Fundamentals and Applications of Sketch Processing

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

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Creation Process

- Tracking Samples
- 2D Sketches
- Models & Animations
- Raster Samples
- 3D Sketches
- Data for Learning

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

For more:
Creation Process

Tracking Samples → 2D Sketches → 3D Sketches → Stroke Construction & Drawing Interface
2D Stroke Construction

2D sample sequence
- (x, y)
- Timestamp
- Pressure
- Tilt

2D stroke representations
- Polylines
- Parametric curves
- Splines
- etc.
More than connecting dots

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

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3D Stroke Construction

3D sample sequence
- (x, y, z)
- Timestamp
- Orientation

3D stroke representations
- Tubes
- Calligraphic curves (ribbons)
- etc.
3D Ribbon Construction

Curved ribbon

Bent ribbon

What ruling direction?

[AdaptiBrush (Rosales et al) SIGGRAPH 2021]
3D Ribbon Construction

Challenging gestures

[AdaptiBrush (Rosales et al) SIGGRAPH 2021]
2D Drawing Software

**Classic/Desktop**
- Photoshop
- Clip Studio Paint
- Krita

**Cartoon**
- Harmony
- TVPaint
- Animate

**Touchable Display**
- Procreate
- Fresco

**Painting Simulator**
- Rebelle

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3D Sketching Interface

gravity sketch

shapes xr

Tilt Brush by Google

N Kayurova, https://www.youtube.com/watch?v=UVHvdMJcOJU
3D Sketching Interface

Open problems…

N Kayurova, https://www.youtube.com/watch?v=UdMJoGJ
3D Sketching Interface: Analogy to 2D Drawing

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

Hard to draw mid-air

Depth inaccuracy

[Experimental Evaluation of Sketching on Surfaces in VR (Arora et al.) CHI 2017]
3D Sketching Interface: Domain-Specific
Auto snapping & fairing

Immediate surfacing

[Chenxi Liu]

[Auto snapping & fairing]

[Immediate surfacing]

[Chenxi Liu]

[Auto snapping & fairing]

[Immediate surfacing]

[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

Raster Samples

2D Sketches

Creation Process

Vectorization
Working with Raster Sketches

Raster rough sketch → Raster clean sketch

Vectorization
Raster Sketch Cleanup

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

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

Ink and erase

[Smart Inker (Simo-Serra et al.) SIGGRAPH 2018]
Working with Raster Sketches

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

Average (6 drawings)  Dracolion  Moose

Misclassified CCs (%)
Vectorize Sketches as Graphs

Similar to [Noris 2013]

(a) Input sketch  (b) Skeleton  (c) Topological graph  (d) Hypergraph  (e) Curve network

[Fidelity vs. Simplicity (Favreau et al.) SIGGRAPH 2016]
Vectorize Sketches as Graphs

(a) Topological graph  (b) Hypergraph  (c) Reconstructed curves

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

\[ U_{\text{fidelity}}(x) = \sum_{h \in H_x} \epsilon(h) \quad U_{\text{simplicity}}(x) = \sum_{h \in H_x} (1 + \mu \text{Deg}(B^h_x)) \]
Vectorize Sketches as Graphs

\[ U(x) = U_{\text{fidelity}}(x) + U_{\text{simplicity}}(x) \]

- \( U_{\text{fidelity}}(x) = X_{h}^2 H_x \cdot \overline{h} \)
- \( U_{\text{simplicity}}(x) = X_{h}^2 H_x \cdot \left(1 + \mu \deg(B_x^h)\right) \)
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 via PolyVector fields (Bessmeltsev and Solomon) SIGGRAPH 2019

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

(a) Traced curves

Chenxi Liu
Vectorize Sketches via 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

[Mo et al. SIGGRAPH 2021]
Diffusion-Model-Based Sketch Generation

CLIPasso

“The penguin is shuffling, taking cautious steps.”

“CLIPascene

“The jazz saxophonist performs on stage.”

“CLIPascene

“The gazelle galloping and jumping.”

LiveSketch

Vectorization

SketchKnitter

Condition

Ours
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:
Creation Process

Tracking Samples

2D Sketches

Raster Samples

Sketch Cleanup & Flat Colorization
Typical Sketches
Typical Sketches
Sketch Topology: Cleanup/Simplification/Consolidation

1. Clustering

Input *vector* sketch

Sketch Cleanup
Sketch Cleanup: Clustering

[B]eautification 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

Input stroke sequence  Our current strips  Our current fitting curves

[UnitMaker (Liu et al.) SIGGRAPH 2023]
Sketch Topology: Cleanup/Simplification/Consolidation

1. Clustering
2. Fitting

Input vector sketch
Sketch Cleanup: Fitting

- Curve fitting/smoothing
- Point reordering
  - Ordered points
  - Points unfold
  - Unorganized points
  - Pen strokes

Position-based
Tangent-based

- Barla’05
- Liu’15
- Orbay and Kara’11
Sketch Cleanup: Fitting

[StrokeStrip (Van Mossel et al.) SIGGRAPH 2021]
Sketch Cleanup: Fitting

(a) Input

Gradient Orientation

(b) Arc Length Cluster Parameterization

(c) Relaxed Parameterization

(d) Stroke-Orthogonal Cross-Sections

(e) Final Parameterization

(f) Curve Fitting
Sketch Topology: Flat Colorization/Junction Reconstruction
Sketch Topology: Flat Colorization/Junction Reconstruction
Sketch Flatting: Region Filling

(a) Segmentation mask
(b) Trapped-ball segmentation
(c) Our segmentation result

Move this fixed size ball

Multiway Graph Cut

[Chenxi Liu]

[Zhang et al. TVCG 2009] [Lazybrush (Sýkora et al.) Eurographics 2009]
Sketch Flatting: Region Filling

(a) Segmentation mask
(b) Trapped-ball segmentation
(c) Our segmentation result

Move this fixed size ball

[Chenxi Liu]

[Chenxi Liu]

[Zhang et al. TVCG 2009]

[Lazybrush (Sýkora et al.) Eurographics 2009]
Sketch Flatting: End-to-End

Fills gaps

[Sasaki et al. CVPR 2017]
Sketch Flatting: End-to-End

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

Flat Colorization

Neural fill

Down-sample & Re-line

Connected-components filling

Trapped ball filling

Neural lines

Recursion

Color bleeding removal

Output
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

Raster Samples

Creation Process

2D Sketches

Sketch Lifting

3D Sketches
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

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

**Descriptive Lines**
- Silhouette: smooth, ridge
- Discriptive cross-section
- Creases: ridges (occluded), volleys

**Construction Lines**
- Global context: vanishing points
- Local context: axis
- a. Scaffolds
- b. A square for an ellipse
- c. Tangents to an ellipse for a square

Professional CC0 sketches!

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

**Silhouette:** smooth, ridge

**Creases:** ridges (occluded), valleys

**Descriptive Lines**

**Construction Lines**
Sketch Lifting

[Gryaditskaya et al. SIGGRAPH Asia 2020]

Axis-aligned constructive lines
Sketch Lifting

Lifting

(a) Input Sketch  
(b) Segmented building blocks

(c) Symmetry planes and stroke correspondences  
(d) 3D reconstruction

[Gryaditskaya et al. SIGGRAPH Asia 2020]  
[Hähnlein et al. SIGGRAPH 2022]
Creation Process

Tracking Samples → 2D Sketches → 3D Sketches → Sketch Surfacing → Models & Animations
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

VIPSS normals (c)
VIPSS surface (d)

Input

Our Recon

Curve sketch (a)
Point samples (b)

[VIPSS (Huang et al.) SIGGRAPH 2019] [Xu et al. SIGGRAPH 2023]

Sketch Surfacing
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

[SurfaceBrush (Rosales et al.) SIGGRAPH 2019]
[Piecewise-smooth surface fitting onto unstructured 3D sketches (Yu et al.) SIGGRAPH 2022]
Surface Reconstruction from 3D Tubes

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:
Creation Process

Tracking Samples

2D Sketches

Models & Animations

Raster Samples

3D Sketches

Sketch-Based Modeling & Animation

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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

Scaffold requirement relaxed

[Schmidt SIGGRAPH’09]

Surfacing Curve Networks

[Xu SIGGRAPH’14]
Sketch-Based Modeling: Geometric & CAD Models

Existing shape and input sketch

Resulting shape matching the sketch

Protocol
SubPoly: <plane 1, length 0.78>
AddSweep: <plane 1, length 0.1>
BevelCorner: <plane 1, corner 3>

Type: sweep

Extrude Parameter Fitting
Bevel Parameter Fitting
Add/Sub Parameter Fitting
Sweep Parameter Fitting

Commands:
Add: <Cylinder, length 0.18>
Add: <Cylinder, length 0.61>
Add: <Recprism, length 0.18>
Sub: <Cylinder, length -0.18>

CAD Modeling

[Li SIGGRAPH Asia’20]

[Li SIGGRAPH’22]
Sketch-Based Modeling: Domain Specific

Layered 3D Models
[De Paoli SIGGRAPH’15]

Building Models
[Nishida SIGGRAPH’16]

Garment Design
[Li SIGGRAPH’18]

Liquid Modeling
[Yan SIGGRAPH Asia’20]

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

“a 3D model of mushroom house”

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

Posing

Animation

Preston Blair "Line of action"
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]
[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:
Creation Process

2D Sketches

3D Sketches

Raster Samples

Data for Learning

Models & Animations

Sketch-Related Vision Tasks

Tracking Samples
Sketches under a Vision Len

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

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

Human-created drawings
- Novice and professional.
- Sketches and doodles.

A Benchmark for Rough Sketch Cleanup

Google quick draw

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.
Understanding Sketches: Correspondences

[SketchDesc (Yu et al.) TCSVT 2020]  [SketchZooms (Navarro et al.) CG Forum 2021]
Understanding Sketches: Abstraction

<table>
<thead>
<tr>
<th>Human</th>
<th>CLIPasso</th>
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<tbody>
<tr>
<td>32 seconds</td>
<td>32 strokes</td>
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<tr>
<td>16 seconds</td>
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<tr>
<td>8 seconds</td>
<td>8 strokes</td>
</tr>
<tr>
<td>4 seconds</td>
<td>4 strokes</td>
</tr>
</tbody>
</table>

[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: