAPH'16]



Liquid Modeling

[Yan SIGGRAPH Asia'20]



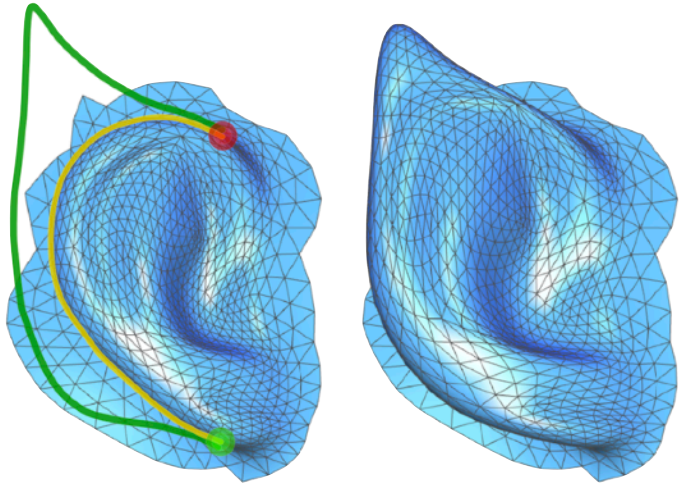
Garment Design

[Li SIGGRAPH'18]

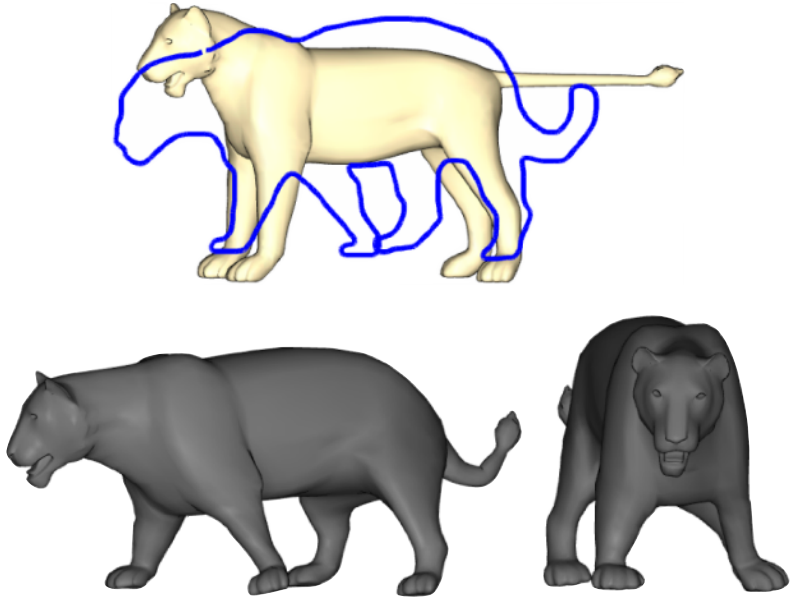
Hair Image Synthesis

[Xiao SIGGRAPH Asia'21]

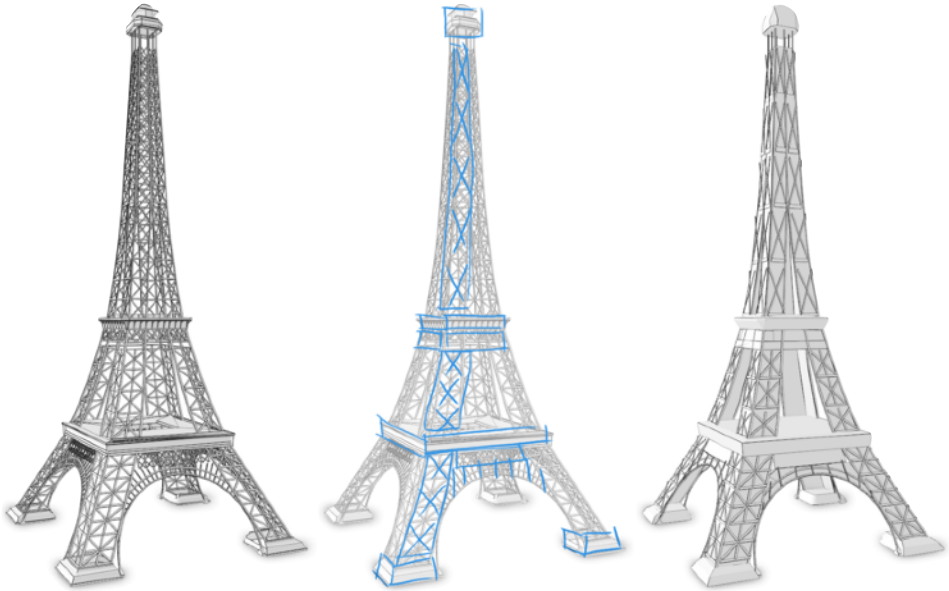
Sketch-Based Editing



[Nealen et al. SIGGRAPH 2005]



[Kraevoy et al. SBIM 2009]



[Kratt et al. CG Forum 2018]

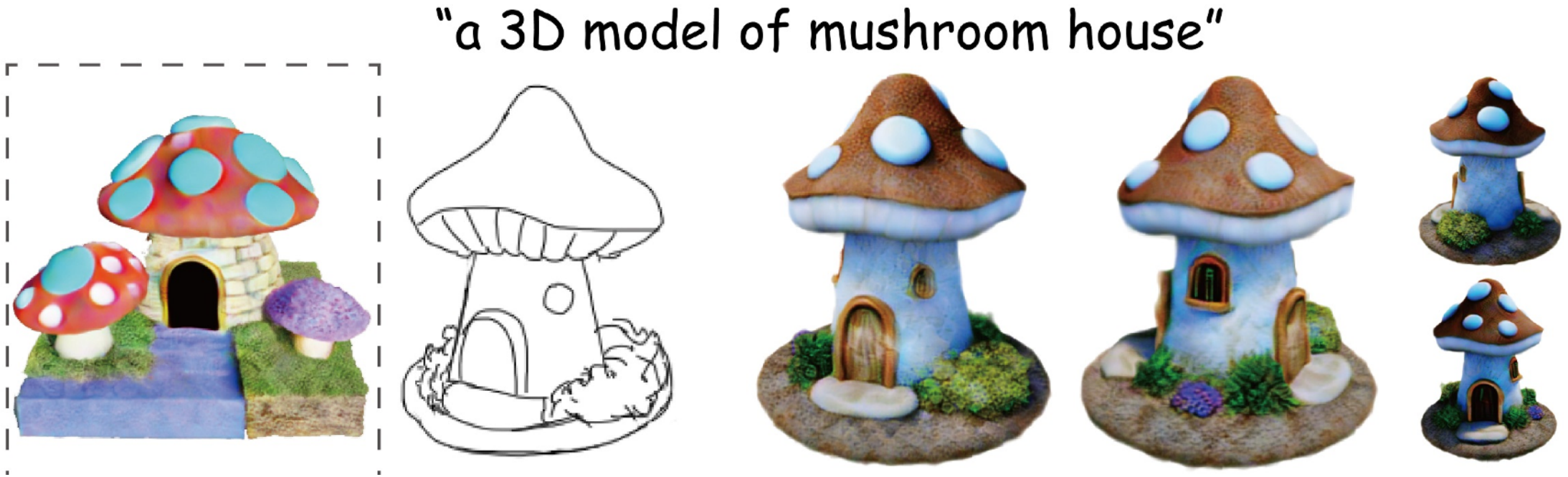
Sketch-Based Editing

Base NeRF

Diffusion-model-based 3D generation + Sketch edits

[SKED (Mikaeili et al.) ICCV 2023]

Sketch-Based Editing



Diffusion-model-based 3D generation + Sketch edits

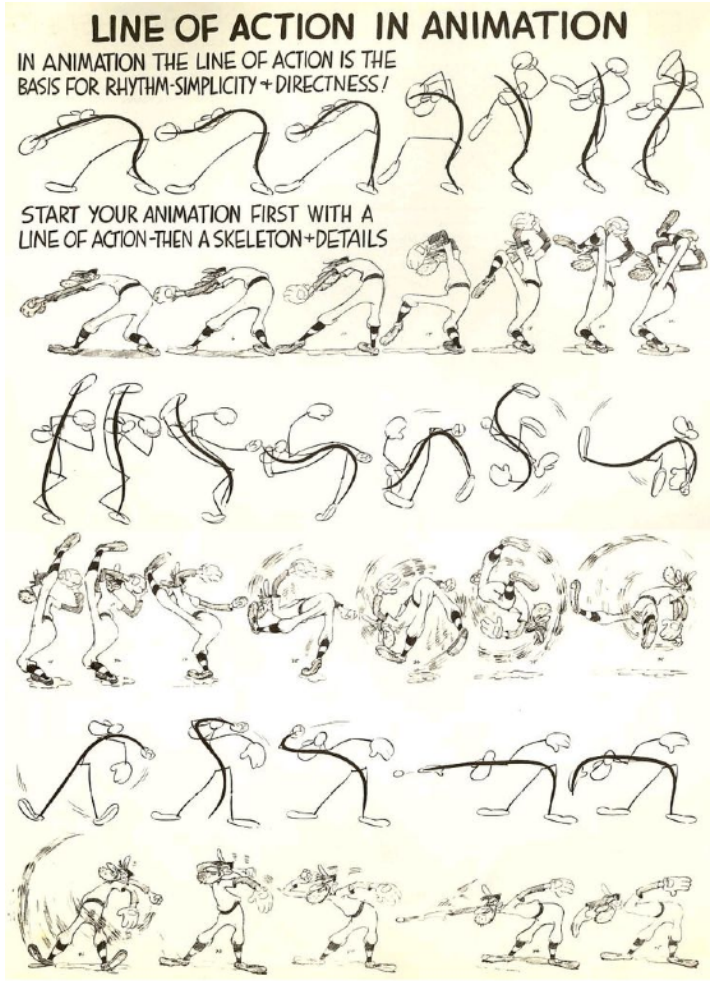
[SketchDream (Liu et al.) **SIGGRAPH 2024**]

Sketch-Based Editing

Diffusion-model-based 3D generation + Sketch edits

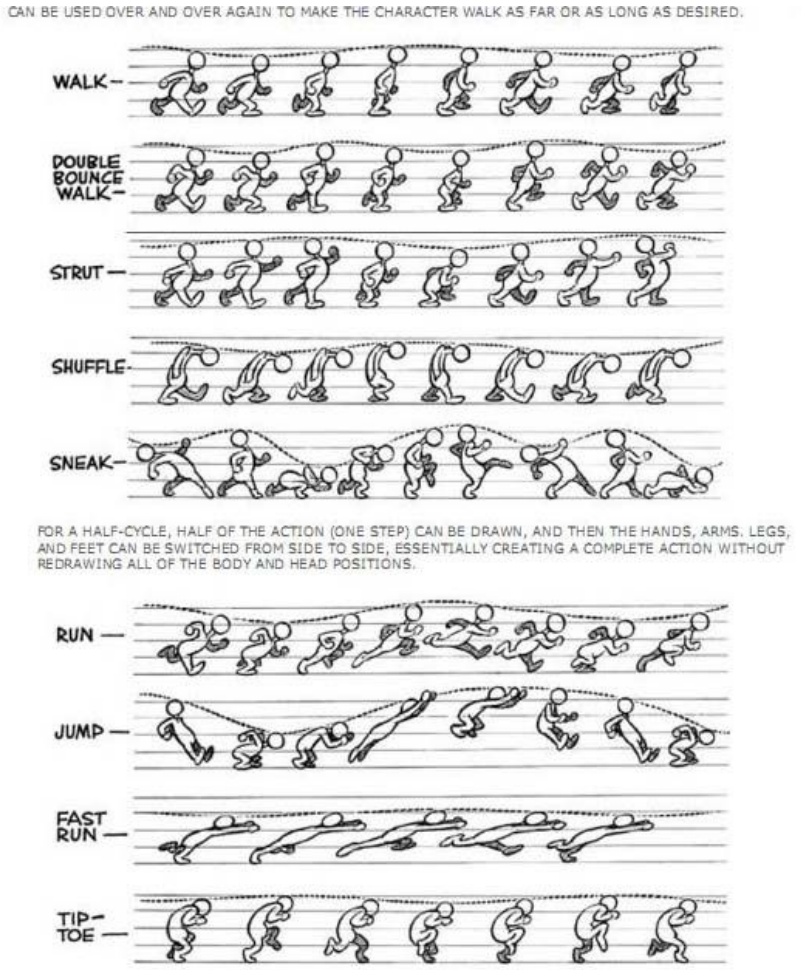
[SketchDream (Liu et al.) **SIGGRAPH 2024**]

Sketch-Based Animation Control



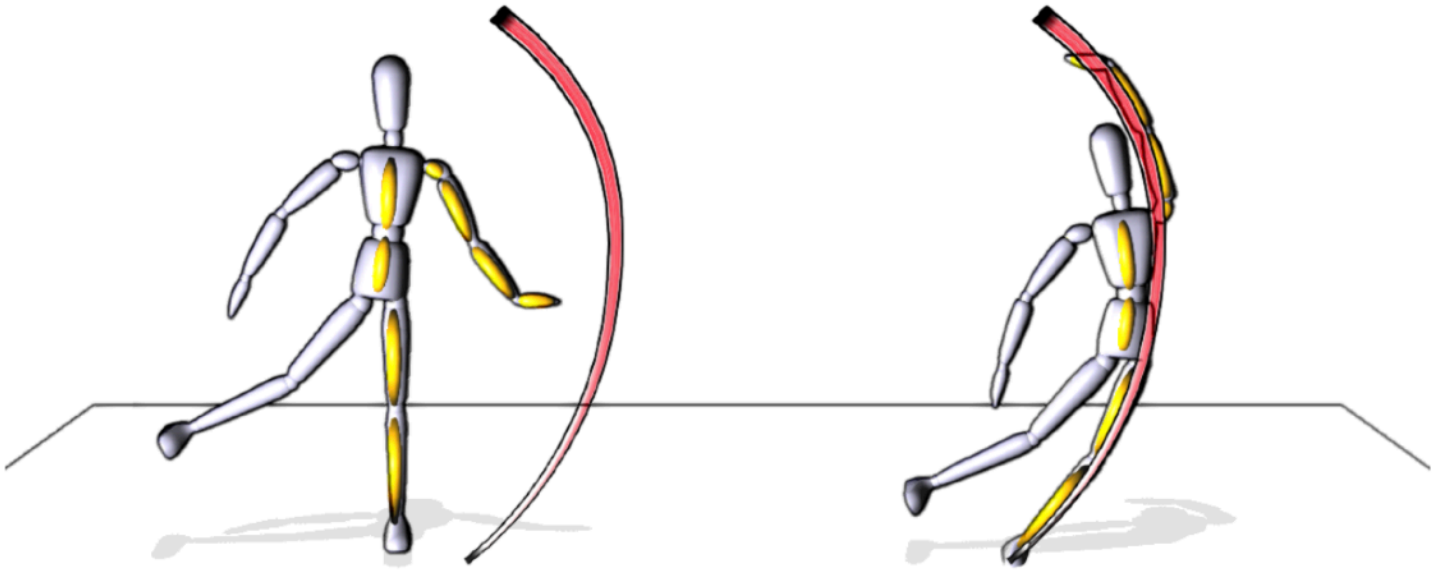
Preston Blair "Line of action"

Posing



Animation

Sketch-Based Animation Control: Posing



[The line of action (Guay et al.) SIGGRAPH 2013]

Sketch-Based Animation Control: Posing

Raster Drawing

Output Pose

Retargeted Pose

[Sketch2Pose (Brodt and Bessmeltsev) SIGGRAPH 2022]

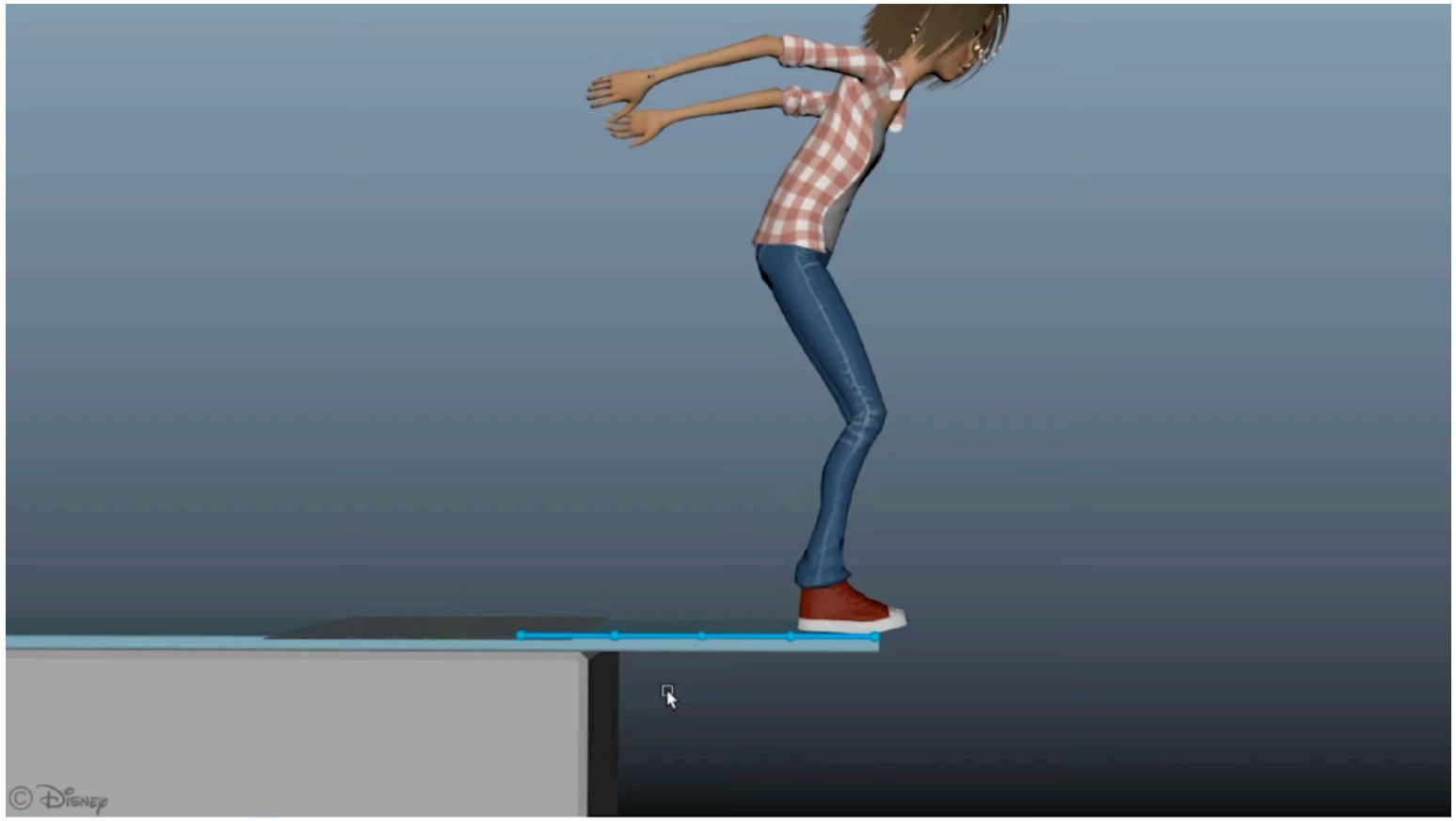
Sketch-Based Animation Control: Animation

[Guay et al. SIGGRAPH 2015]

Sketch-Based Animation Control: Animation

[SketchiMo (Choi et al.) SIGGRAPH 2016]

Sketch-Based Animation Control: Animation



[Tangent-space optimization for interactive animation control (Ciccone et al.) SIGGRAPH 2019]

Takeaways

- Knowledge of sketch-based modeling can be adapted to new areas such as 3D sketching.
- Diffusion-model-based 3D generation can be an interesting direction for sketch-based methods.

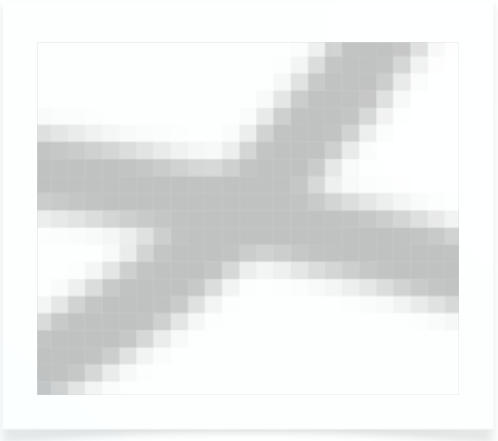
More papers:

Tracking Samples

2D Sketches

Models & Animations

Sketch-Related Vision Tasks



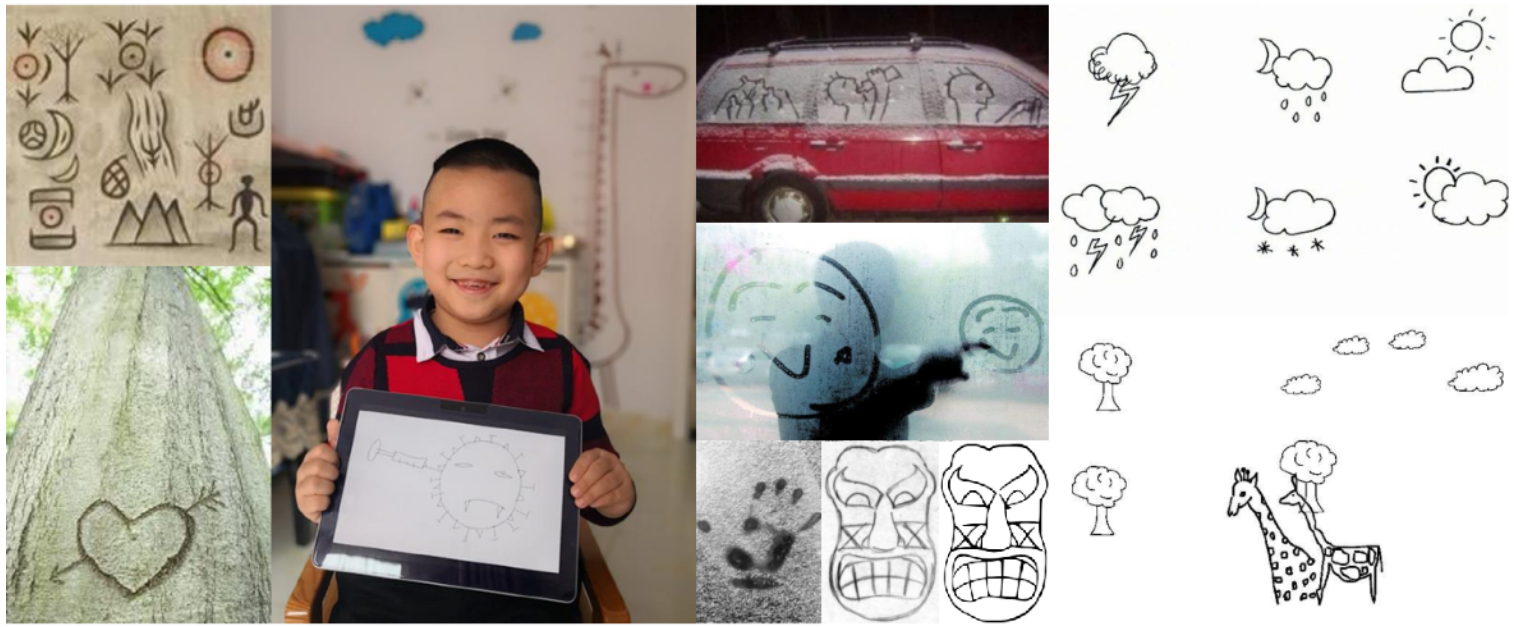
Raster Samples

3D Sketches

Data for Learning

Creation Process

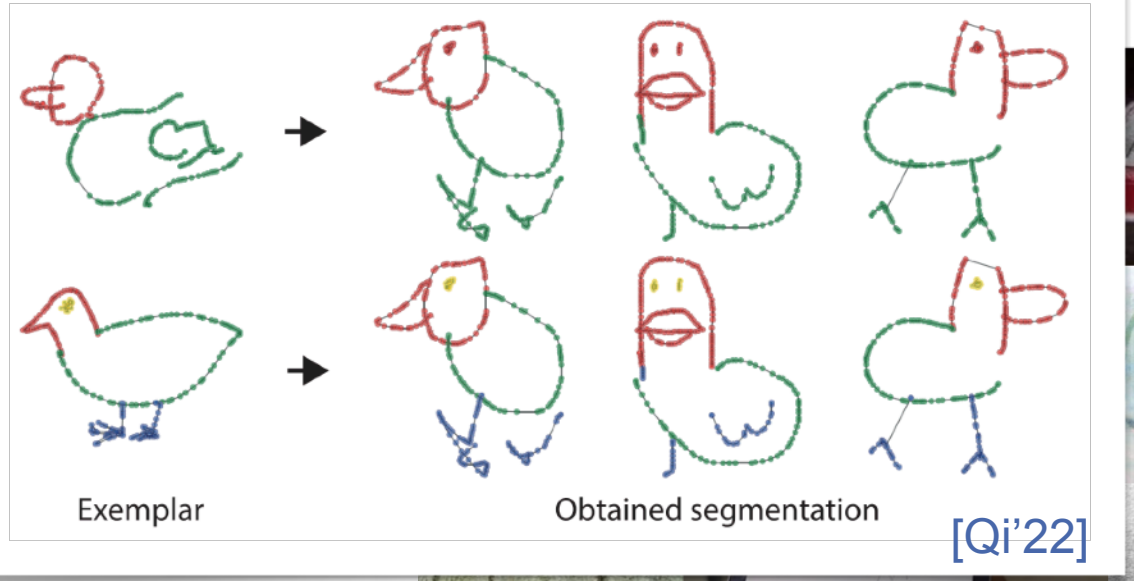
Sketches under a Vision Len



[Deep learning for free-hand sketch: A survey (Xu et al.) TPAMI 2022]

Sketches under a Vision Len

Sketch-Related Vision Tasks

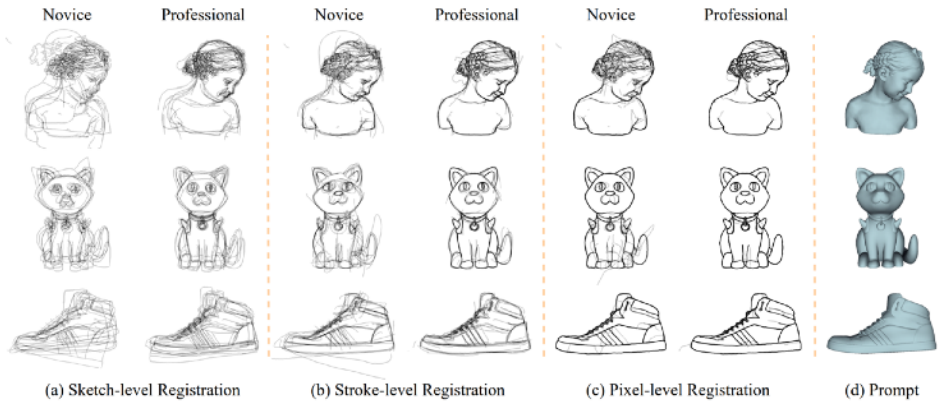


[Qi'22]

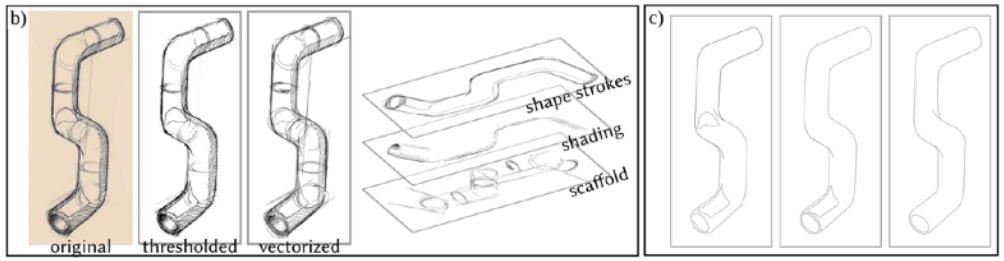
[Bhunia'22]

[Deep learning for free-hand sketch: A survey (Xu et al.) TPAMI 2022]

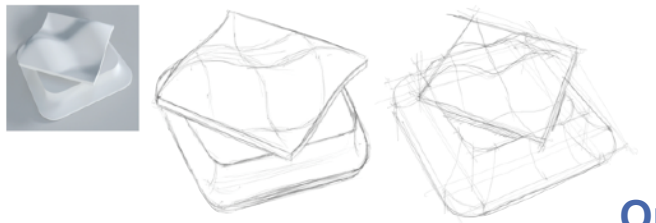
Datasets



DifferSketching



A Benchmark for Rough Sketch Cleanup

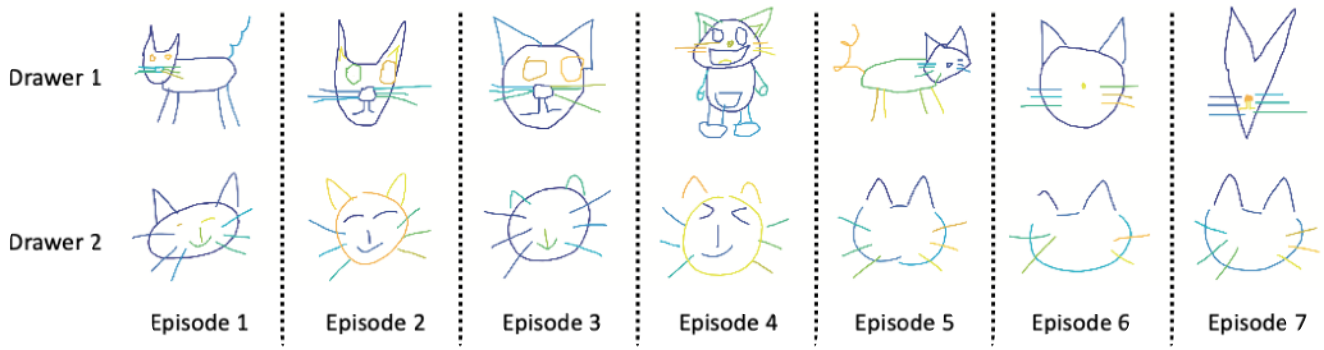


OpenSketch

Google quick draw

Human-created drawings

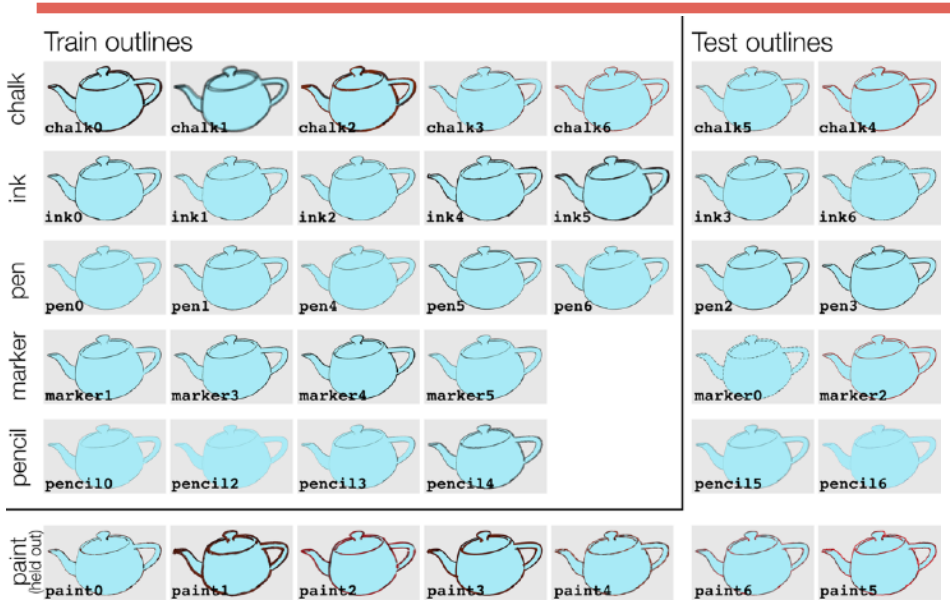
- Novice and professional.
- Sketches and doodles.



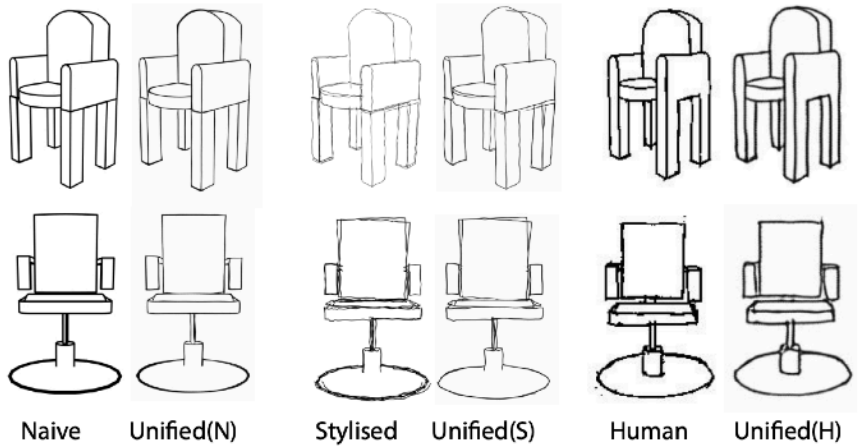
Humans gradually refine their sketching strategies for early recognition.

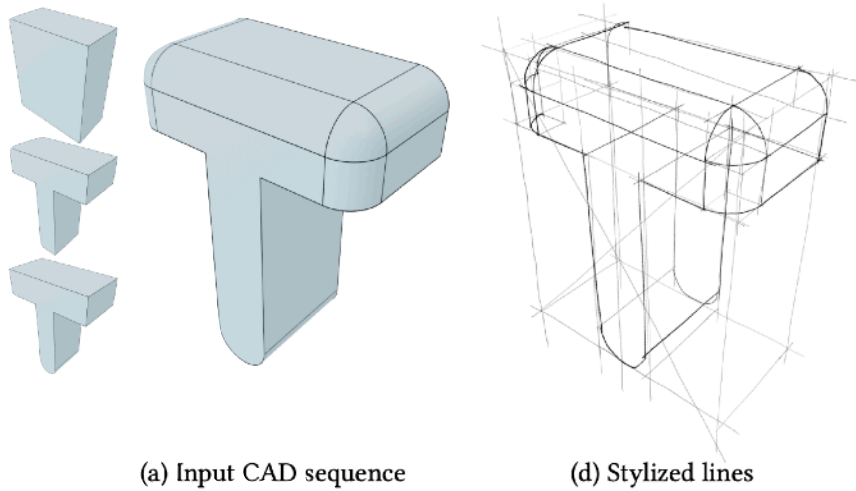
SlowSketch
and more from SketchX lab

Datasets



Creative Flow+

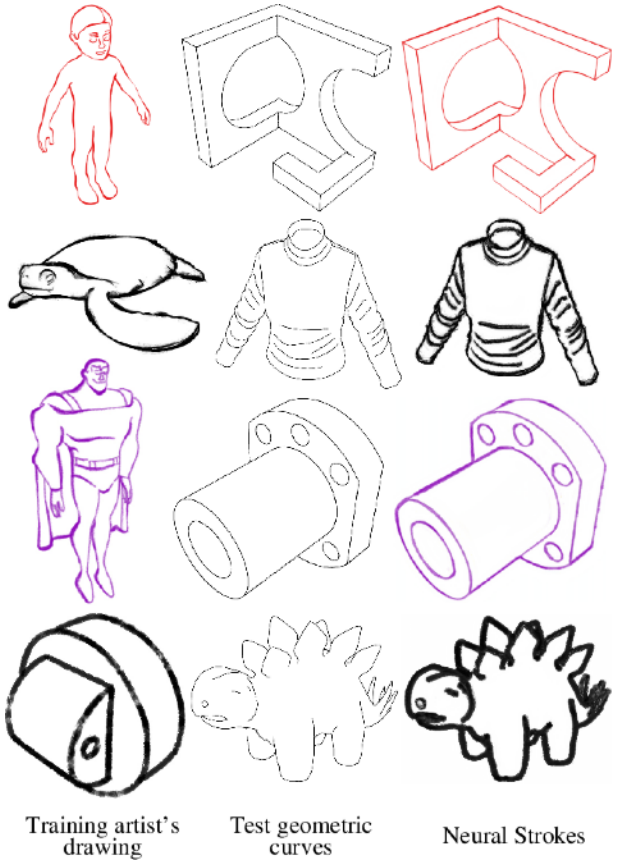




CAD2Sketch

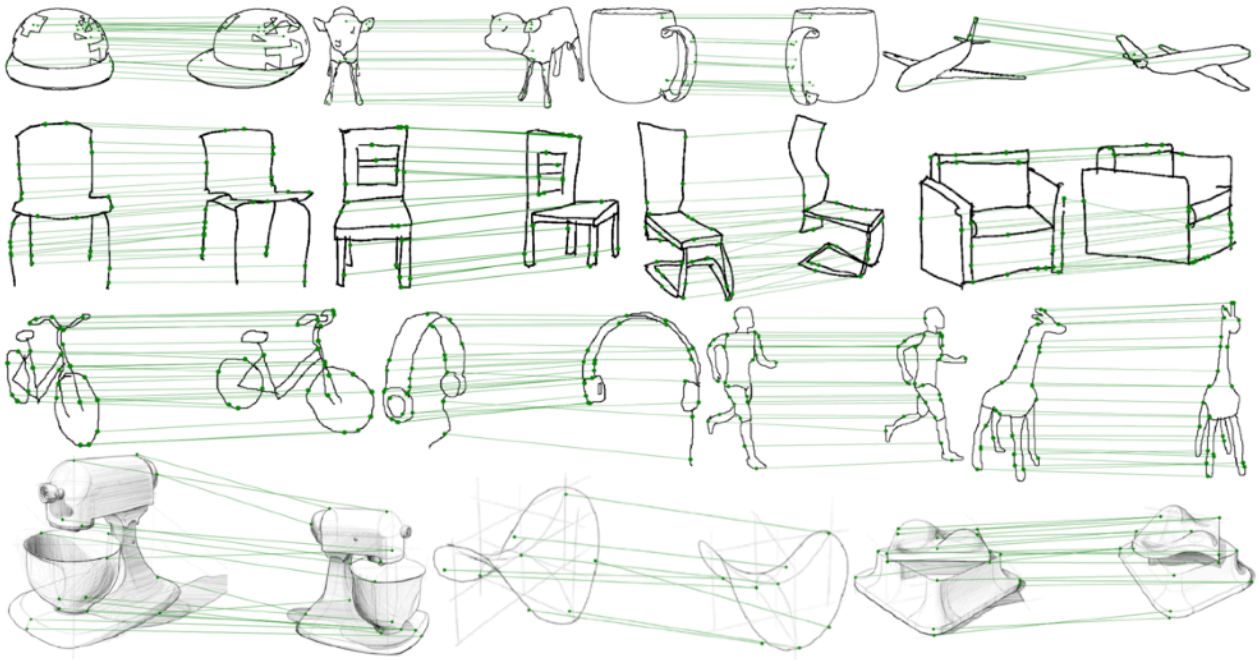
Synthetic drawings

- Generated datasets.
- Non-photorealistic rendering methods.

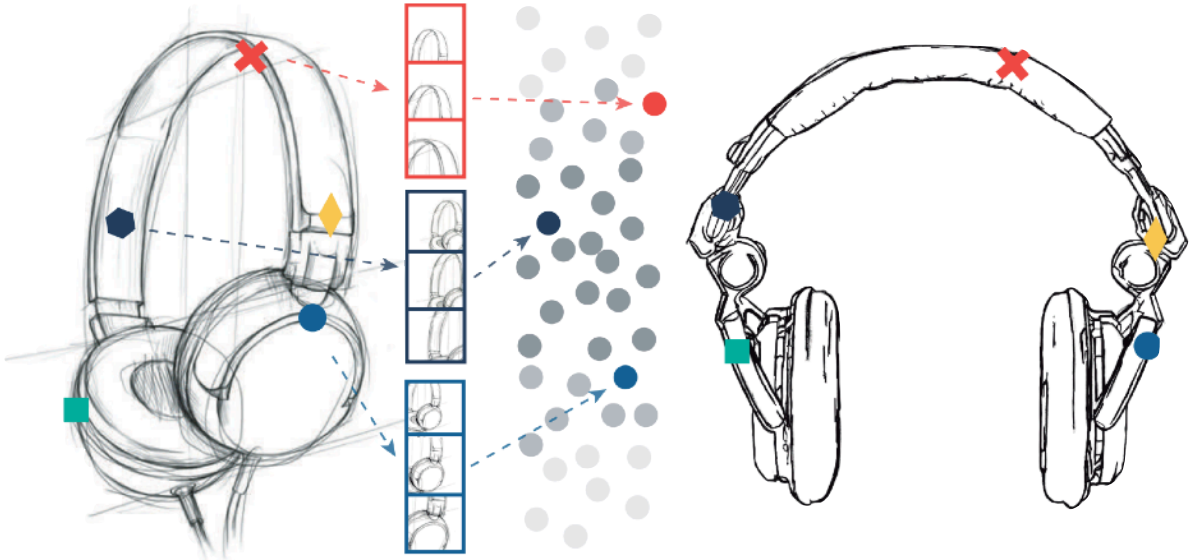


NeuralStrokes

Understanding Sketches: Correspondences

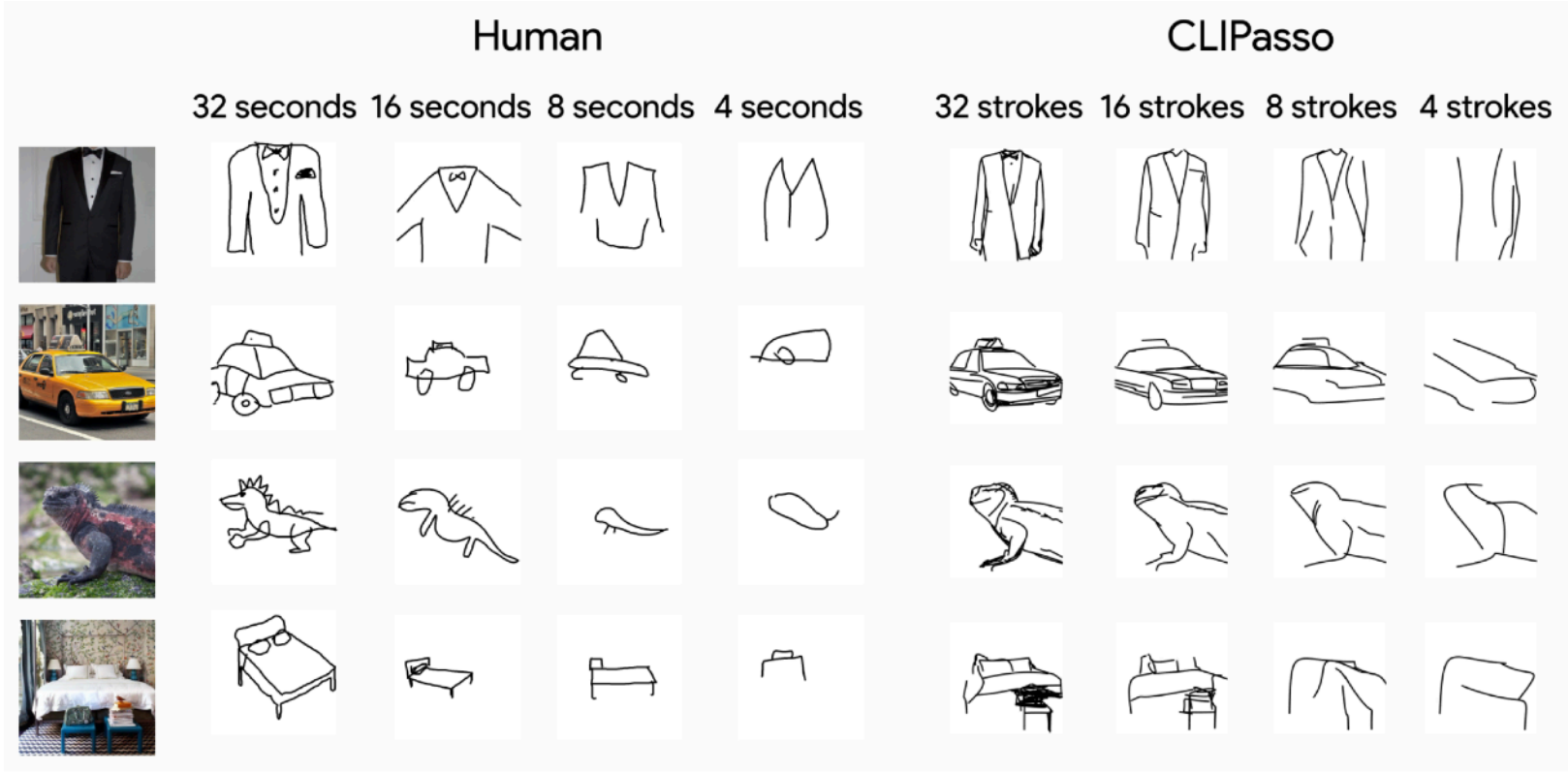


[SketchDesc (Yu et al.) TCSVT 2020]



[SketchZooms (Navarro et al.) CG Forum 2021]

Understanding Sketches: Abstraction



[SEVA (Mukherjee et al.) NeurIPS 2024]

Takeaways

- The majority of current sketch related vision research concentrates on abstract, doodle-like sketches.
- This is partially due to lack of complex and professionally-created data.
- Boundary between graphics and vision sketch related research is being blurred as more methods become learning based.
- It’s interesting to see how data synthesis and pre-trained image models guide the future direction.

More papers: