Fundamentals and Applications of Sketch Processing

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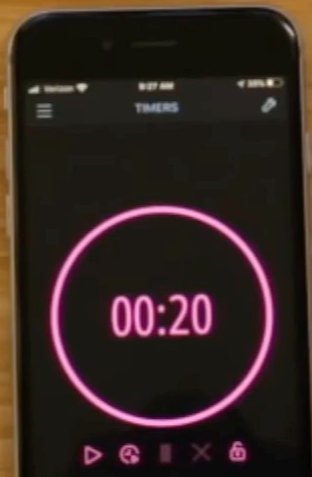
Université de Montréal

UNIVERSITY OF TORONTO



https://www.youtube.com/watch?v=biT46ugaXmc

sketches vs photos

Pose reconstruction?

Monocular pose reconstruction
[Pavlakos et al. 2019]

😭

Monocular pose reconstruction
[Pavlakos et al. 2019]

What’s so special about sketches?

Broken and overdrawn strokes

Strokes with unclear meaning

Shape and proportions

Nothing is precise

‘Wrong’ projection

Image © Olga Posukh

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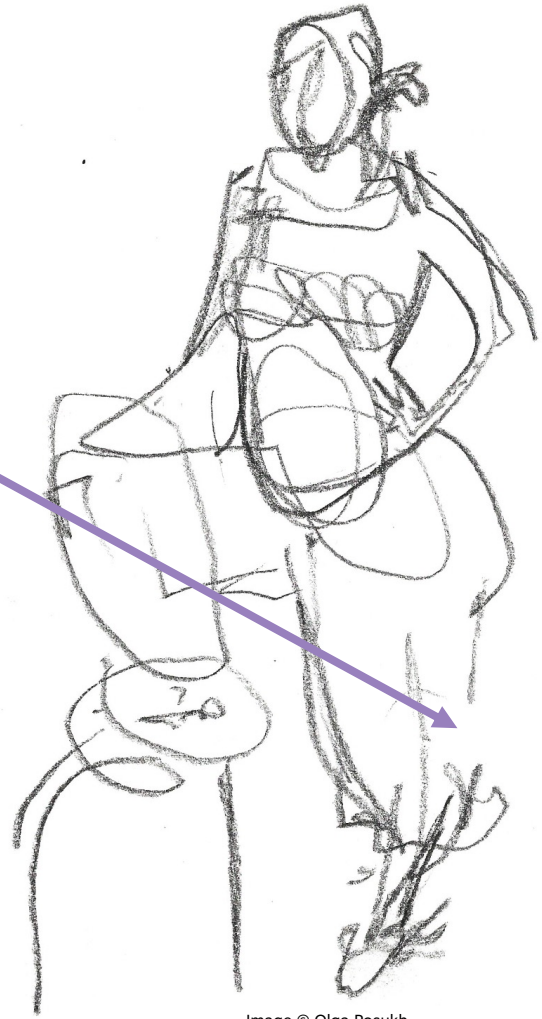

Image © Olga Posukh

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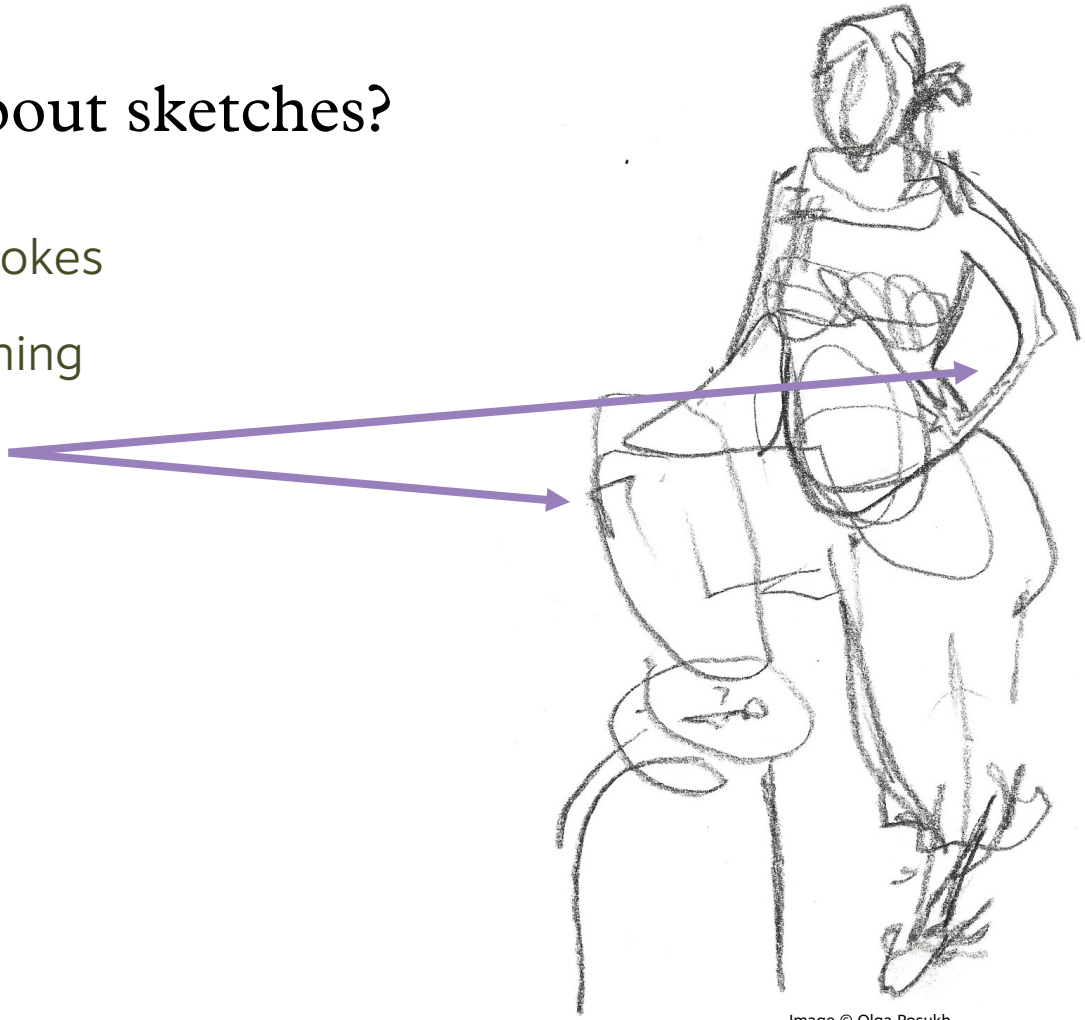

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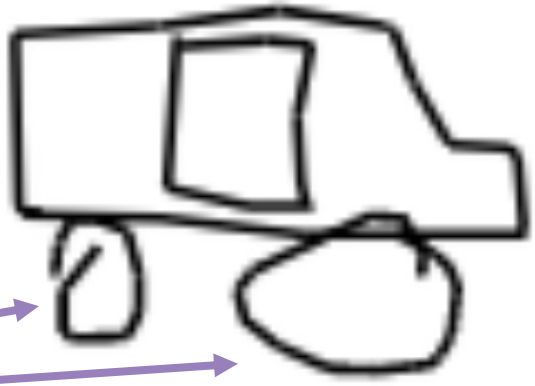

Google Quick, draw! dataset

Image: Hasan Gulec

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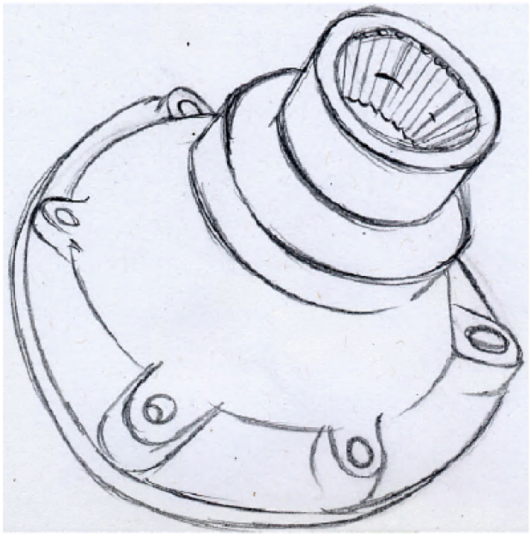

Cole et al., Line Drawings of 3D Shapes, 2009

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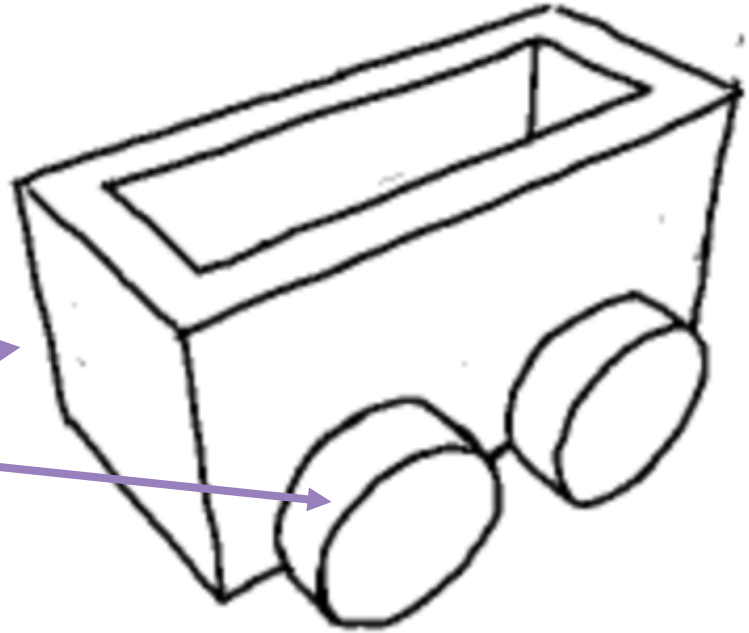

Image [Delanoy et al. 2019]

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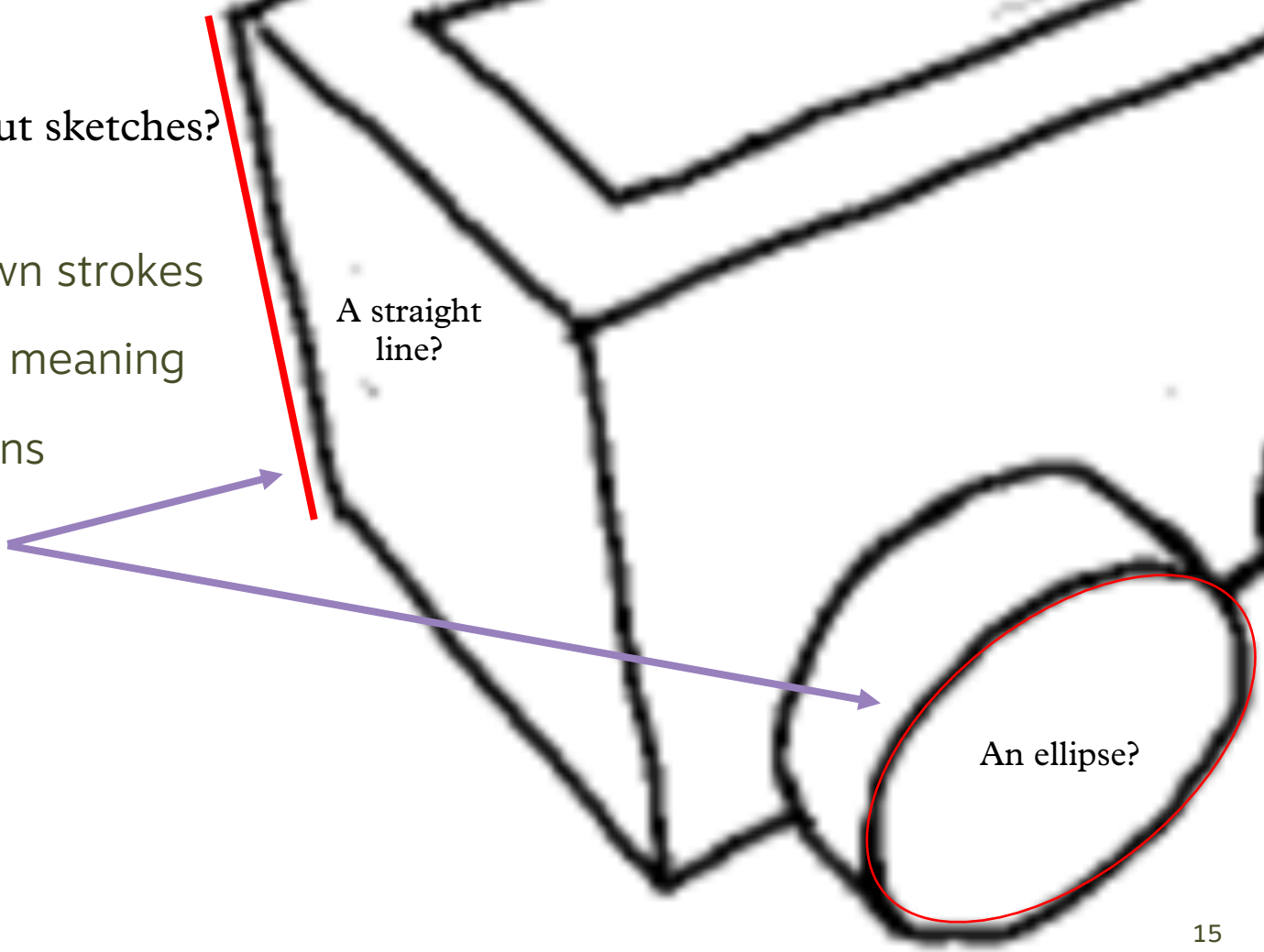

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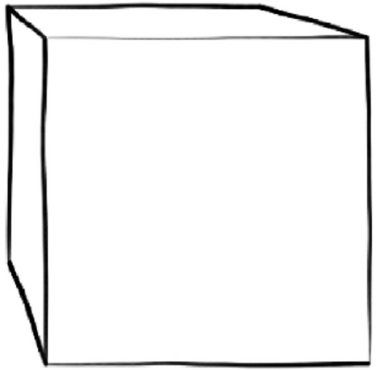
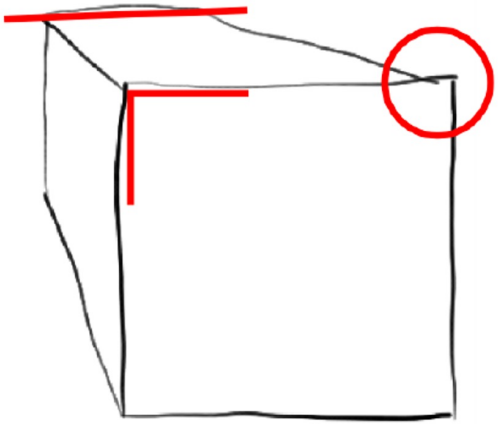


Correct



Artist

Schmidt et al. "On expert performance in 3D curve-drawing tasks", SBIM 2009

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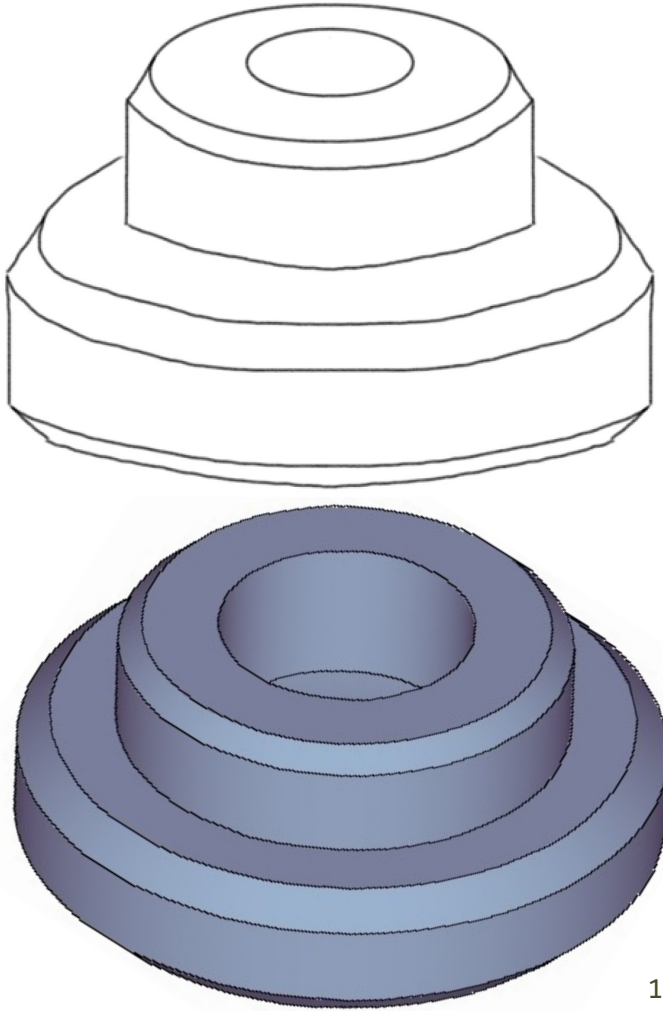
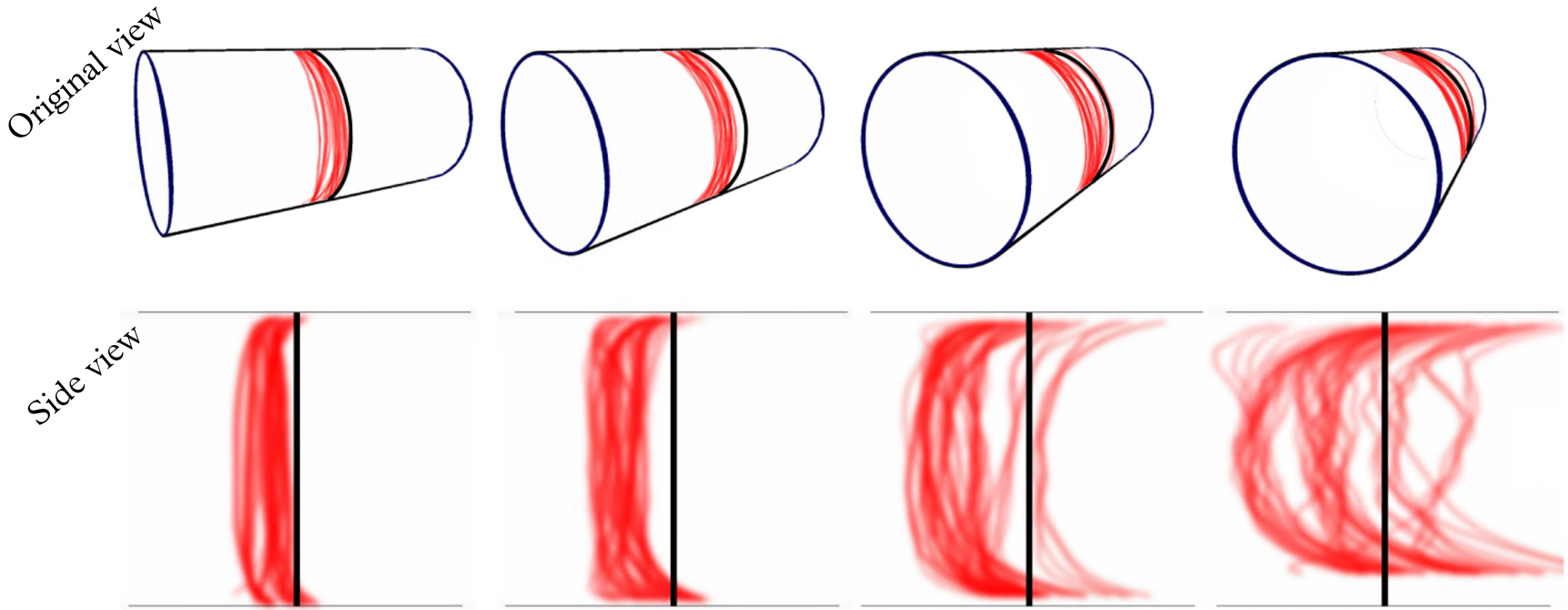


Projection user study: “Draw a circle in the middle”



Schmidt et al. “On expert performance in 3D curve-drawing tasks”, SBIM 2009

Linear perspective

Some AI

Multiperspective

The Pink Studio, Henri Matisse, 1911

Perception: why is it okay for us?

Maybe humans don’t imagine a consistent 3D model while exploring the world?

[Hertzmann, 2024]

Checkpoint

Sketches are not photos. They are heavily distorted and stylized.

Processing has to be guided by perception/data, not simple metrics

Chamfer distance?
Hausdorff?
L_2?

A snail (Jacob van Maerlant, c.1350)

stuff inside sketches

Raster vs vector

https://www.youtube.com/watch?v=vl3hGeSsaBA

Clean vs rough vs filled

1,2,4 © Olga Posukh

© Zoska Leutina

Strokes, endpoints, and junctions

Image © Olga Posukh

Junctions and intersections: real and intended

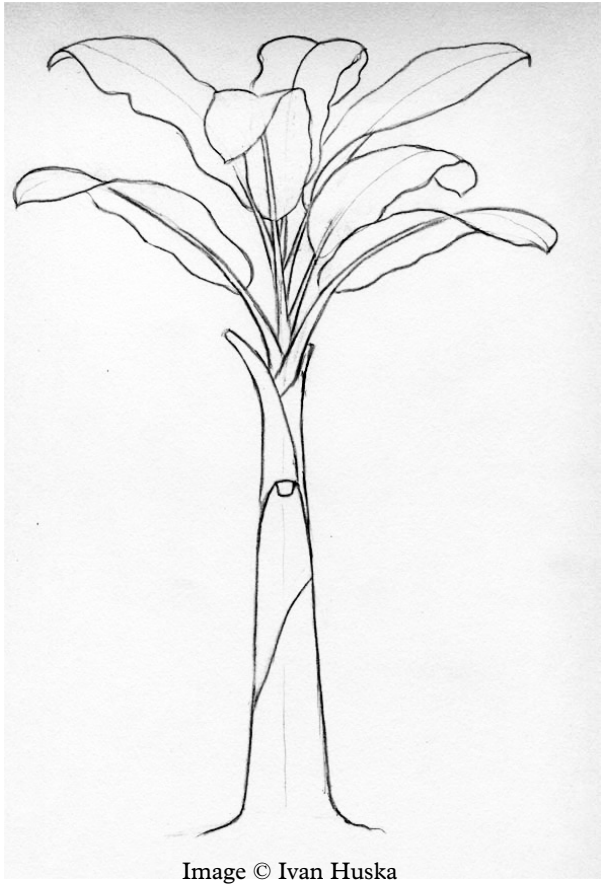


Image © Ivan Huska

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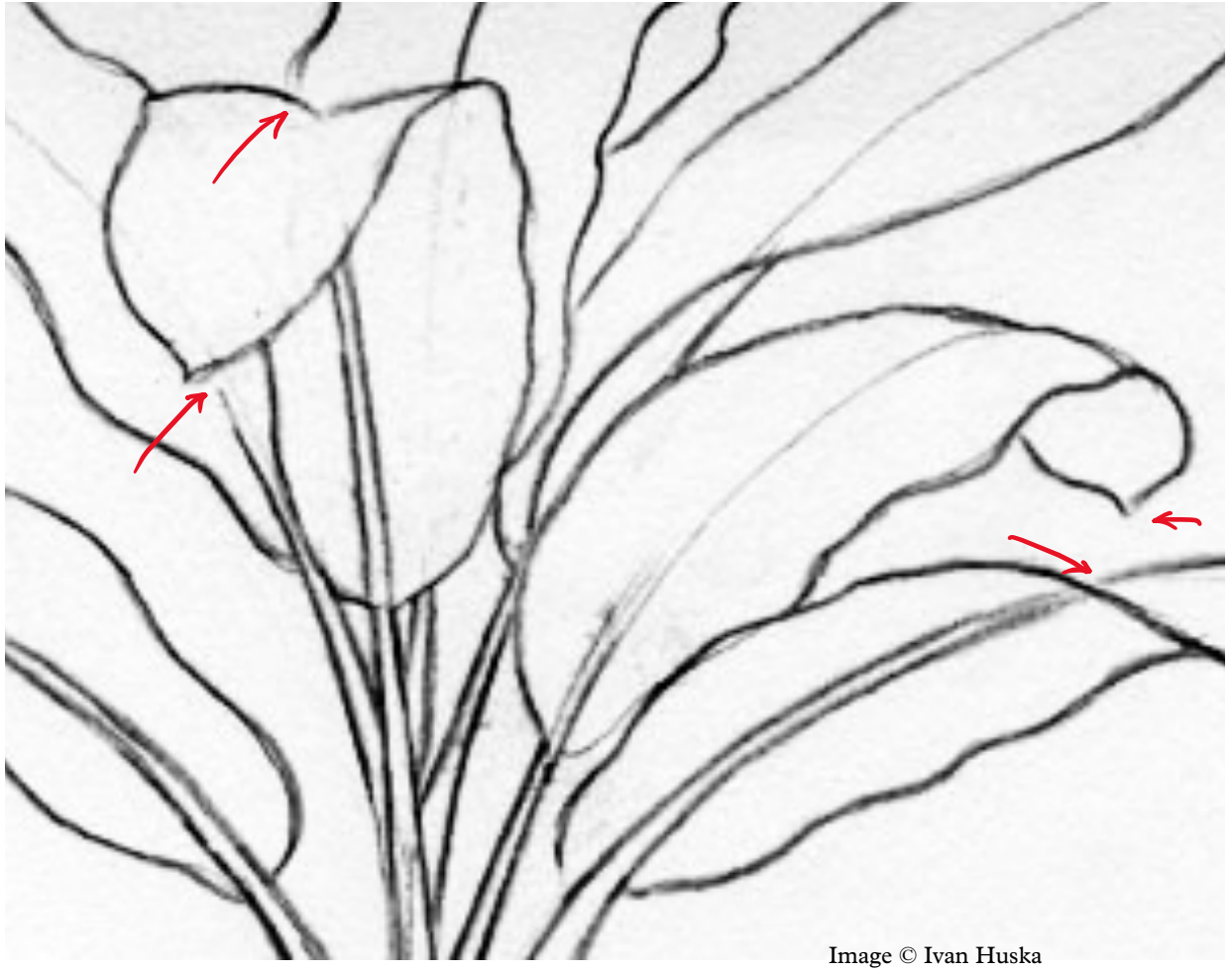
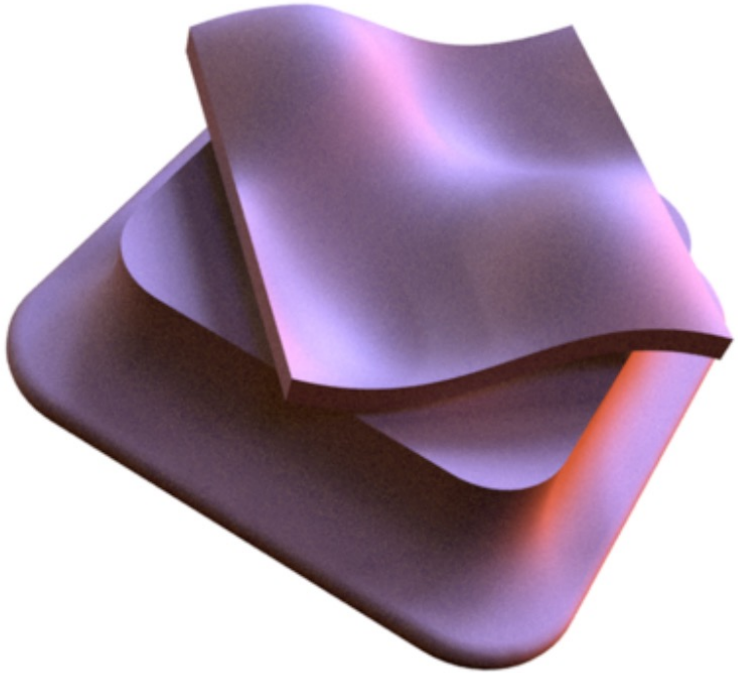
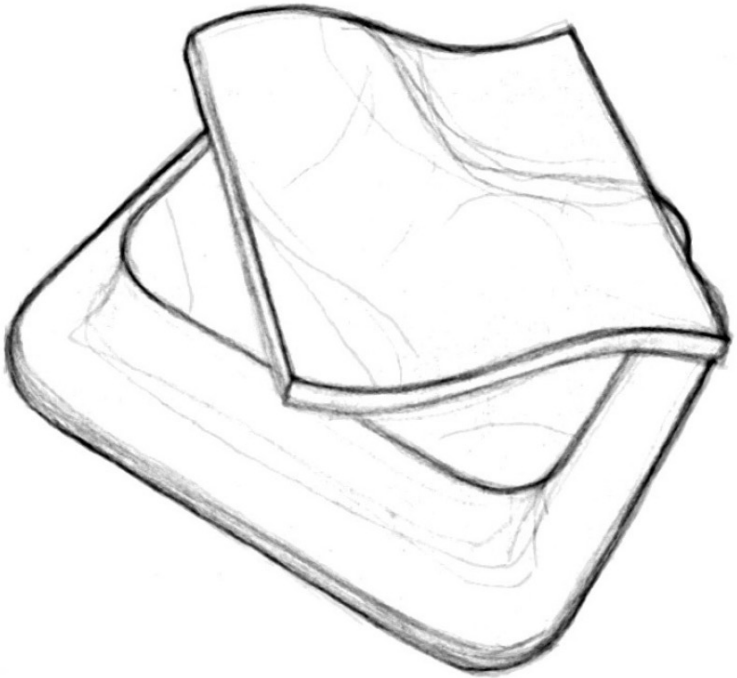


Image © Ivan Huska

Where people draw lines



Prompt

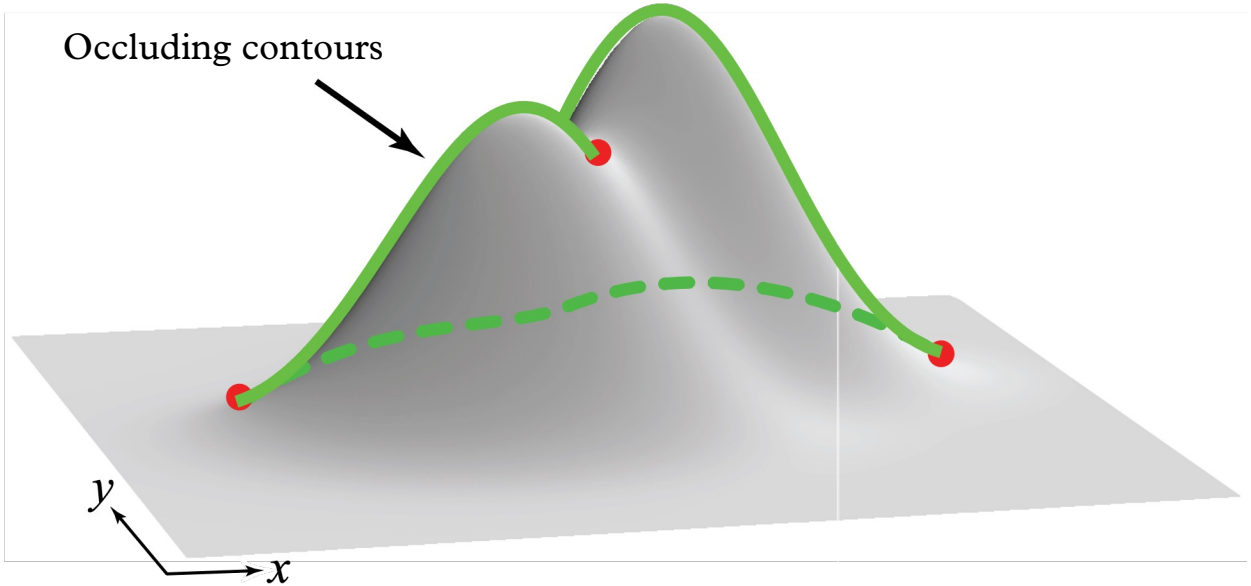


Many artists

Where people draw lines: Occluding contours

points where surface normal is perpendicular to the view direction

$$n \cdot (p - O_{camera}) = 0$$



[Cole et al. 2008]

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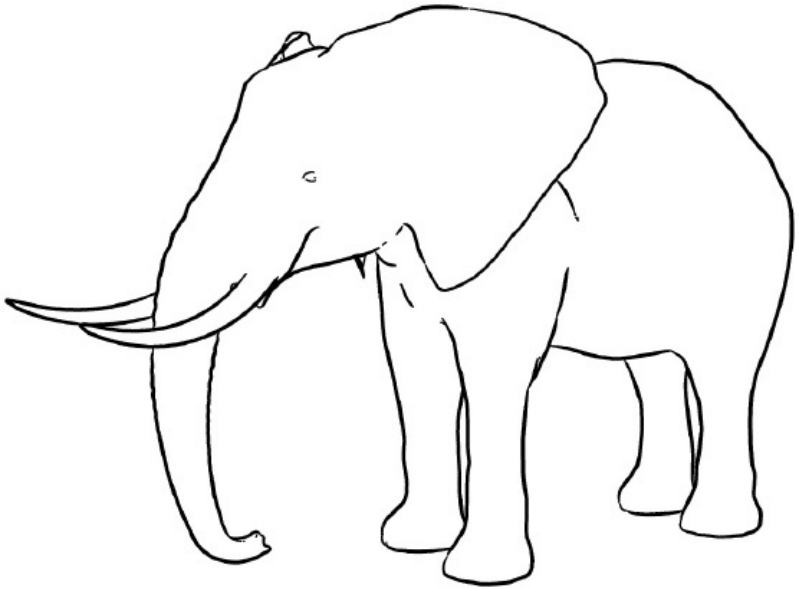
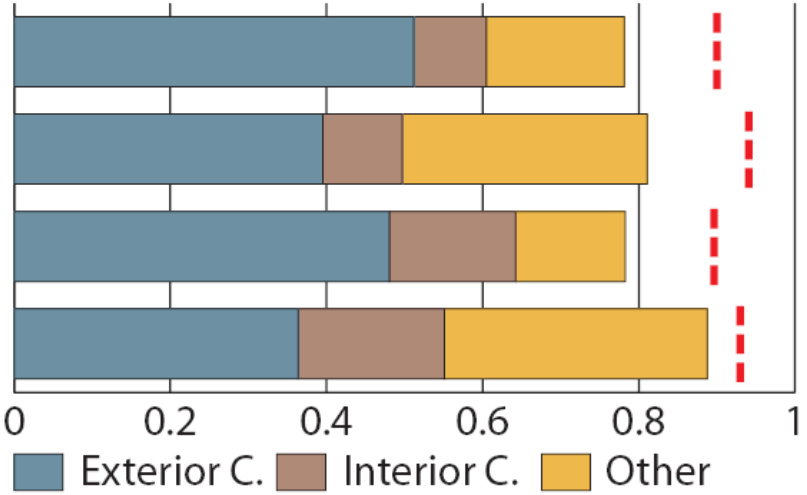




[Cole et al. 2008]

Where people draw lines: Ridges & Valleys (RV) and Apparent RV

Extrema of principal curvature

$$\frac{\partial k_1}{\partial T_1} = 0$$

[Ohtake et al. 2004]

Where people draw lines: Ridges & Valleys (RV) and Apparent RV

Extrema of view-dependent curvature

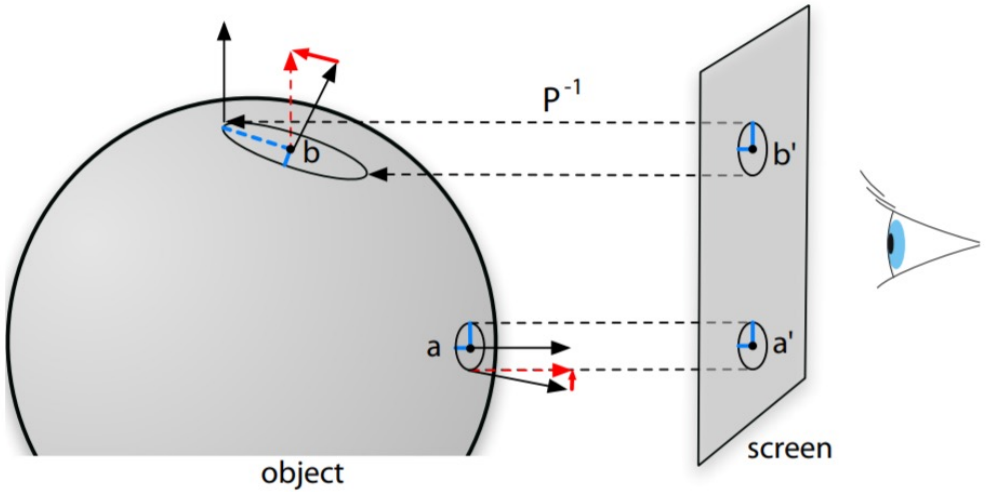
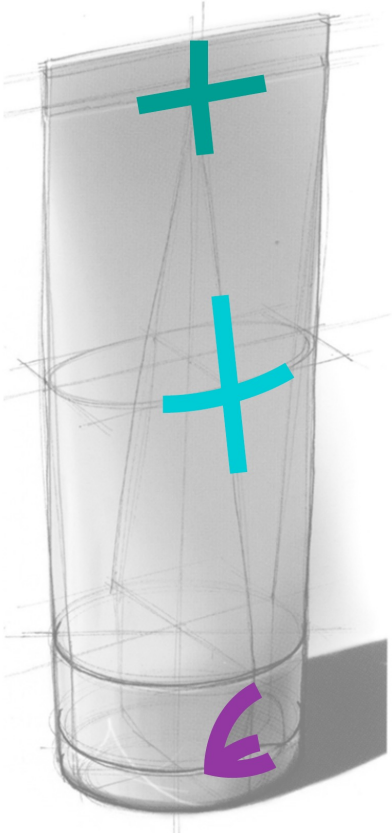


Figure 4: *The maximum view-dependent curvature at b' is much larger than at a' uniquely because of projection.*

[Judd et al. 2007]

2D cross-sections: lines of curvature



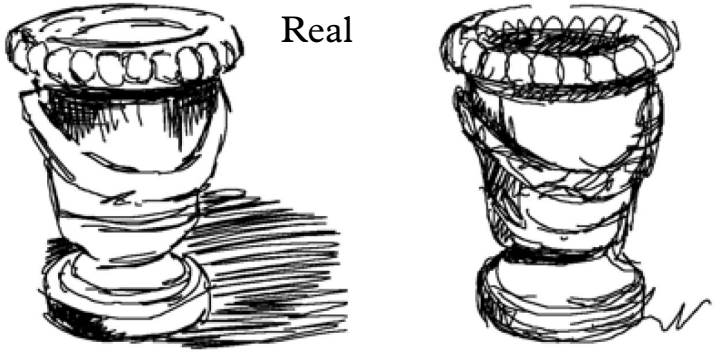
True2Form [Xu et al. 2014]

Can we just use synthetic sketches then? No.

”60% of drawn content is consistent with computer-generated output”

Synthetic

Real



[Wang et al. 2021]

Checkpoint

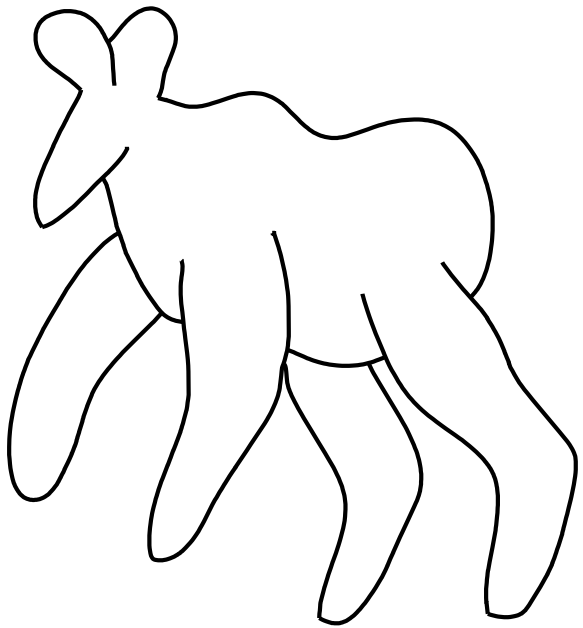
Sketches have many different stroke types, drawn for very different purposes. Those connect at junctions and intersections. They also have fills and textures

Sometimes determining who’s who is difficult.

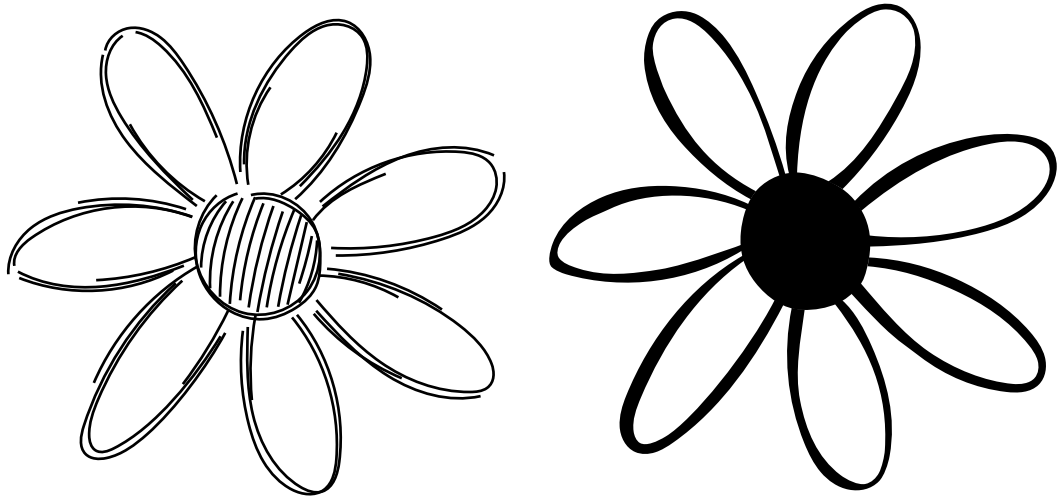
the shapes sketches represent

2D shape

Strokes only: non-manifold

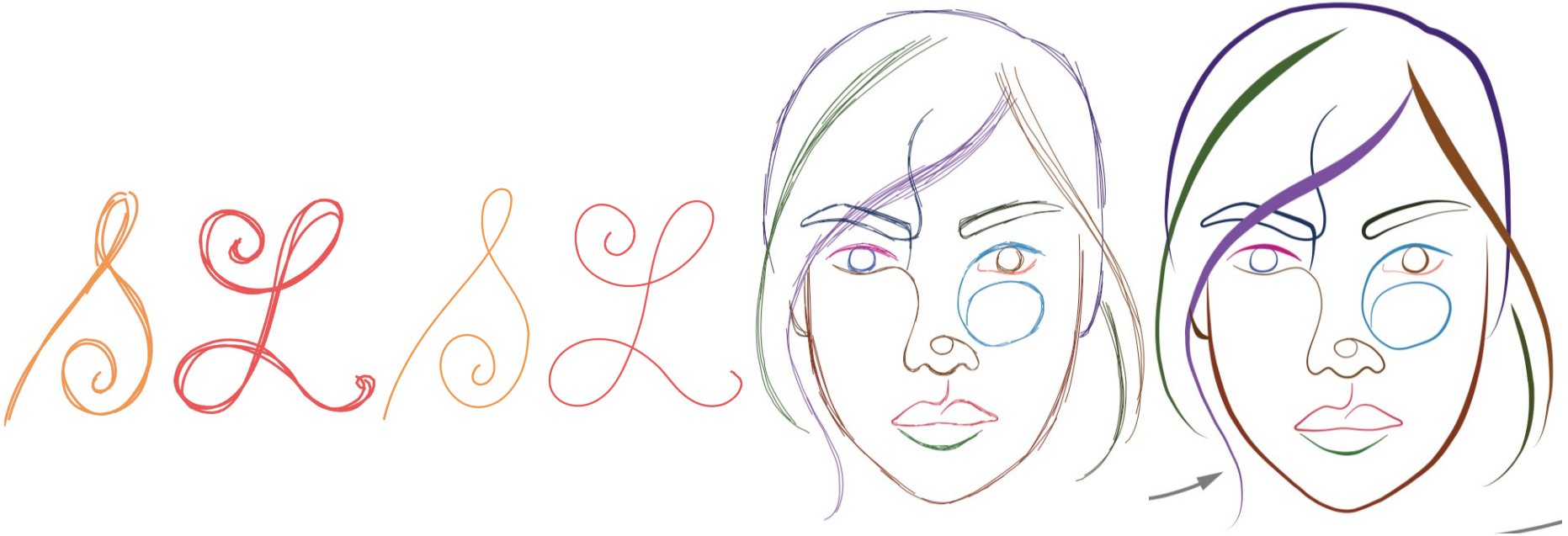


With fills and thickness: 2-manifold



[Myronova et al. 2023]

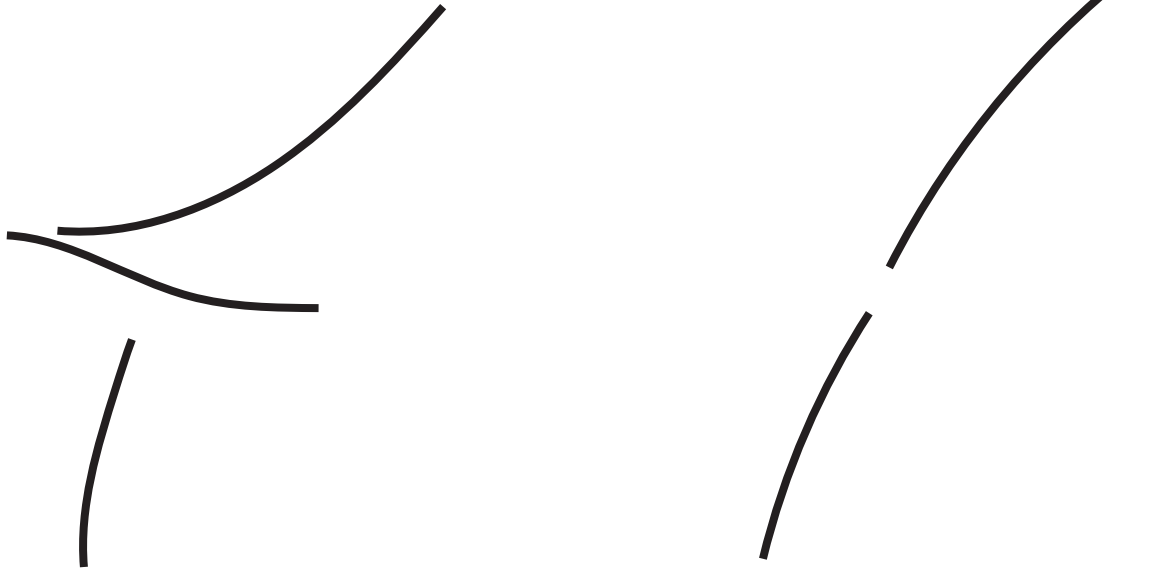
Clusters = approximate curve or variable width



[van Mossel et al. 2021]

Implied junctions and continuations

Gestalt continuity, symmetry, perception stuff



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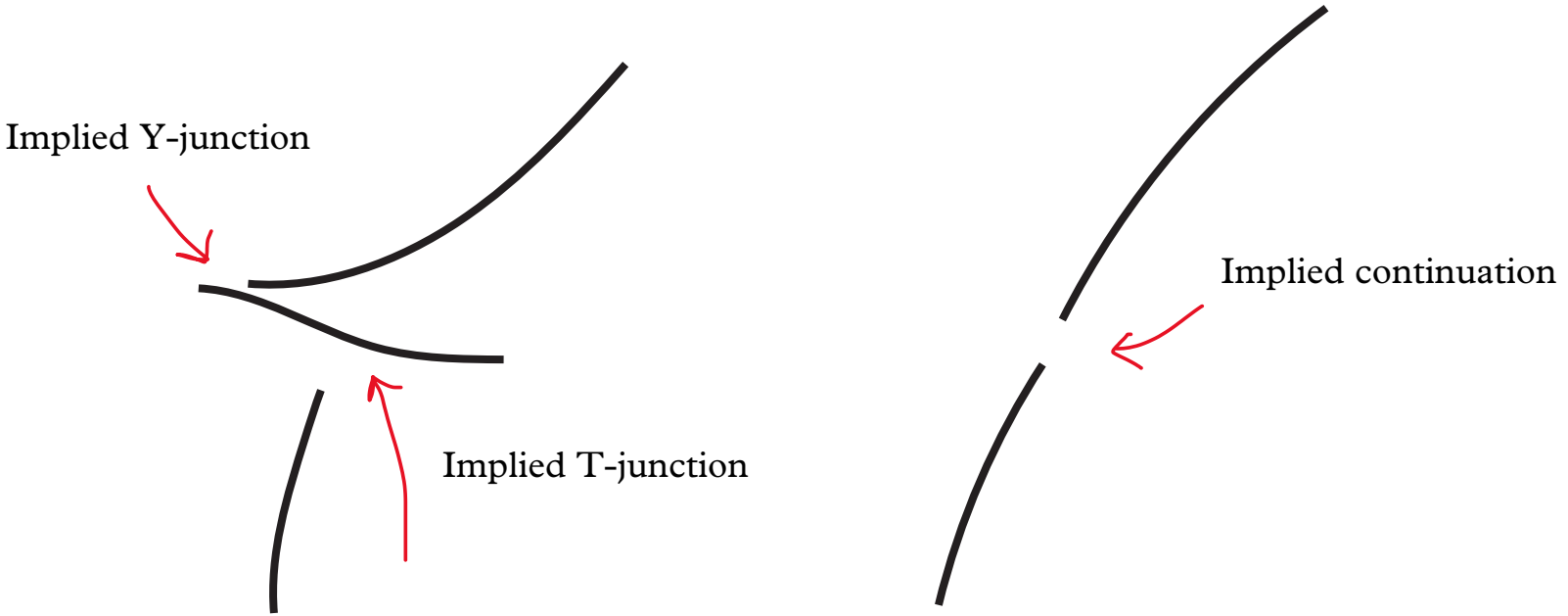
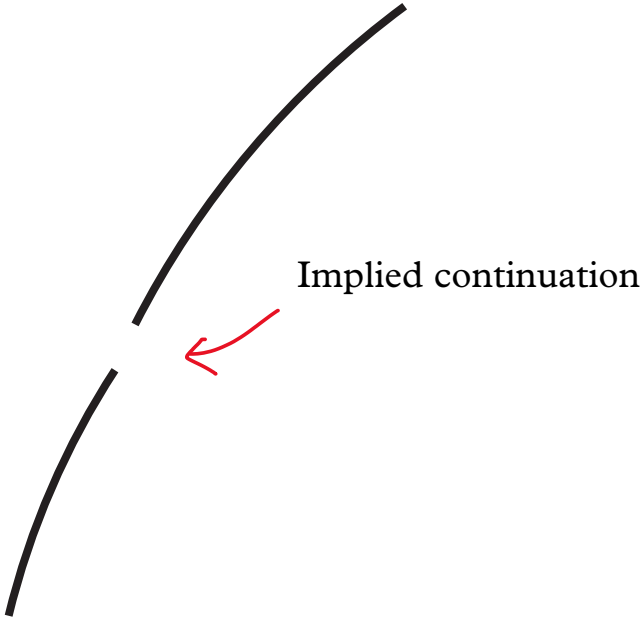


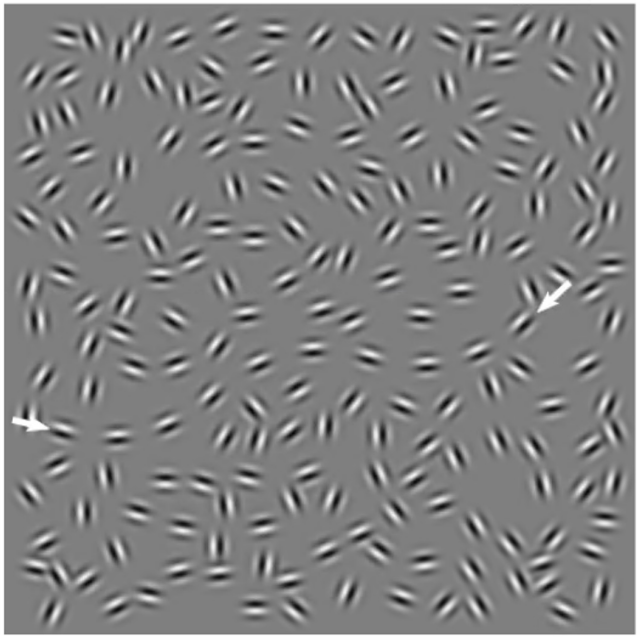
Implied junctions and continuations

Gestalt (Good) Continuation



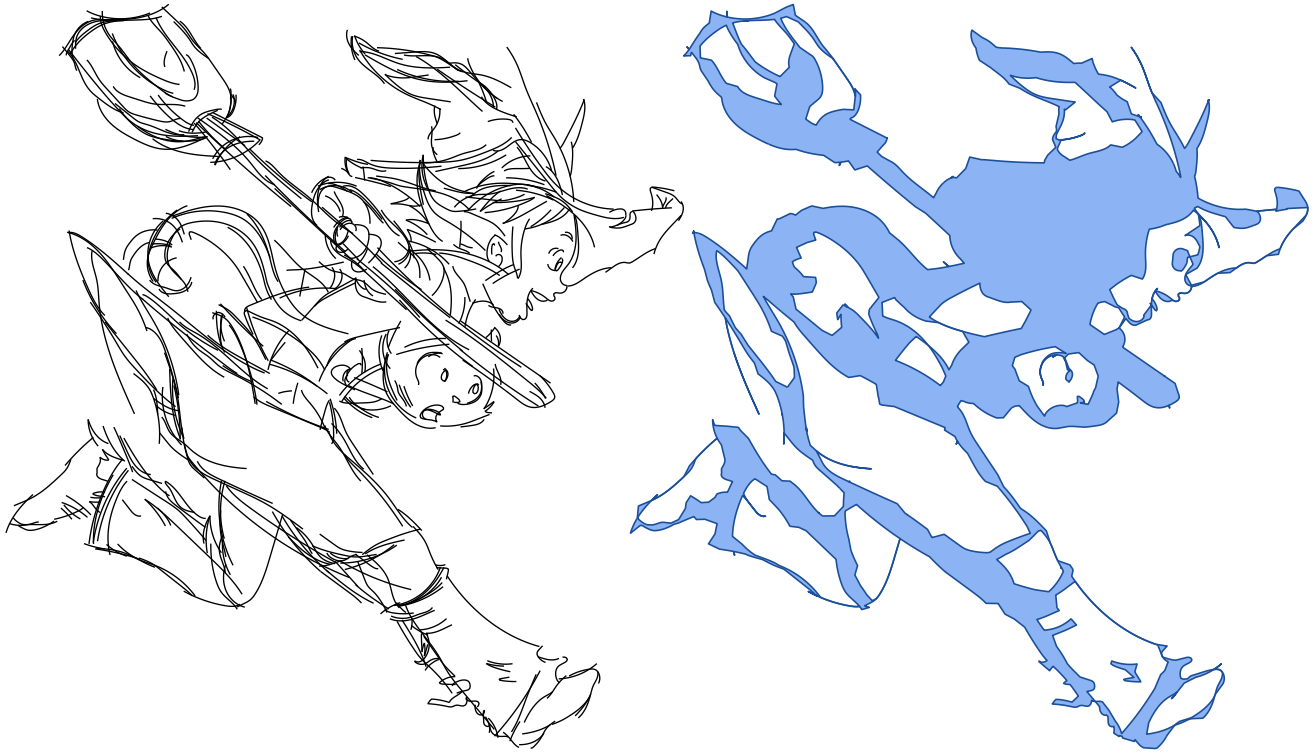
[Koffka 1955]

90% participants see paths if angle < 18°



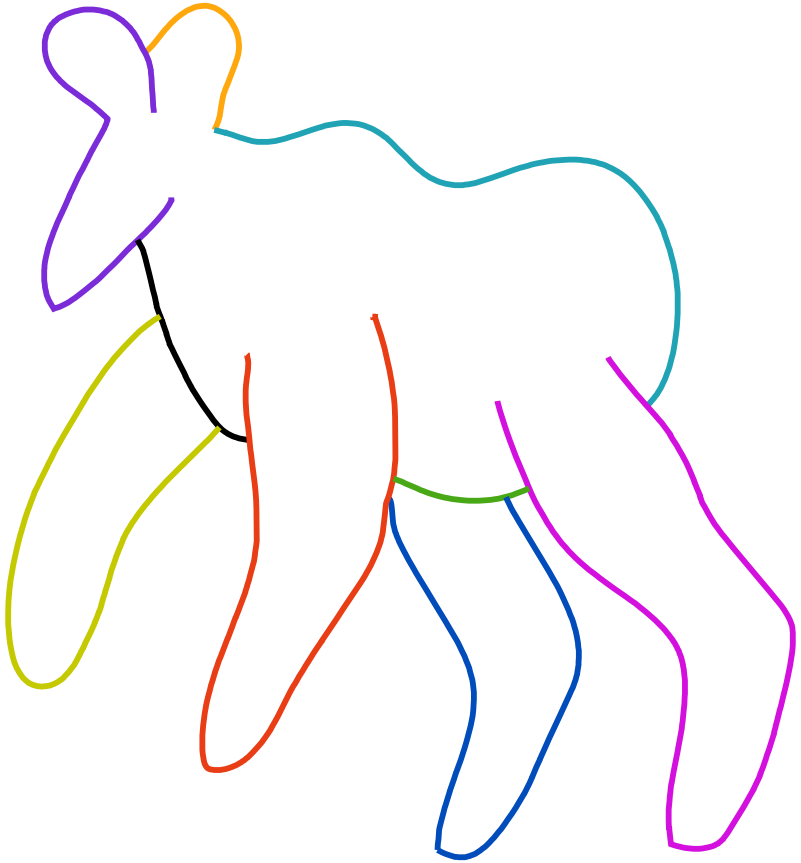
[Hess and Field 1999]

Holes or not? Inside vs outside

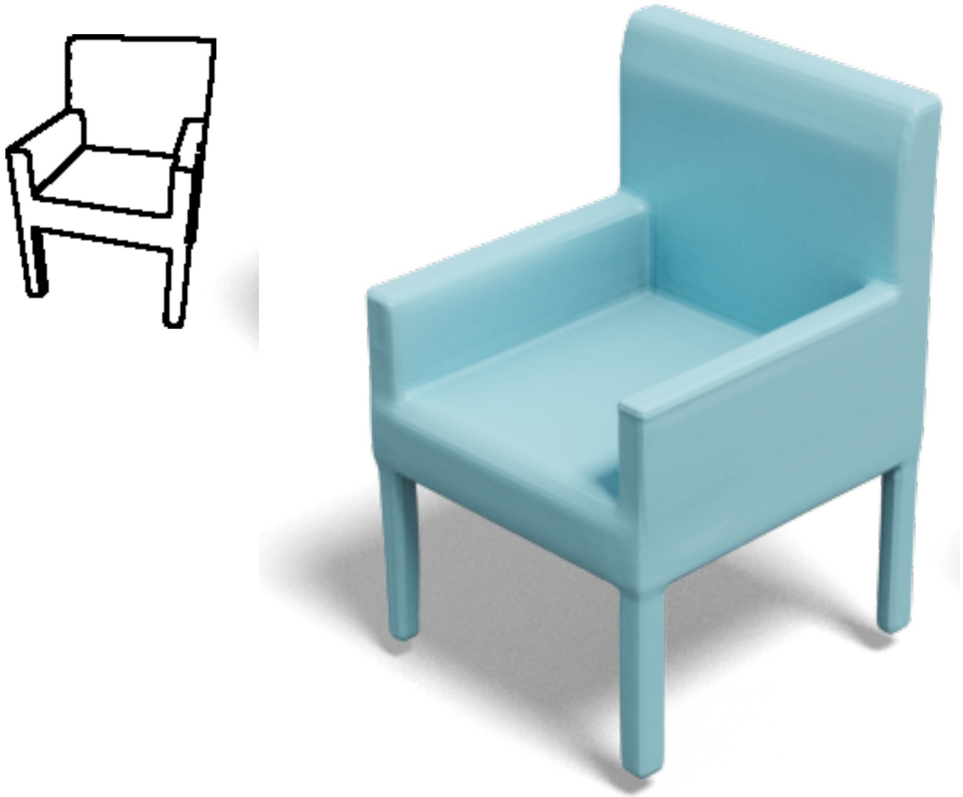


[Myronova et al. 2023]

Junctions and occlusions



3D: smooth unless indicated otherwise



[Zheng et al. 2023]

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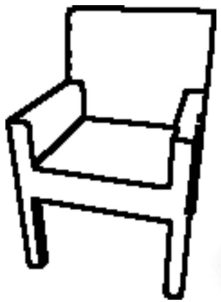

Ground truth
[Zheng et al. 2023]

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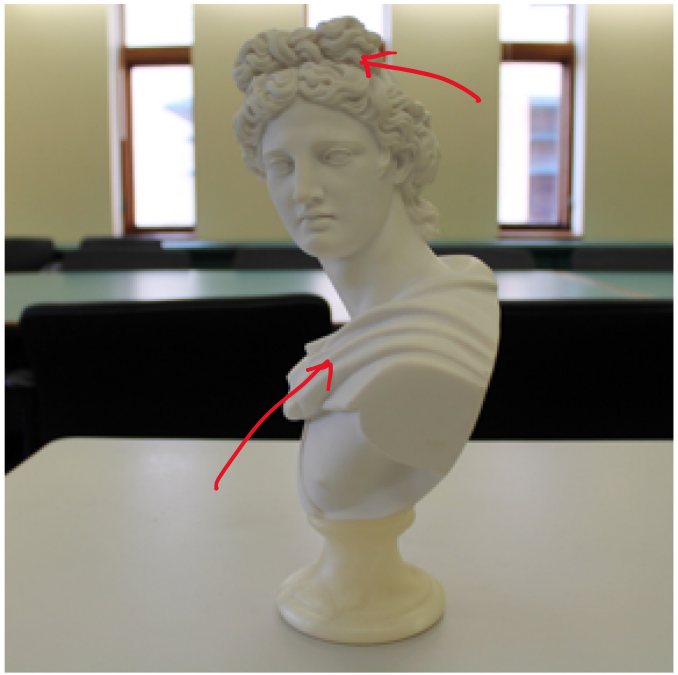

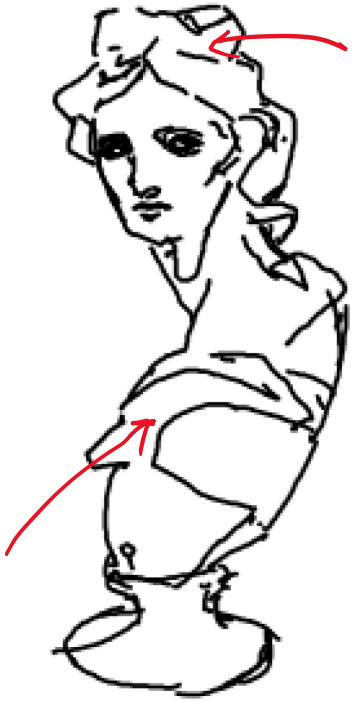

[Wang et al. 2021]

core challenges of sketches

and some solutions

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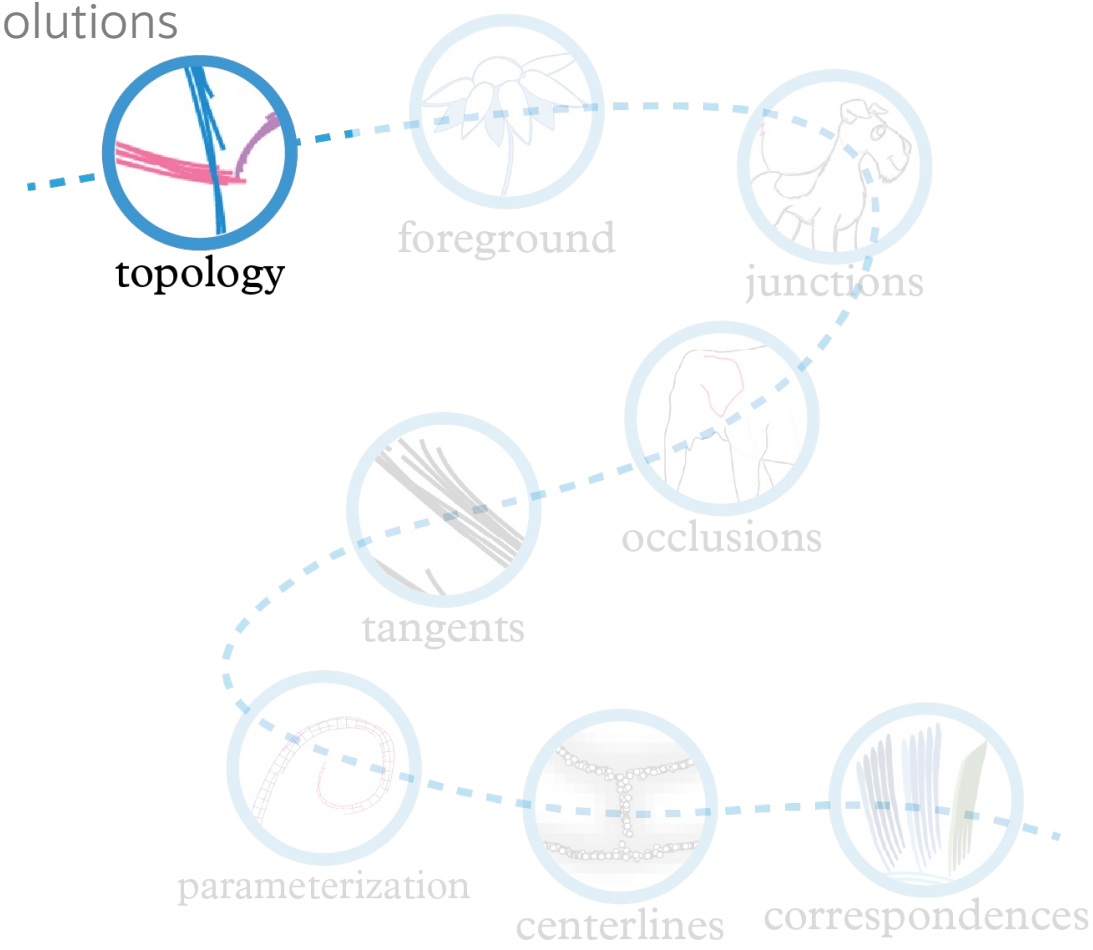
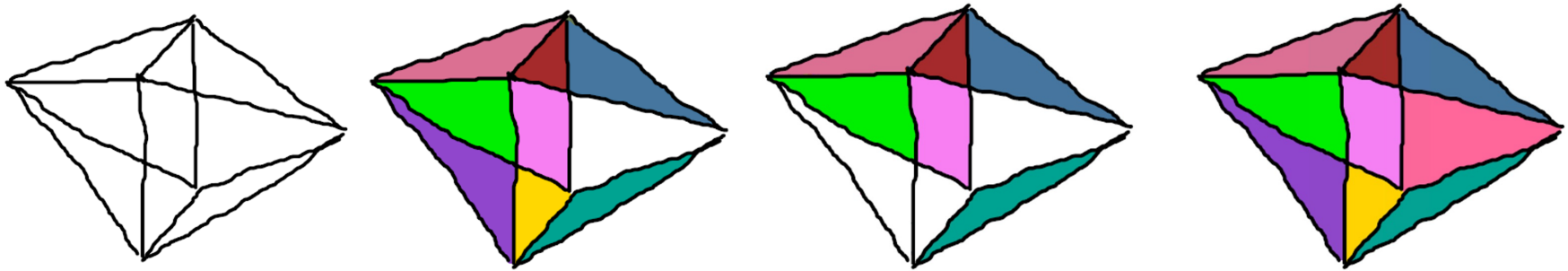


Core challenge: Topology

Are those strokes connected?

Is it a junction?

Is this shape closed?



[Yin et al. 2022]

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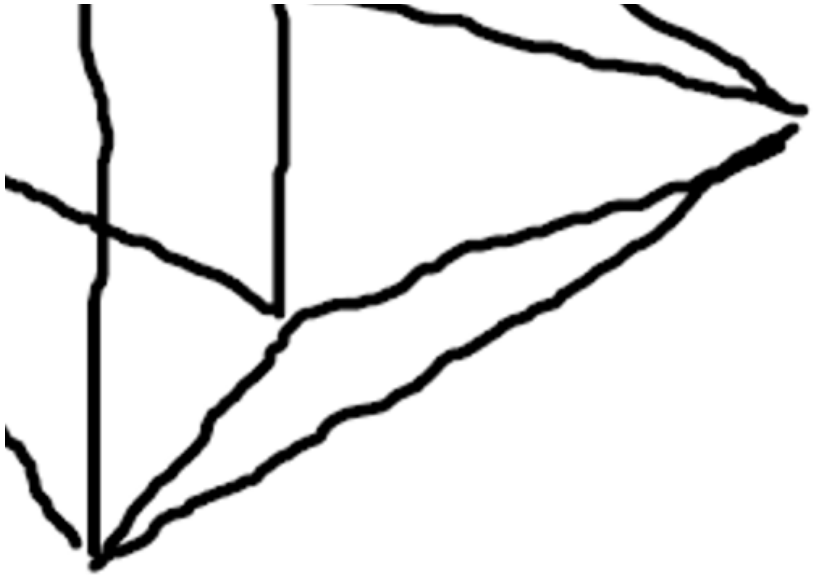

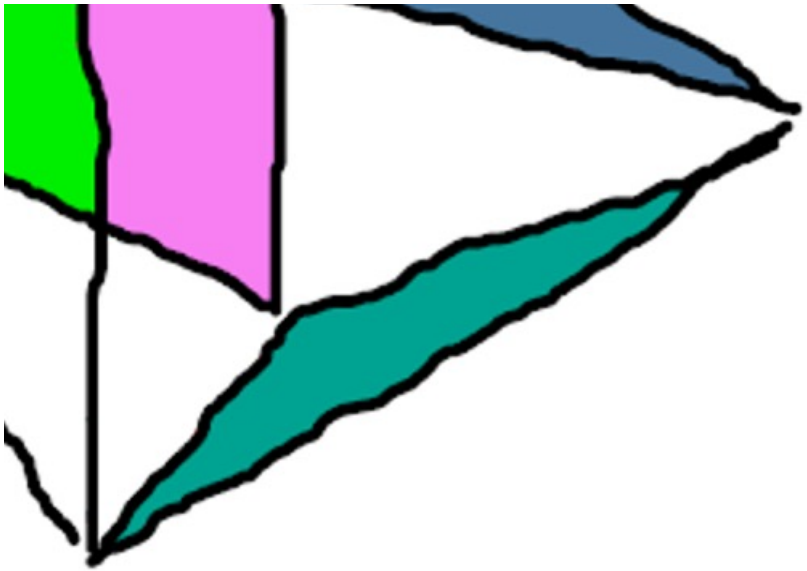

[Yin et al. 2022]

Core challenge: Topology

Bug or feature?

Precision can vary over a single drawing

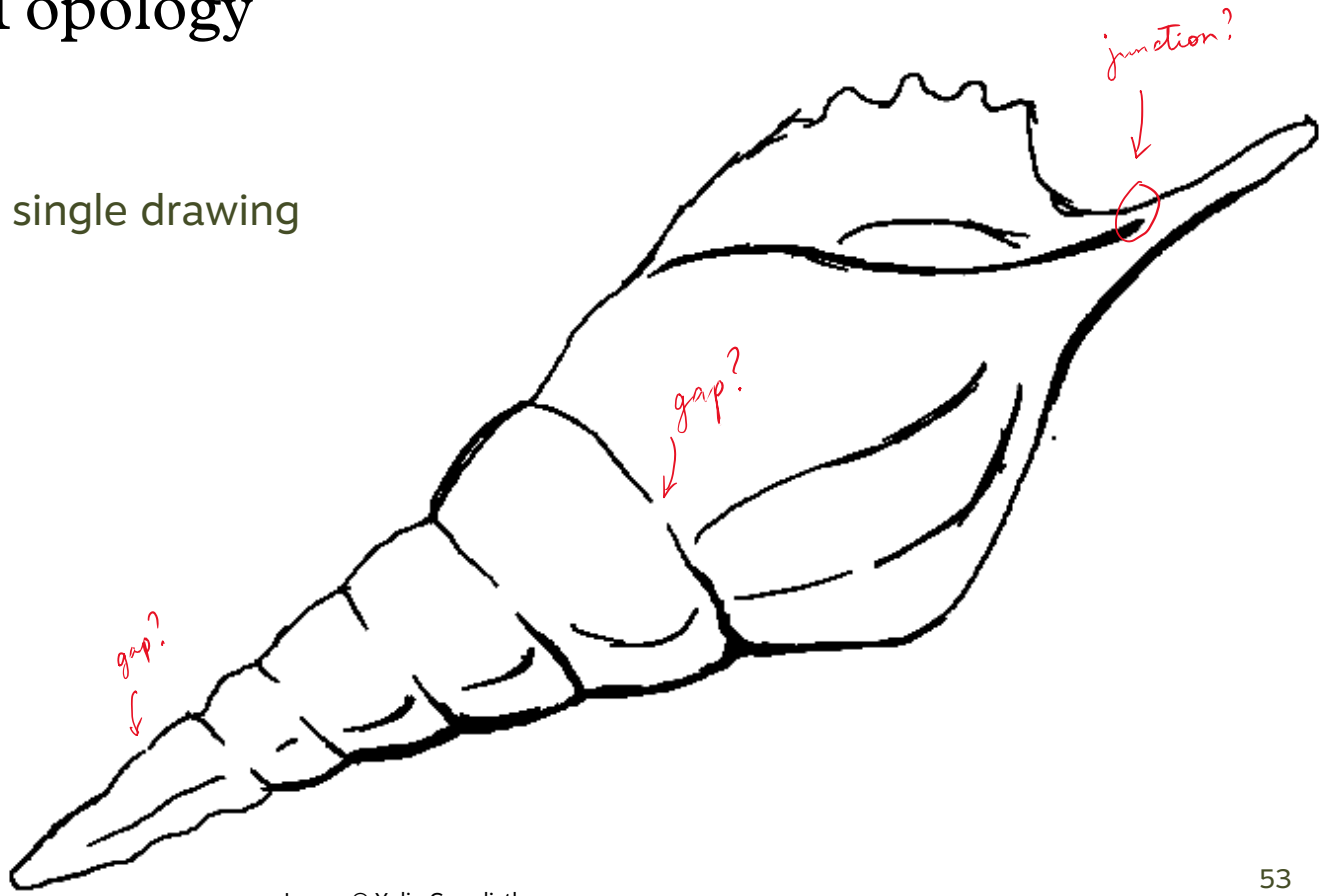

Image © Yulia Gryadistkaya

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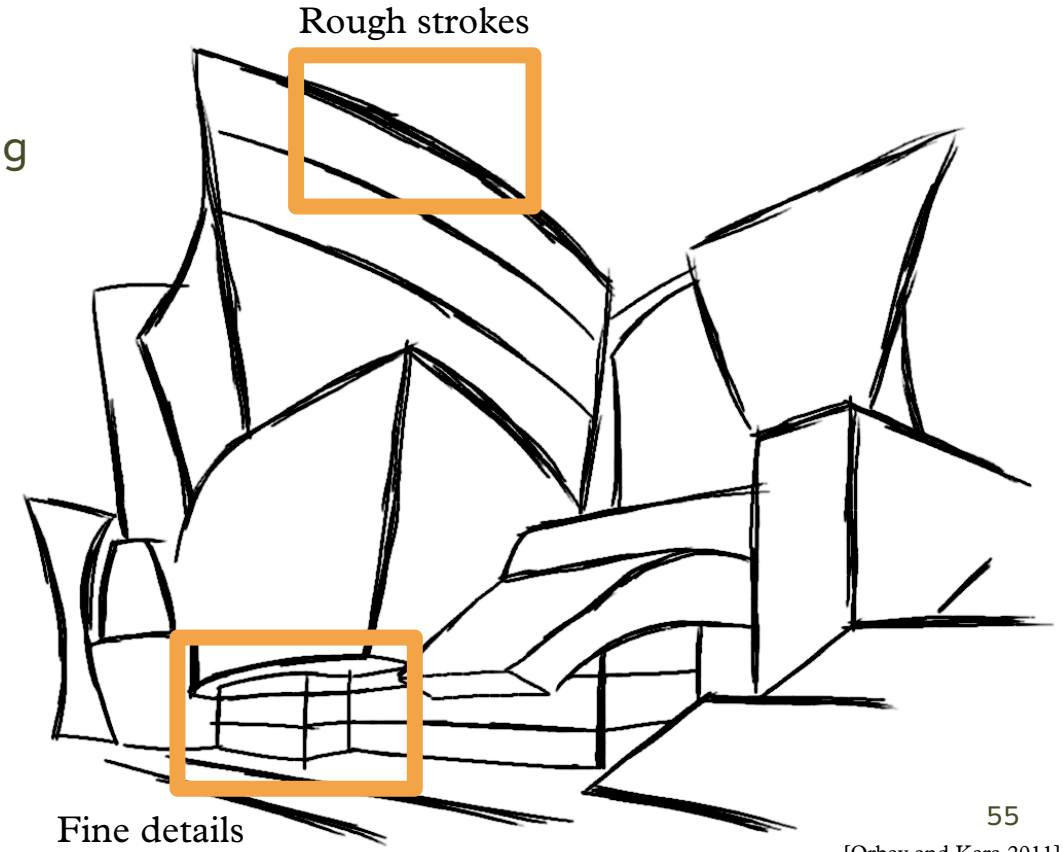
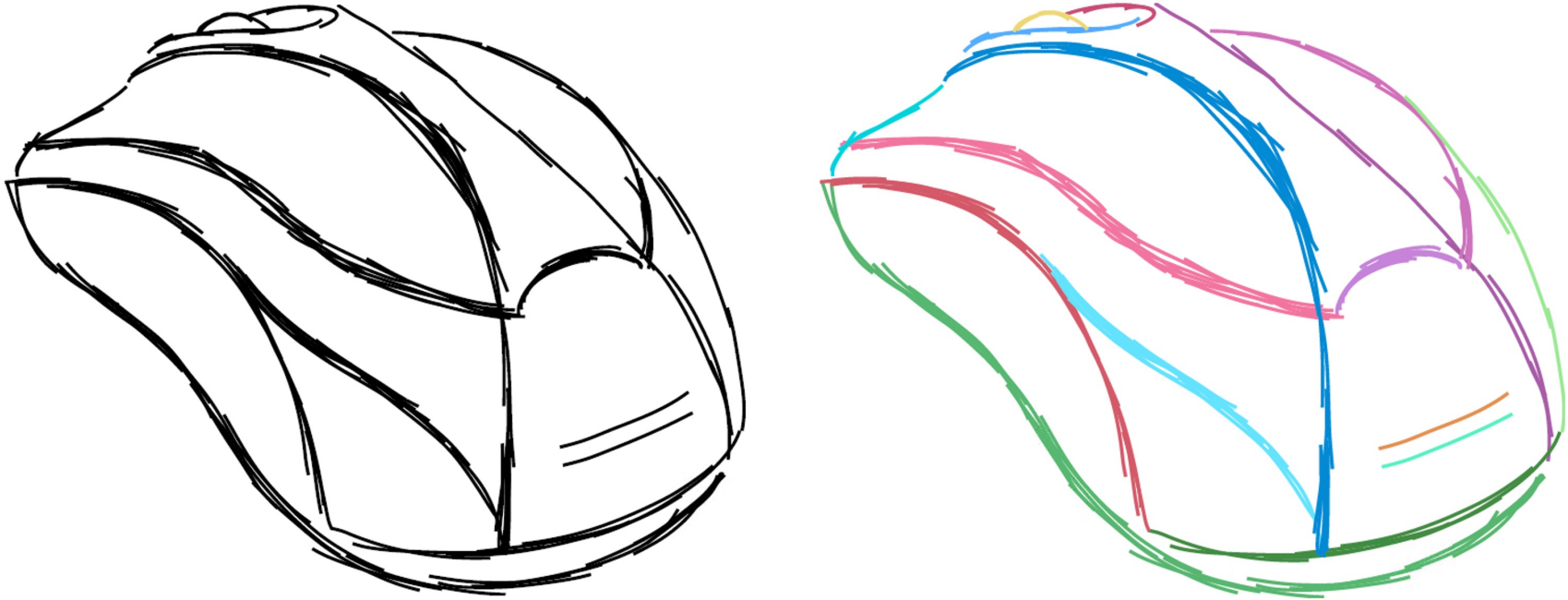


[Orbay and Kara 2011]

Core challenge: Topology

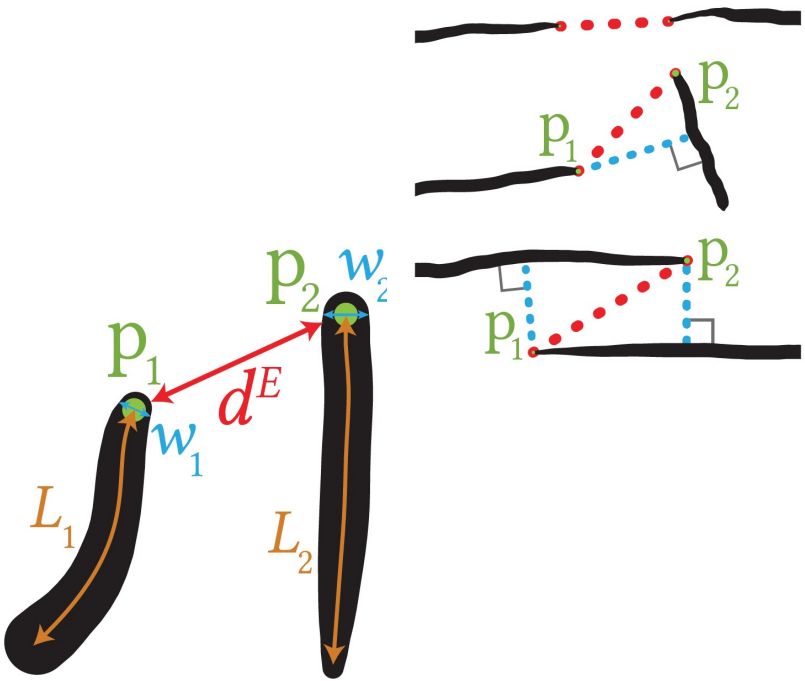
How to segment, or break into clusters?



[Liu et al. 2018]

Topology | Solution: Learning

Hand-crafted features



Classification via **Random Forest**

Random Sampling with Replacement

$\mathcal{X} \in \mathbb{R}^{250\times100}$

$\mathcal{X}_1 \in \mathbb{R}^{60\times100}$

$\mathcal{X}_2 \in \mathbb{R}^{60\times100}$

$\mathcal{X}_n \in \mathbb{R}^{60\times100}$

Train

Aggregate

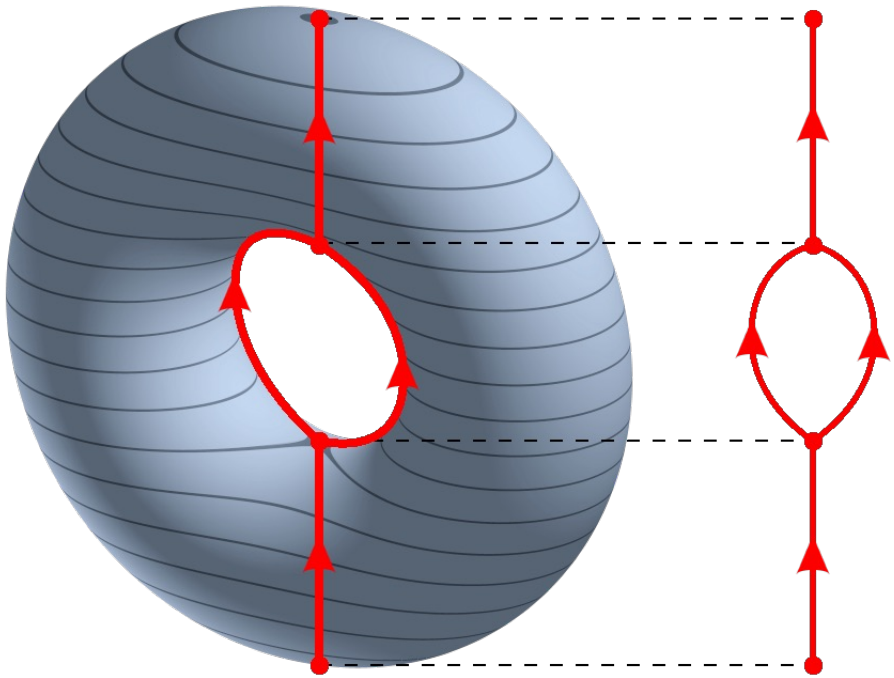
[Yin et al. 2022]

Topology | Solution (?): Reeb Graph

Take some function f on a manifold

Draw all its level sets $f^{-1}(c)$

Contract their connected components



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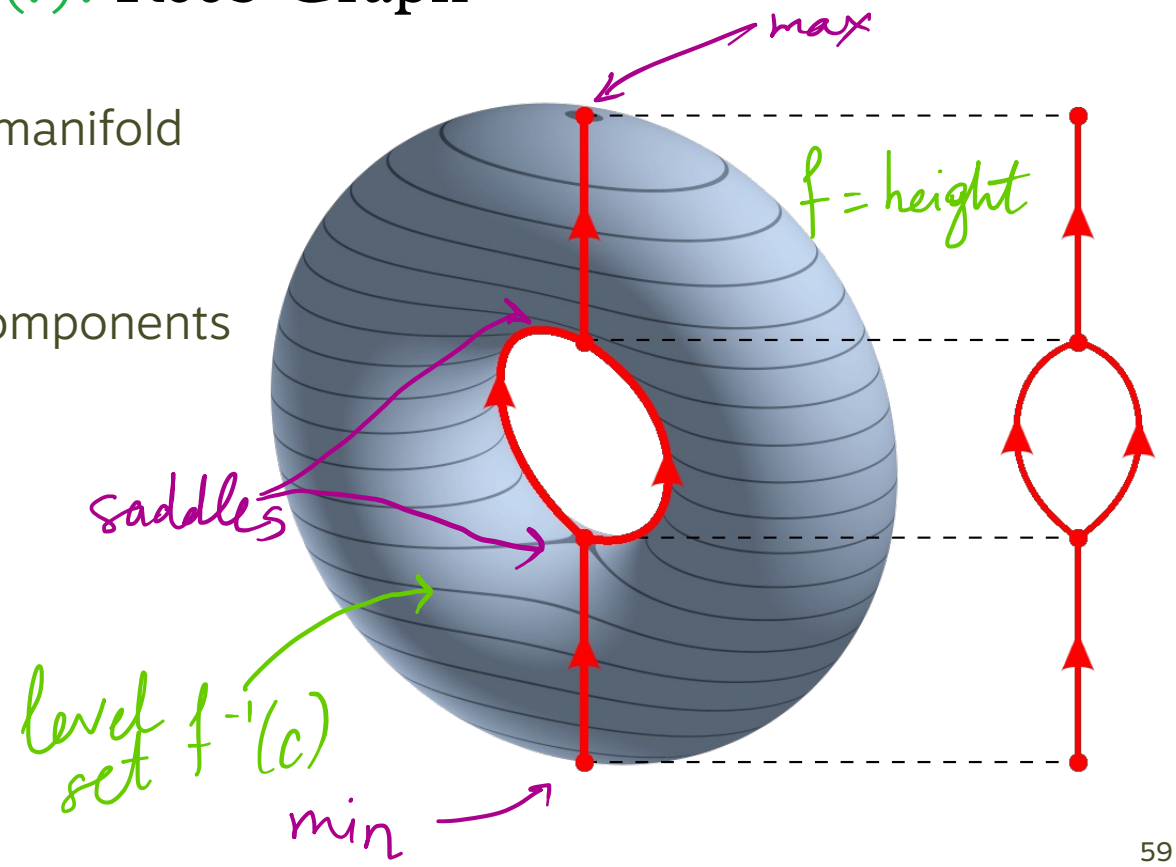
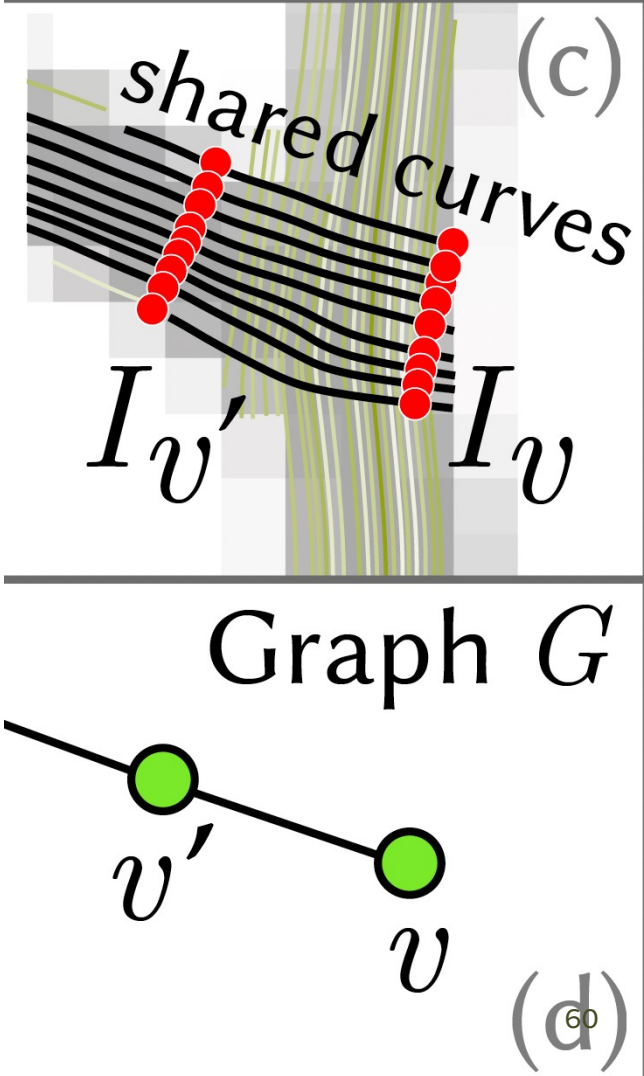


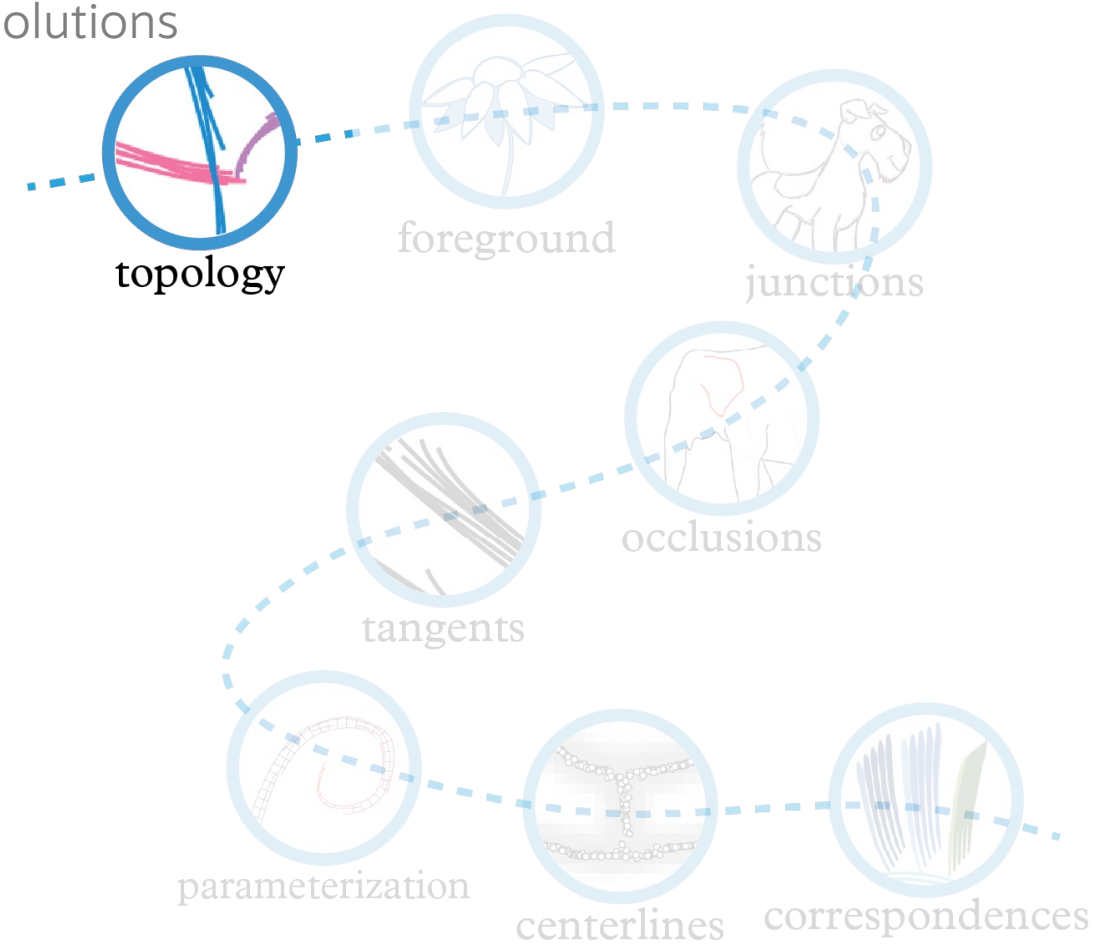
Topology | Solution (?): Reeb Graph

Stroke cluster -> Reeb graph

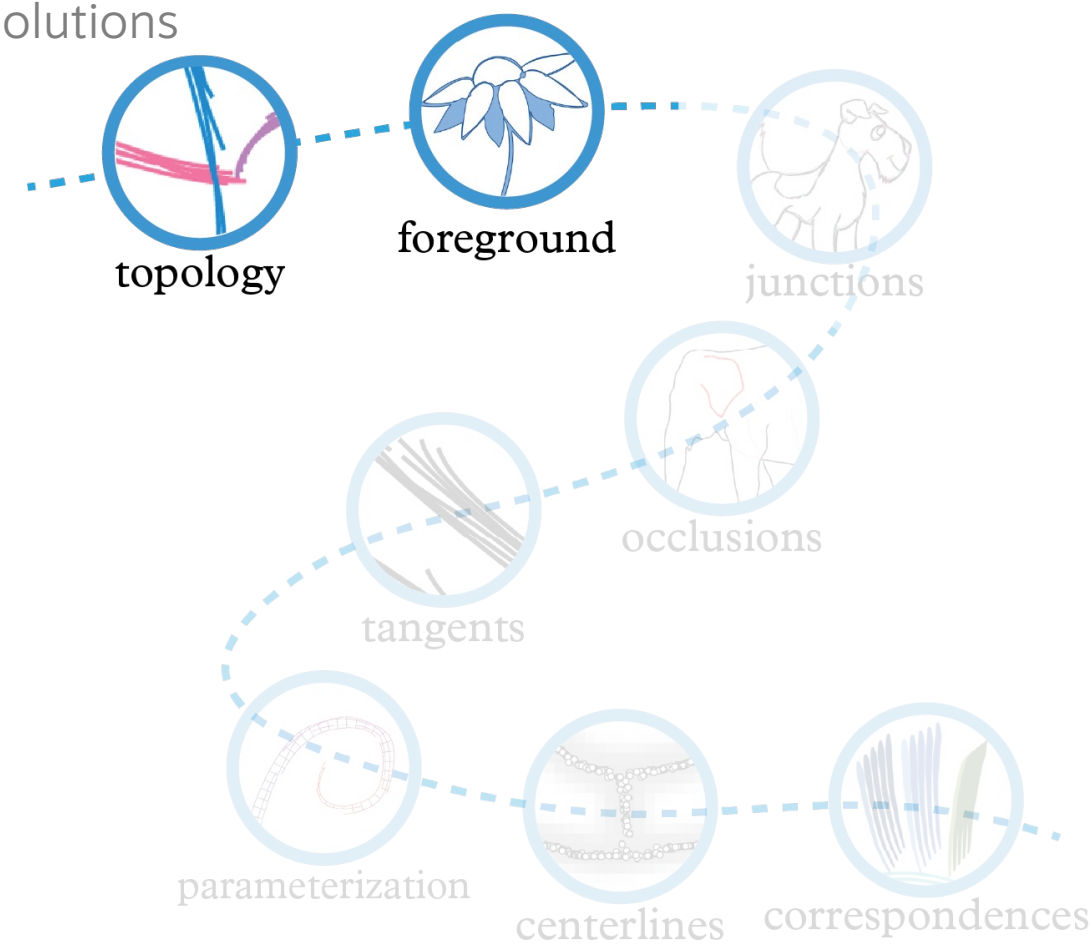
Function = cluster parameterization



core challenges of sketches and some solutions

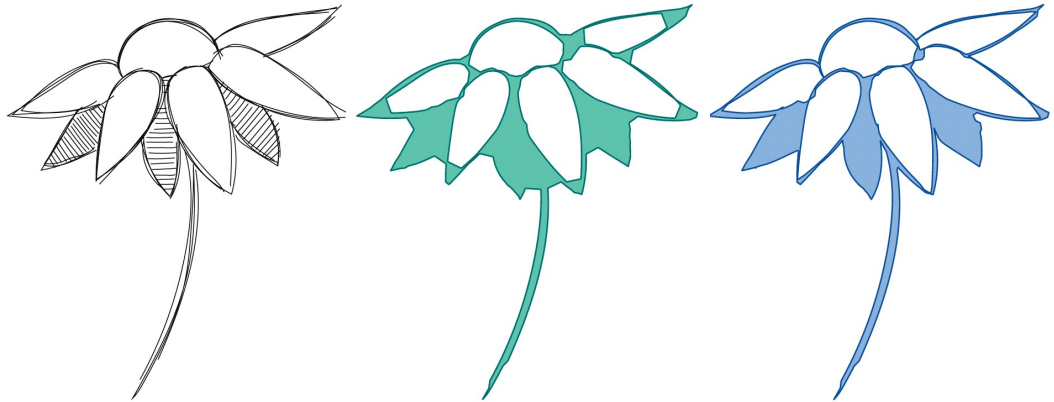


core challenges of sketches and some solutions



Core challenge: Background vs foreground

Image © Zoska Leutina



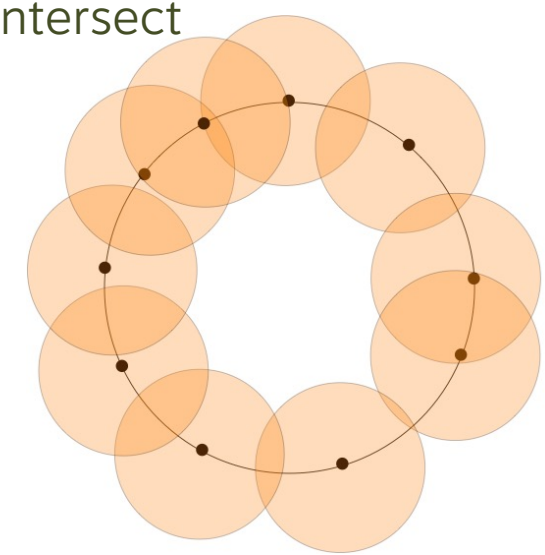
[Myronova et al. 2023]

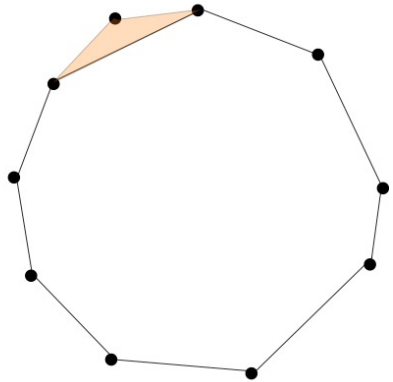
Background vs Foreground | Solution: Čech complex

Input: points $\in \mathbb{R}^2$ or $\mathbb{R}^3, \varepsilon > 0$

Draw an ε-ball around every point

Create a simplex whenever ε-ball intersect

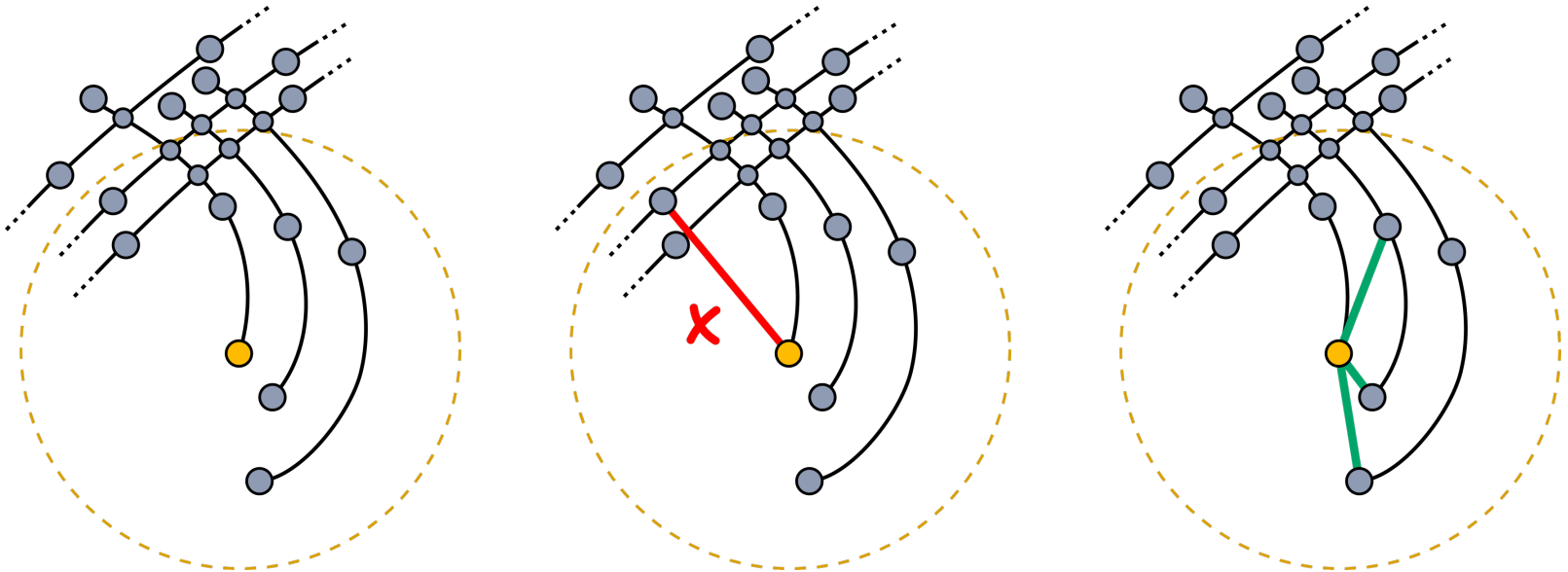




Img: ProboscideaRubber15

Background vs Foreground | Solution: Sketch complex

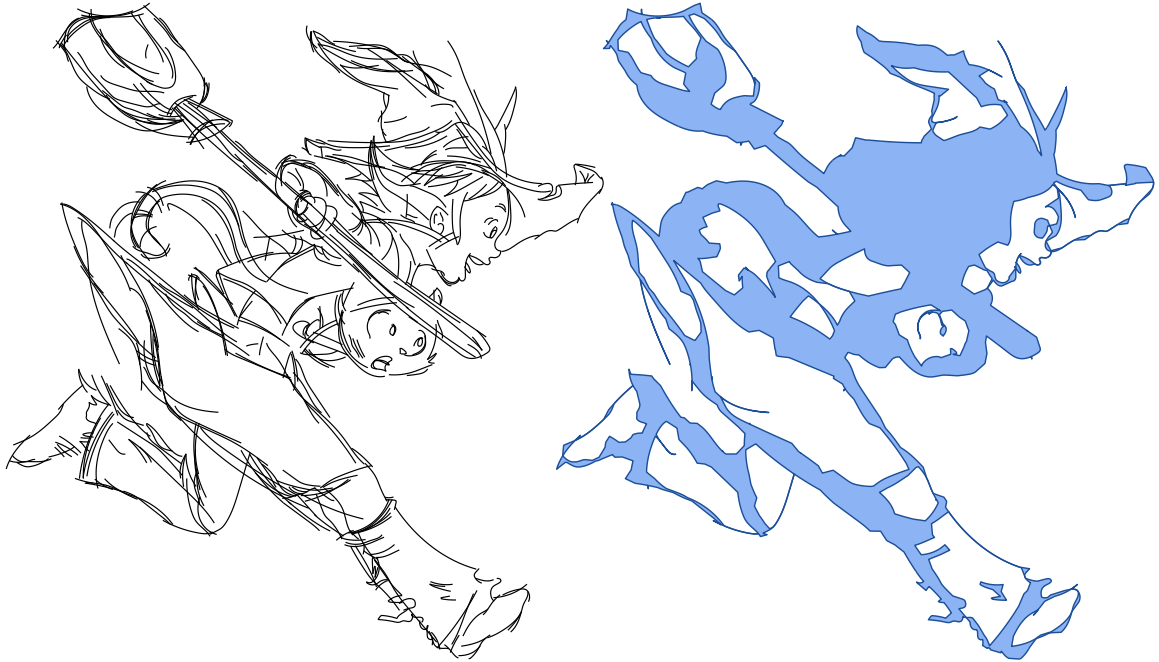
Connect **some** stroke vertices within an ε-radius



[Myronova et al. 2023]

Background vs Foreground | Solution: Sketch complex

Connect **some** stroke vertices within an ε-radius



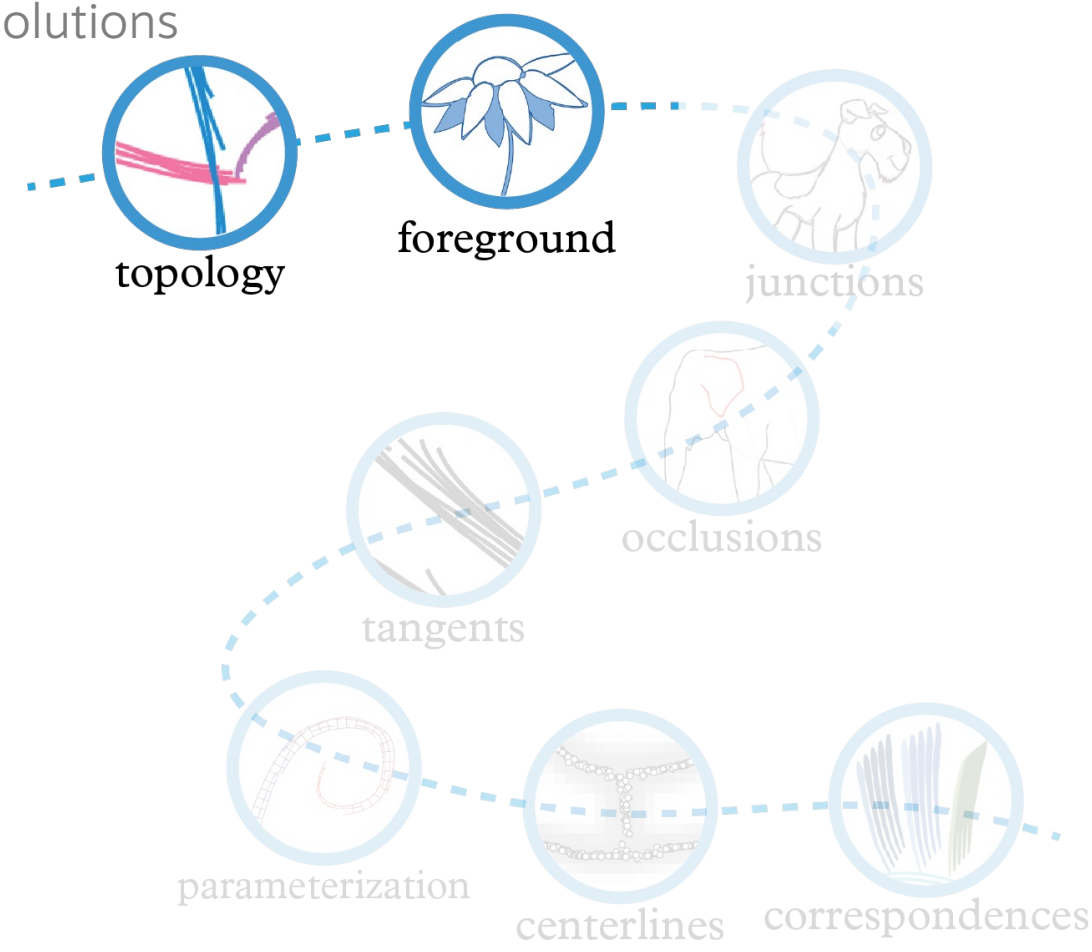
[Myronova et al. 2023]

Background vs Foreground | Solution: Sketch complex

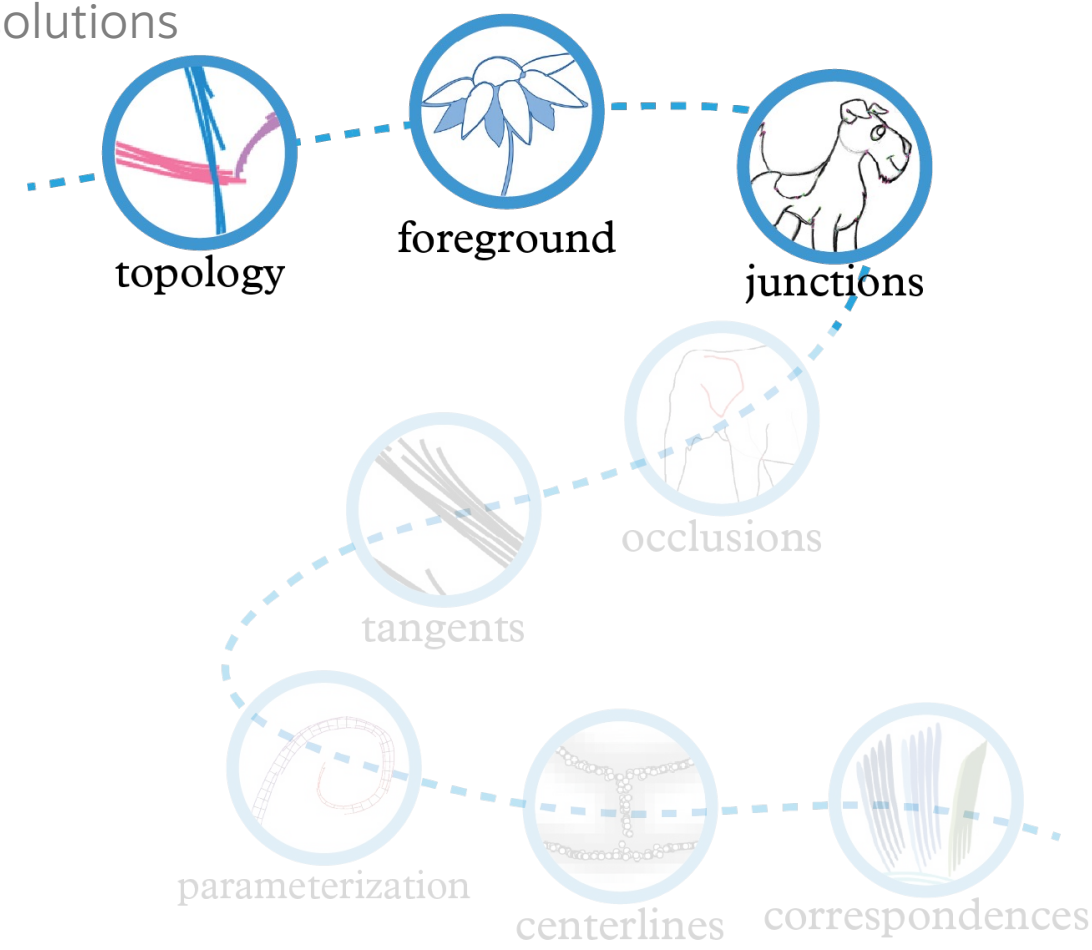
Connect **some** stroke vertices within an ε-radius

[Myronova et al. 2023]

core challenges of sketches and some solutions



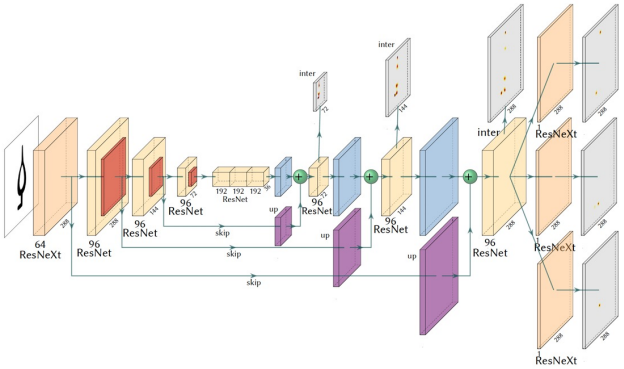
core challenges of sketches and some solutions

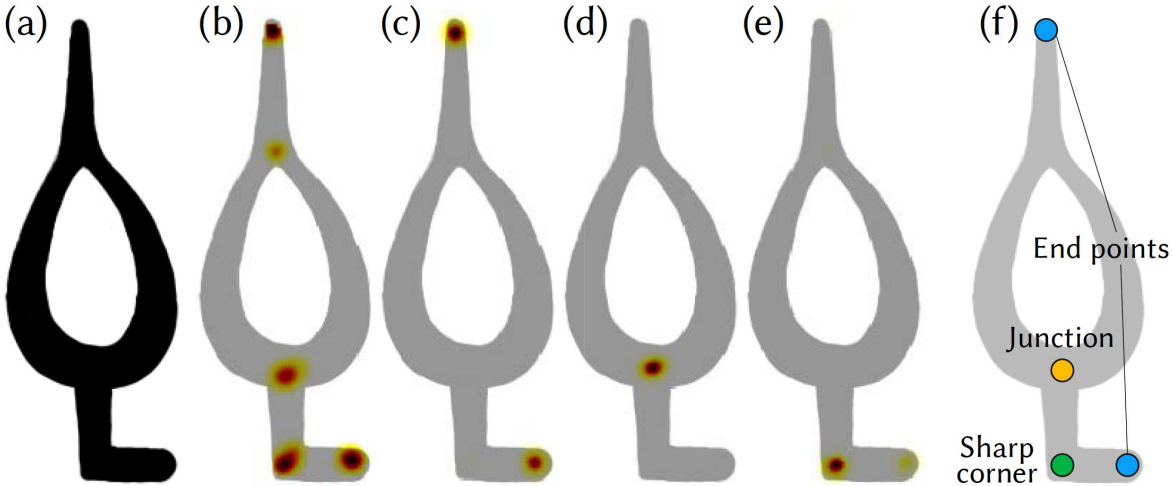


Core challenge: Where are endpoints, junctions, and intersections?

[Puhachov et al. 2021]. Input image © Ivan Huska

Where are endpoints, junctions, and intersections | Solution



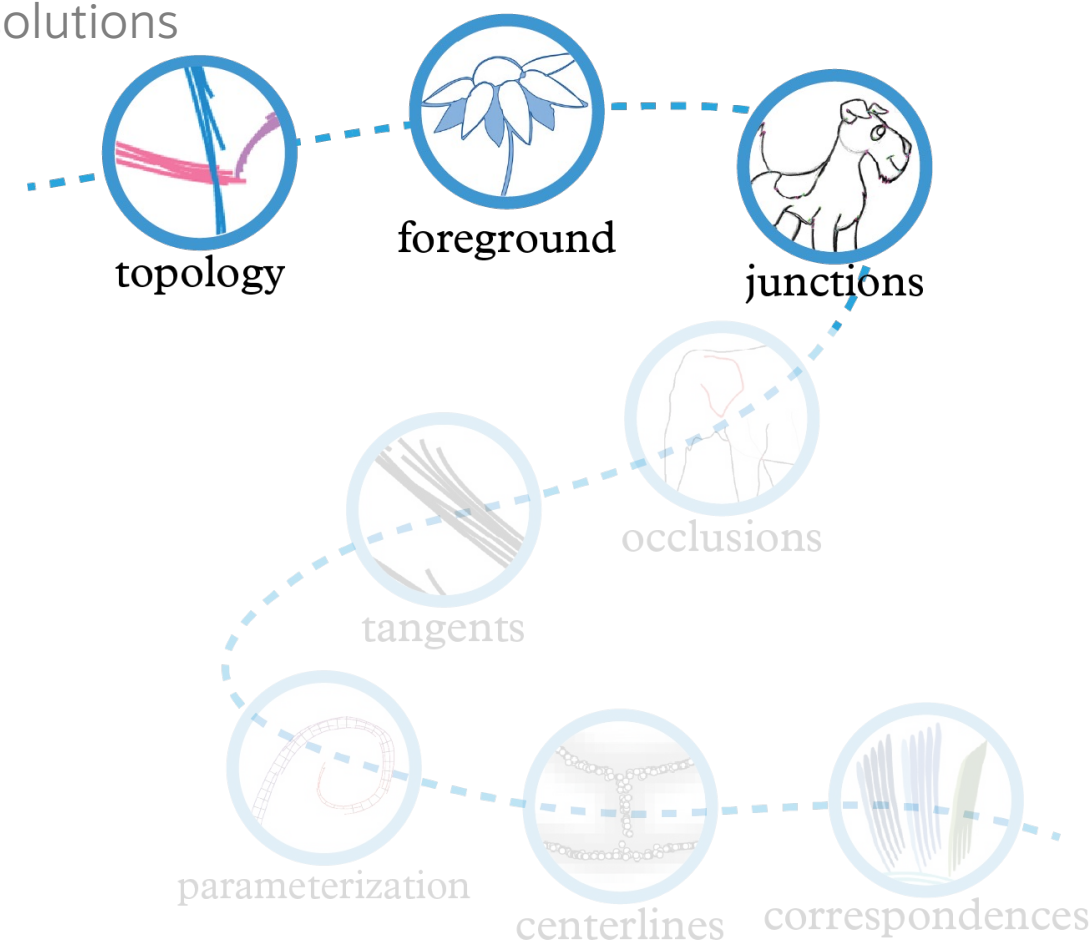


[Puhachov et al. 2021], [Yan et al. 2024]

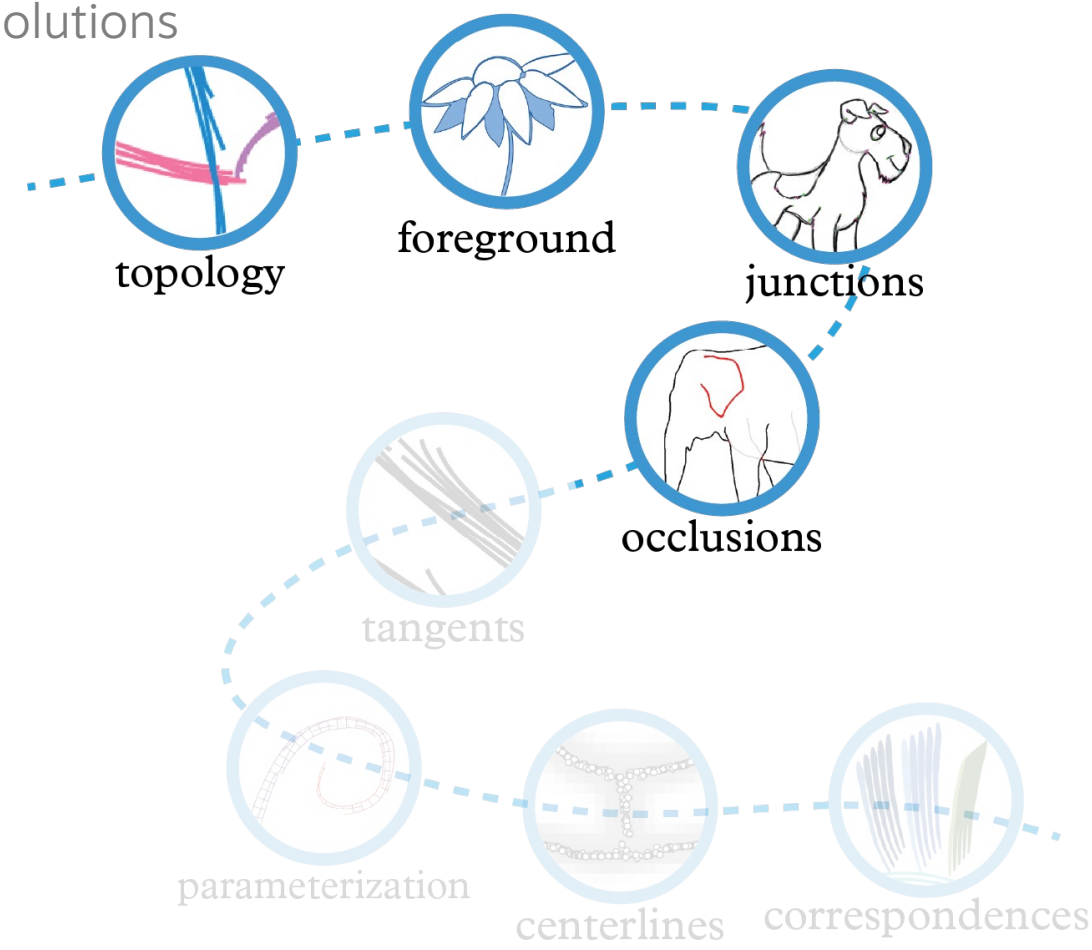
Core challenge: Where are endpoints, junctions, and intersections?

What is the level of abstraction we want?

core challenges of sketches
and some solutions

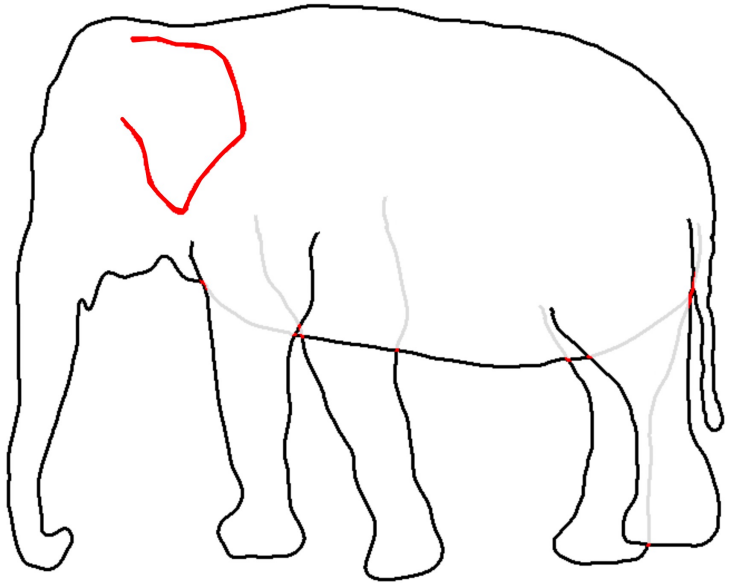


core challenges of sketches
and some solutions



Core challenge: Hidden contours

Draw manually

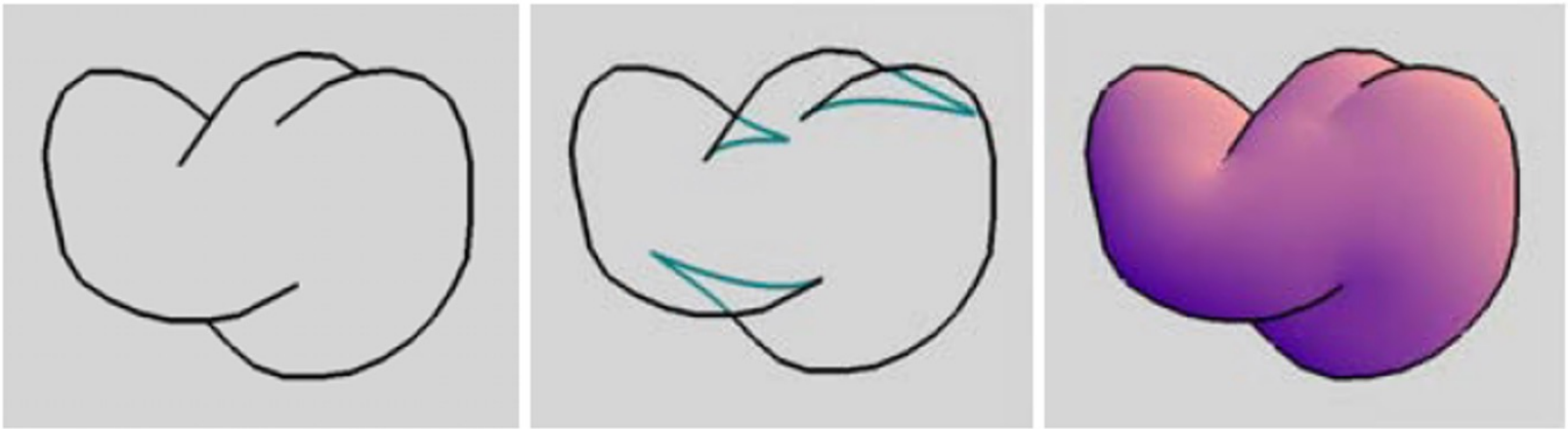


[Dvorožňák et al. 2018]

Core challenge: Hidden contours

We are not good at imagining the shape of hidden contours

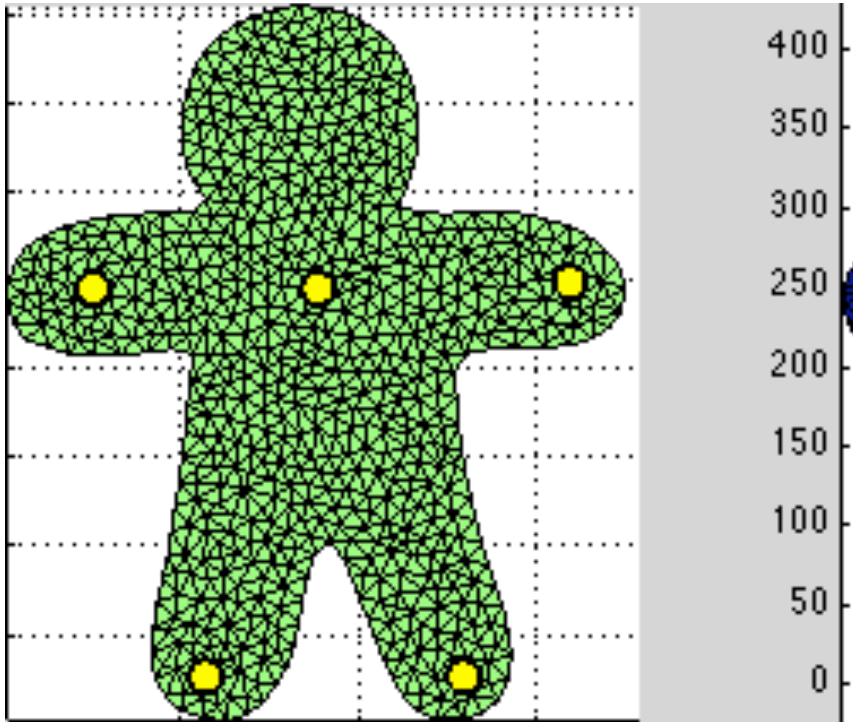
Connect endpoints heuristically with splines?

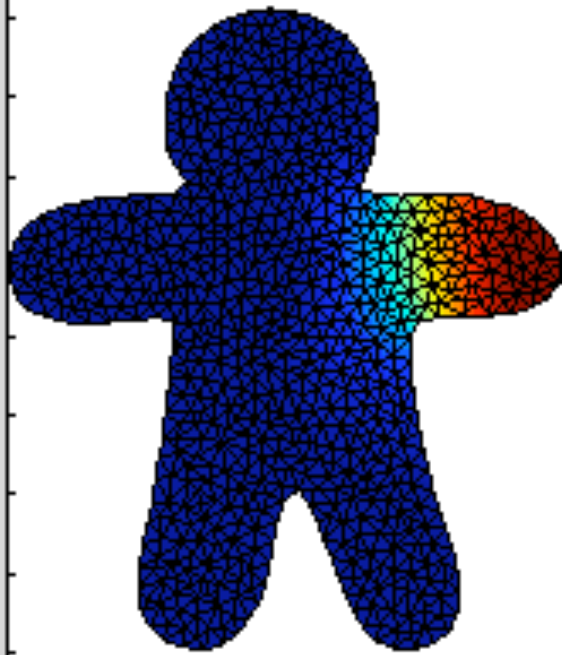


[Karpenko and Hughes 2006]

Core challenge: Occlusions

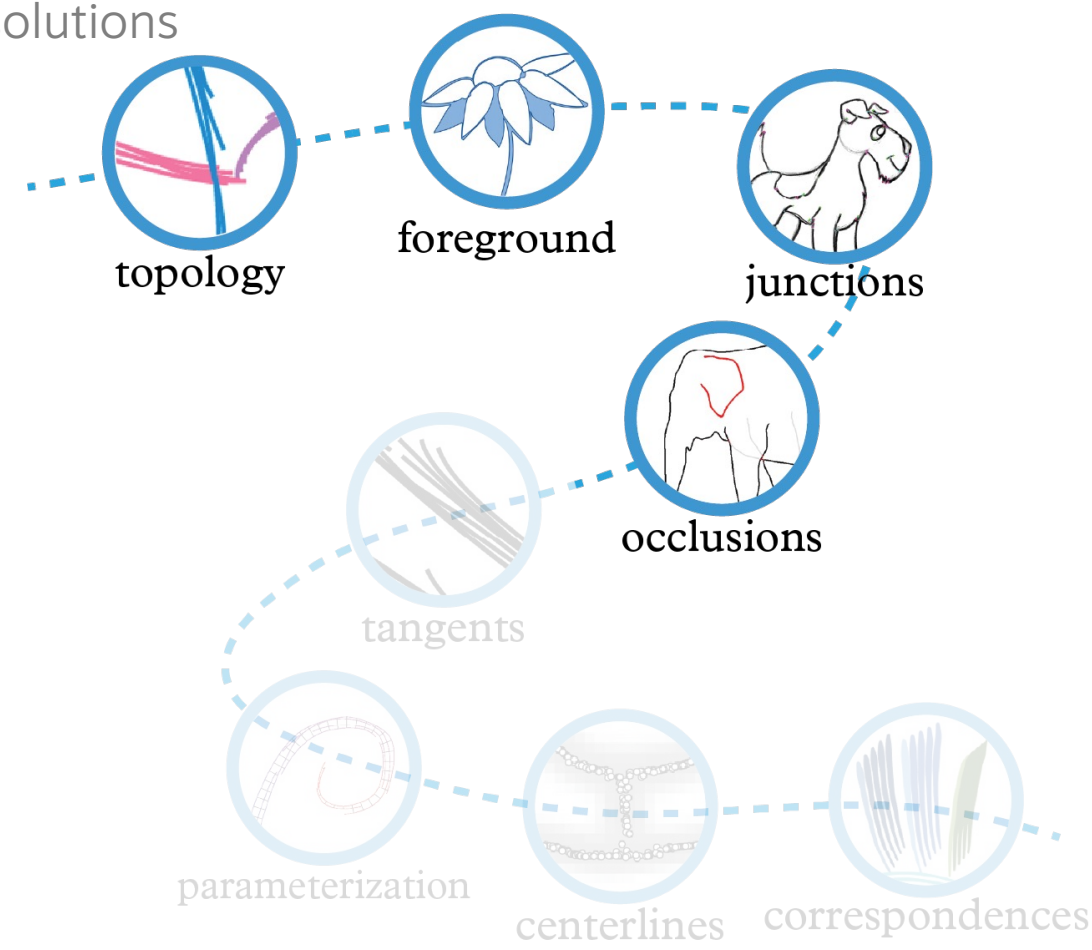
Core challenge: Occlusions



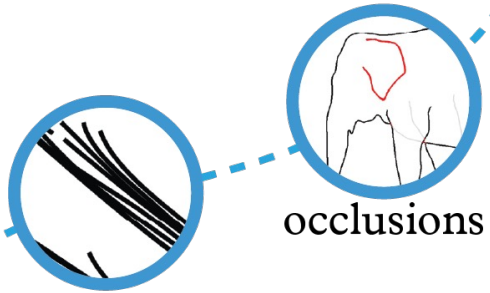


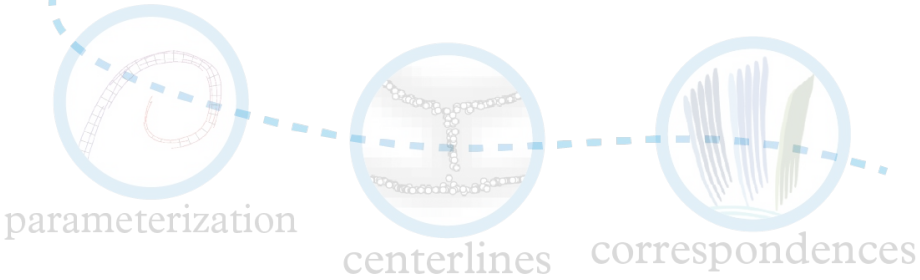
[Jacobson et al. 2011]

core challenges of sketches
and some solutions



core challenges of sketches and some solutions





Core challenge: Tangents?

Tangents near endpoints and junctions

Tangents of overdrawn strokes

Core challenge: Tangents?

Tangents near endpoints and junctions

Tangents of overdrawn strokes

Core challenge: Tangents?

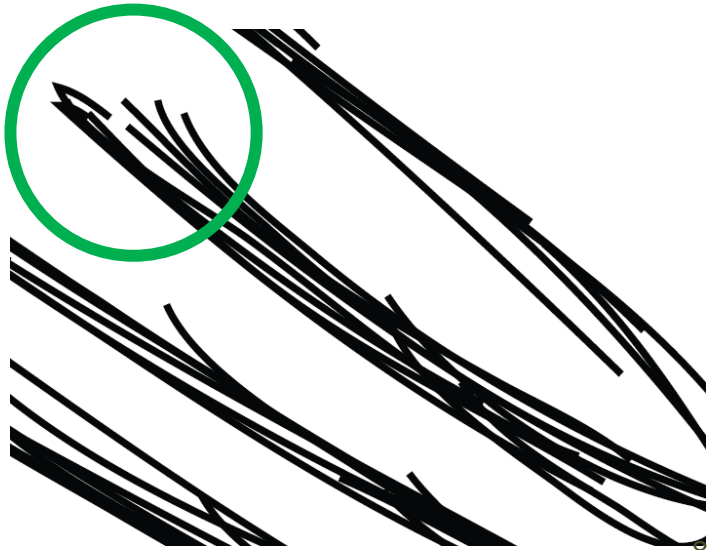
Tangents near endpoints and junctions

Tangents of overdrawn strokes

Core challenge: Tangents?

Tangents near endpoints and junctions

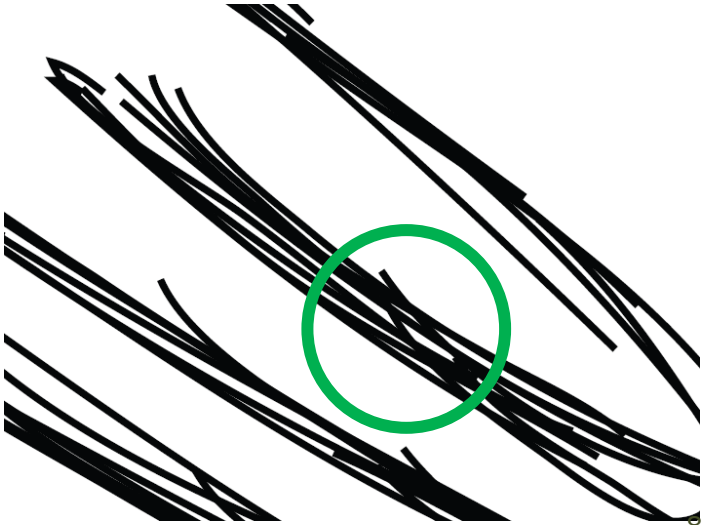
Tangents of overdrawn strokes



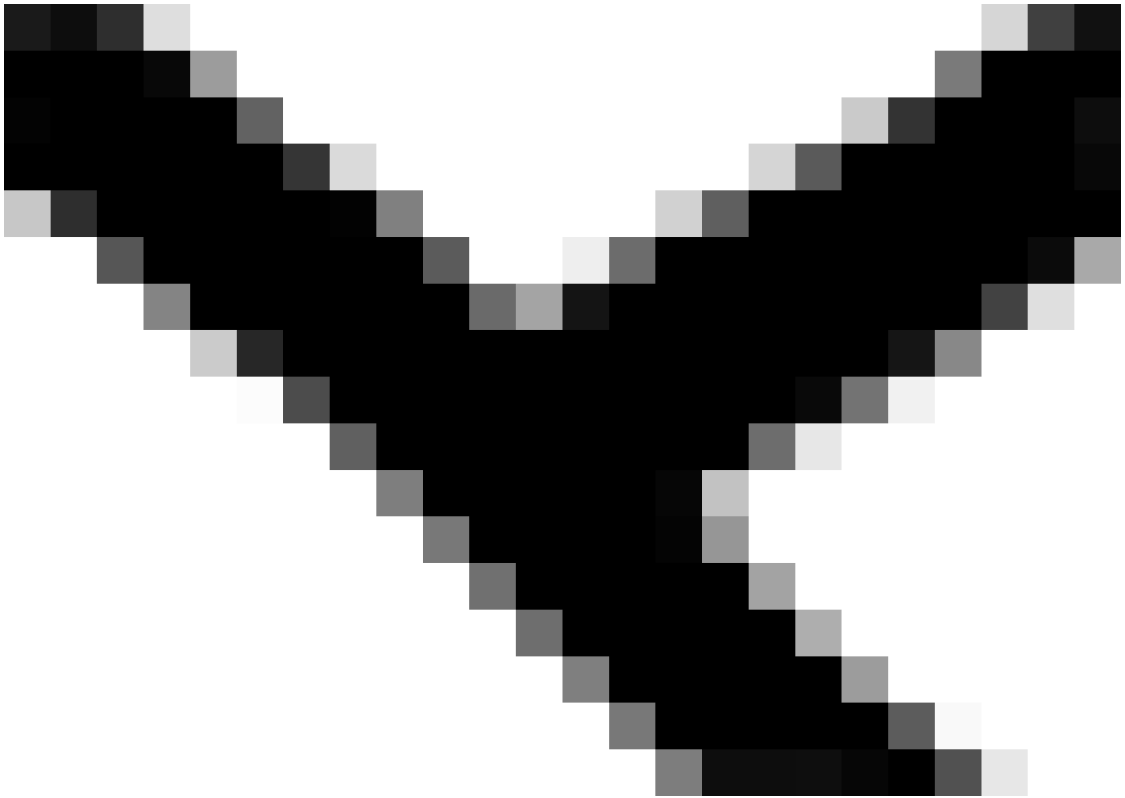
Core challenge: Tangents?

Tangents near endpoints and junctions

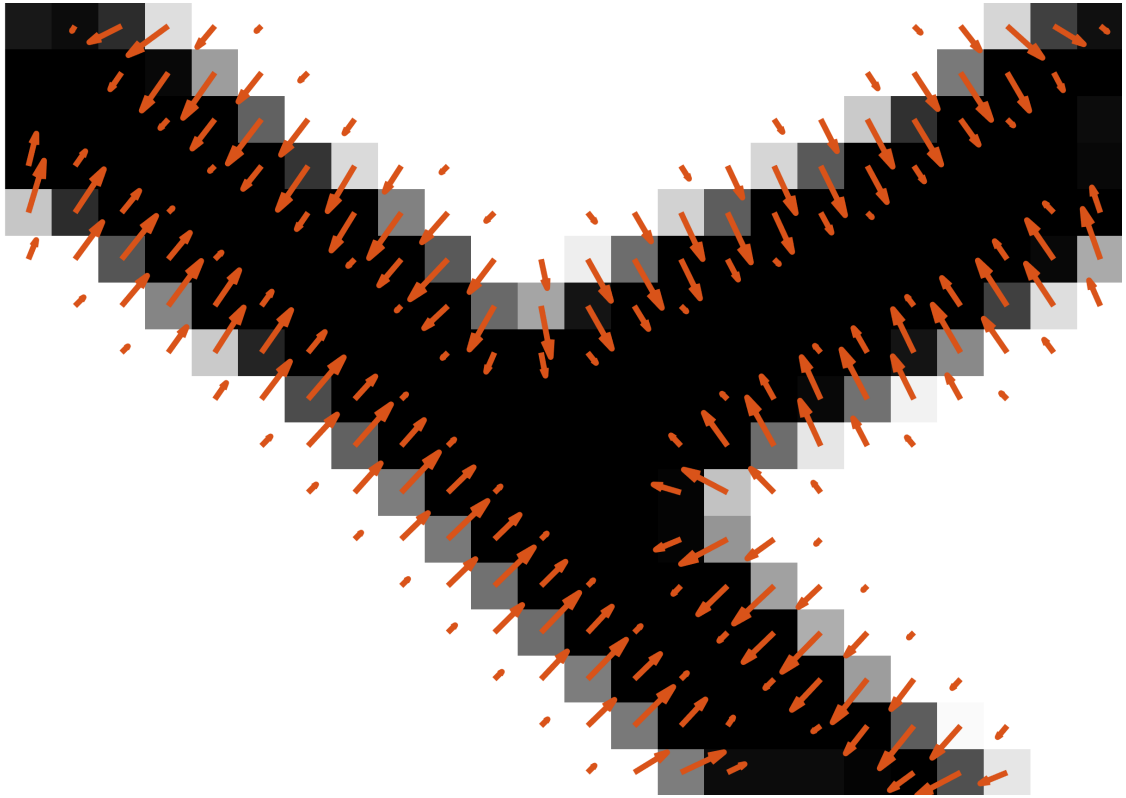
Tangents of overdrawn strokes



Tangents | Solution: Directional and frame fields



Tangents | Solution: Directional and frame fields



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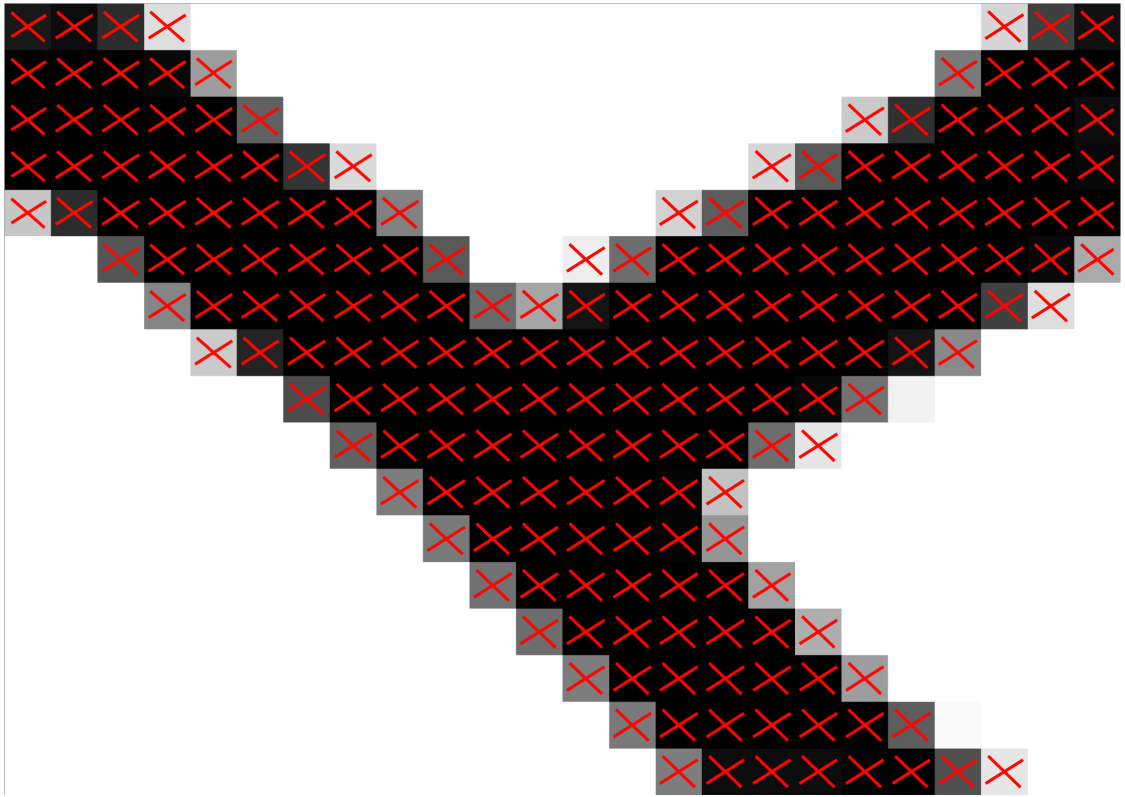
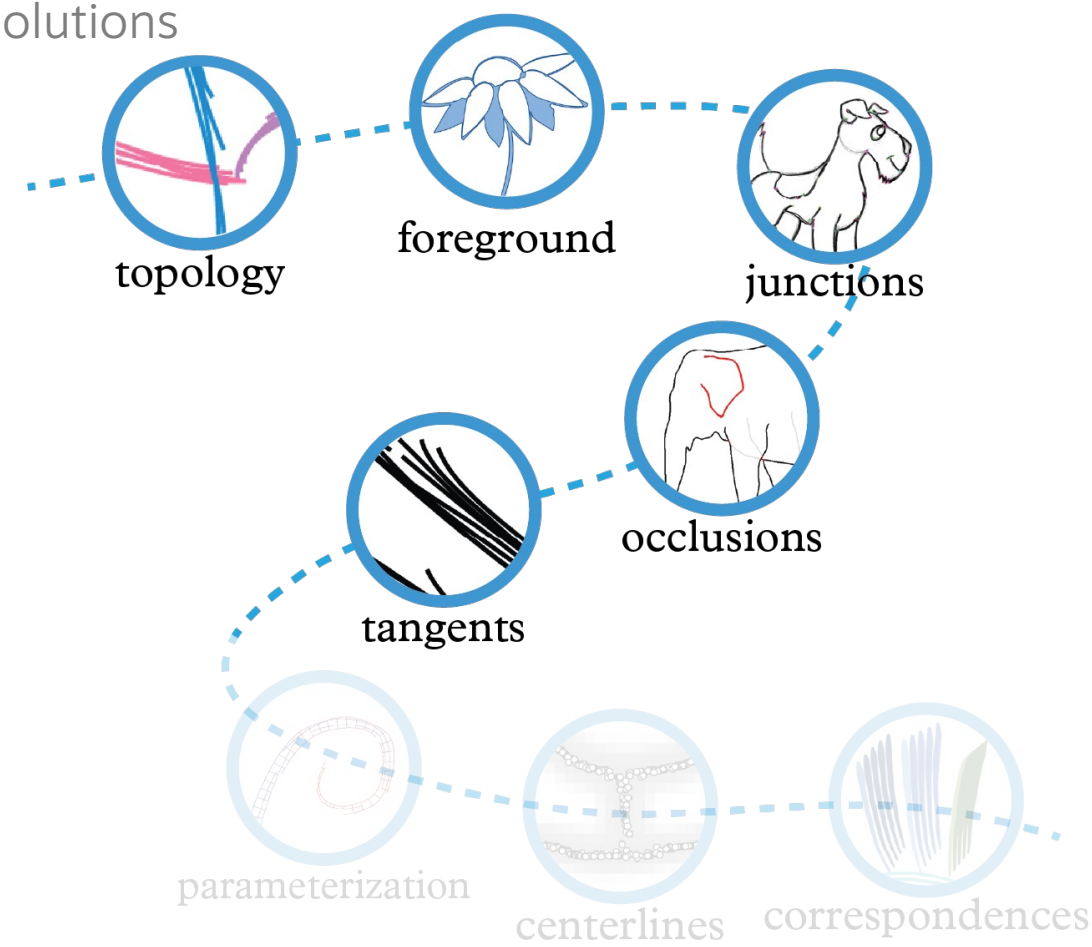
Tangents | Solution: Directional and frame fields



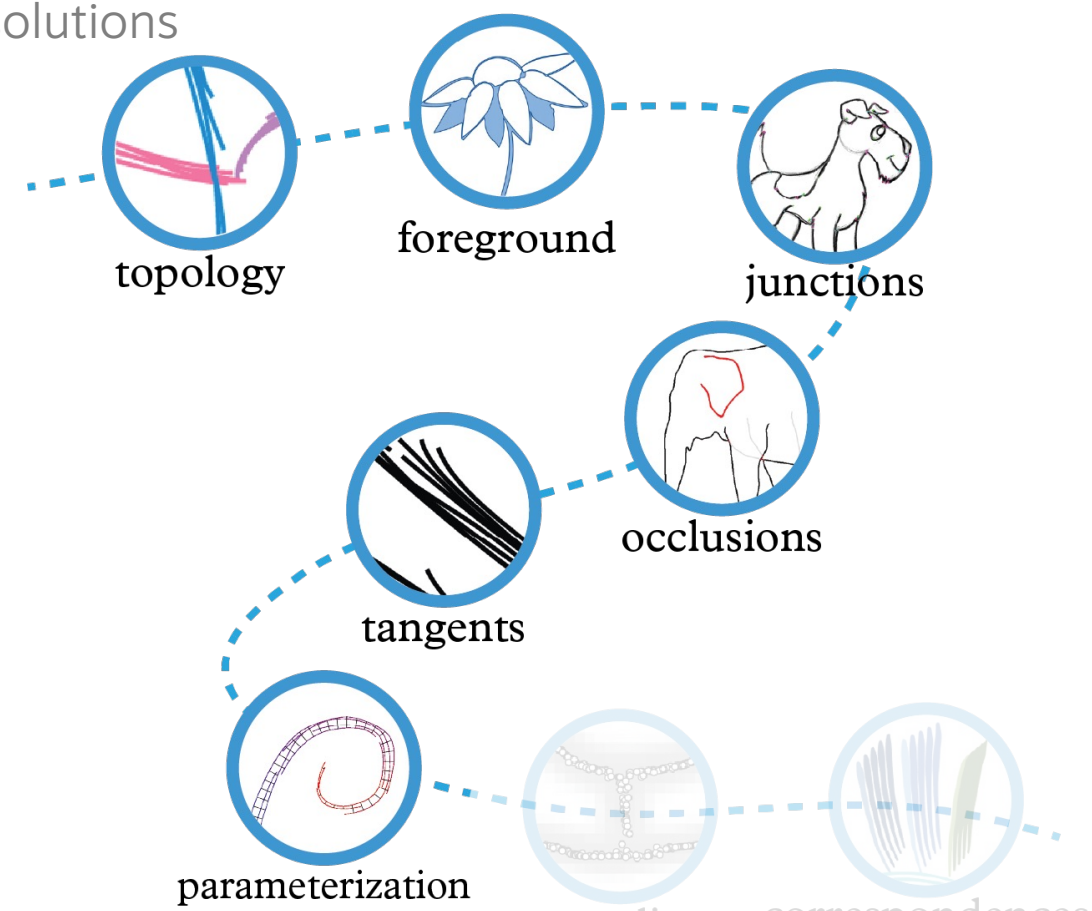
Tangents | Solution: Directional and frame fields

https://medibangpaint.com/en/use/2020/03/how-to-draw-a-snowflake/

core challenges of sketches and some solutions

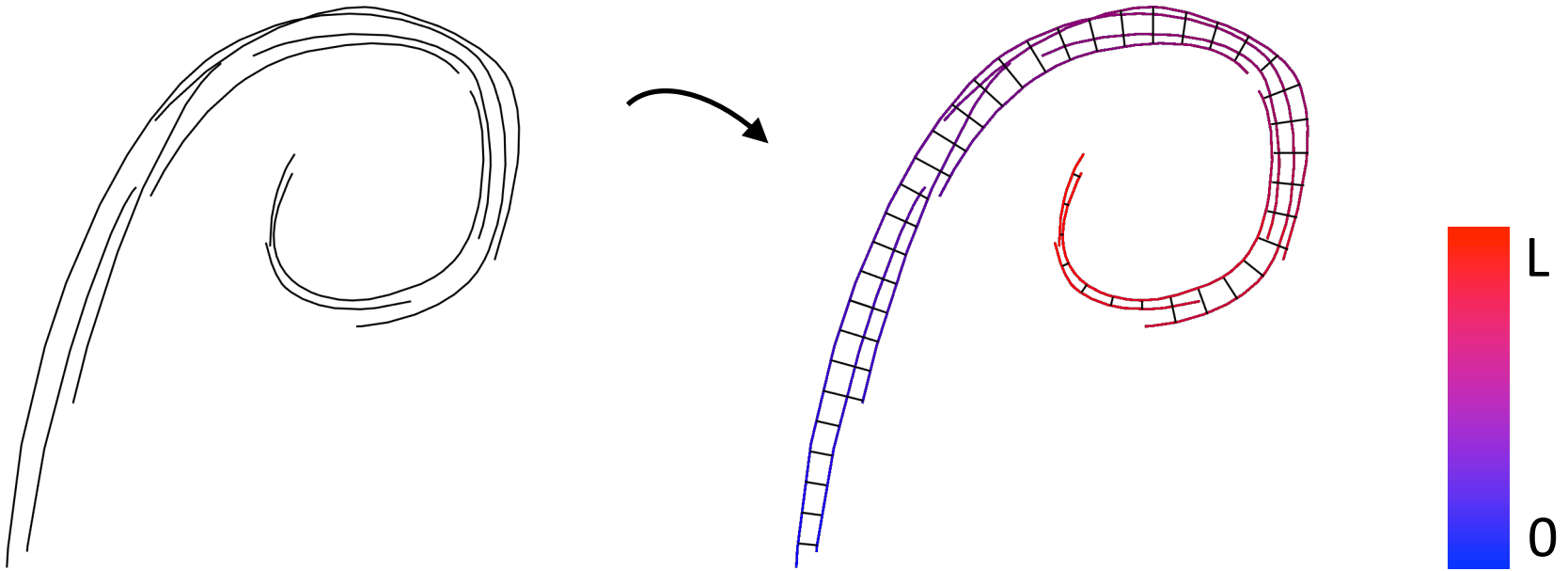


core challenges of sketches
and some solutions



Core challenge: Parameterization

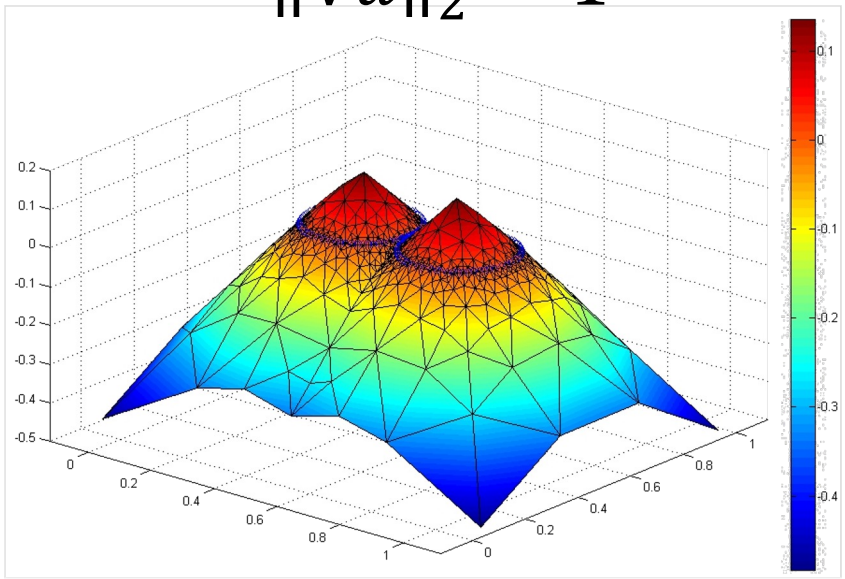
Arclength parameterization of a cluster



[van Mossel et al. 2021]

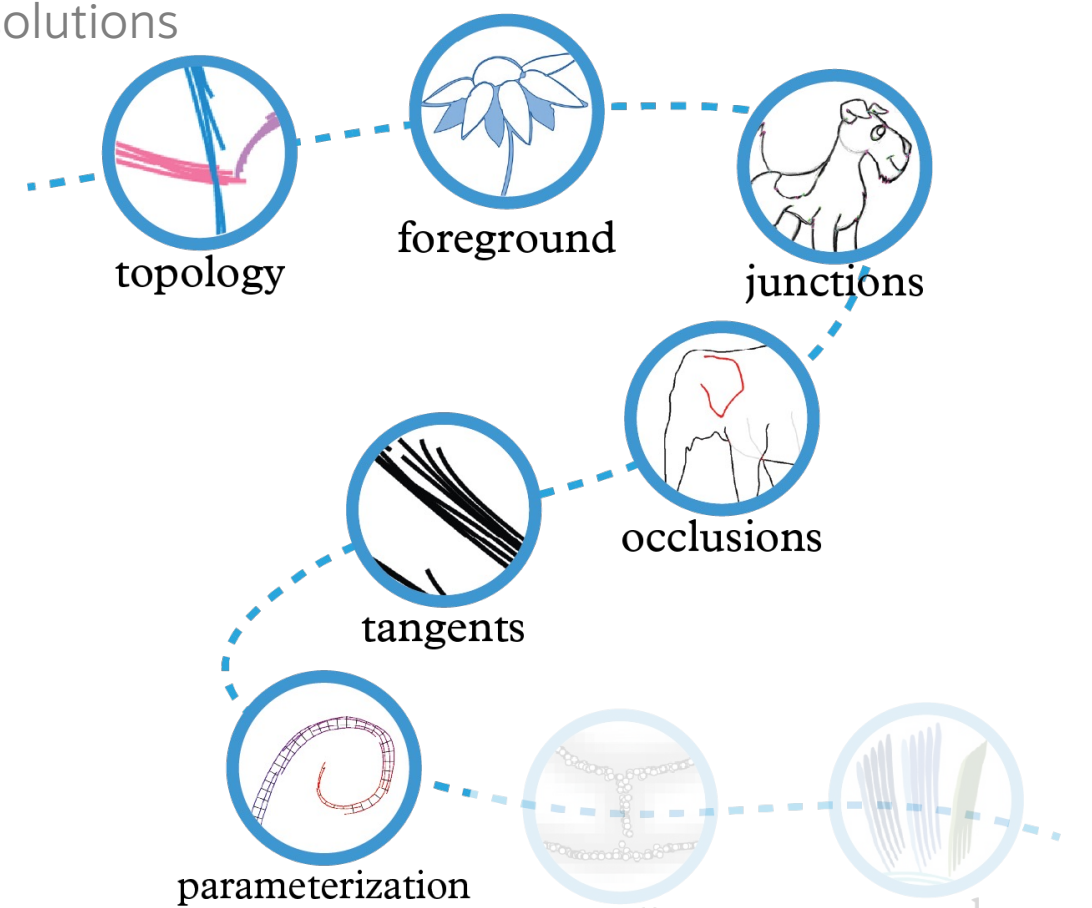
Parameterization | Solution: Eikonal equation

$$\|\nabla u\|_2 = 1$$

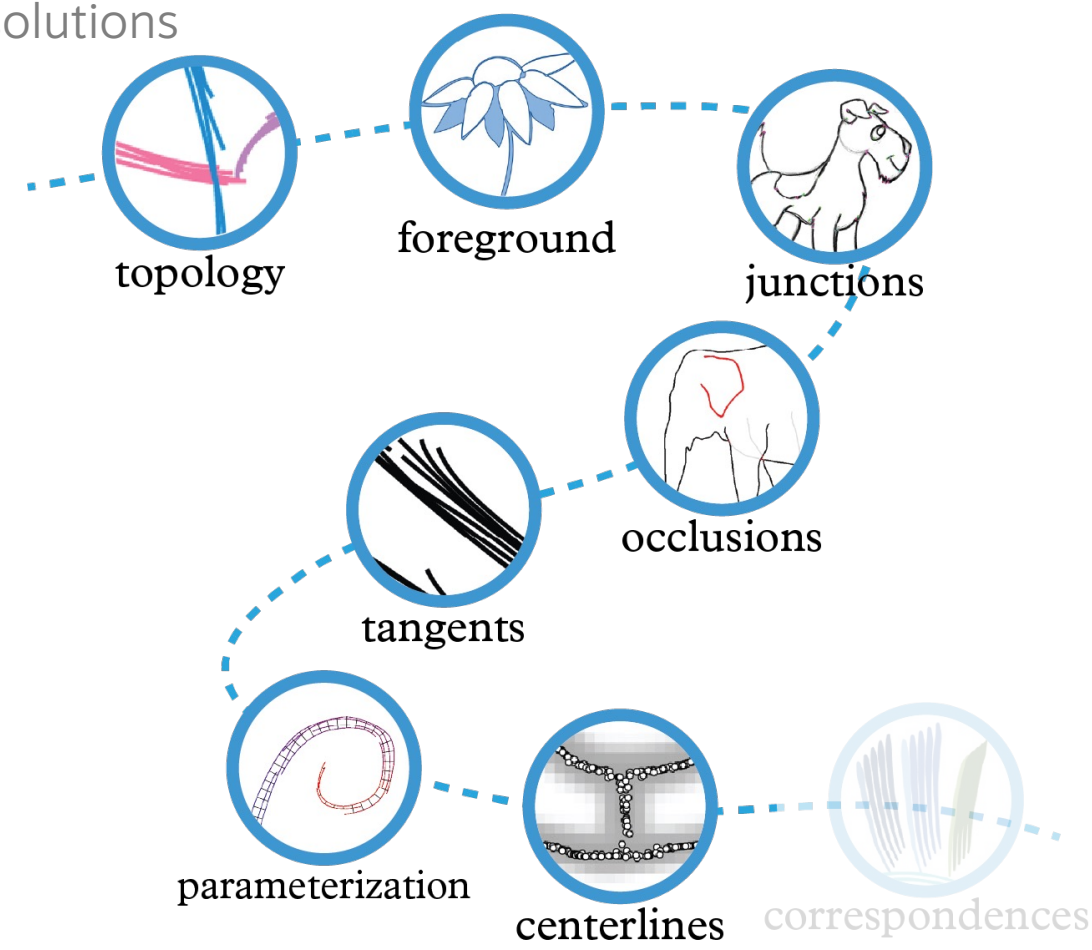


https://www.mathworks.com/matlabcentral/fileexchange/24827-hamilton-jacobi-solver-on-unstructured-triangular-grids/content/HJB_Solver_Package/@SolveEikonal/SolveEikonal.m

core challenges of sketches
and some solutions

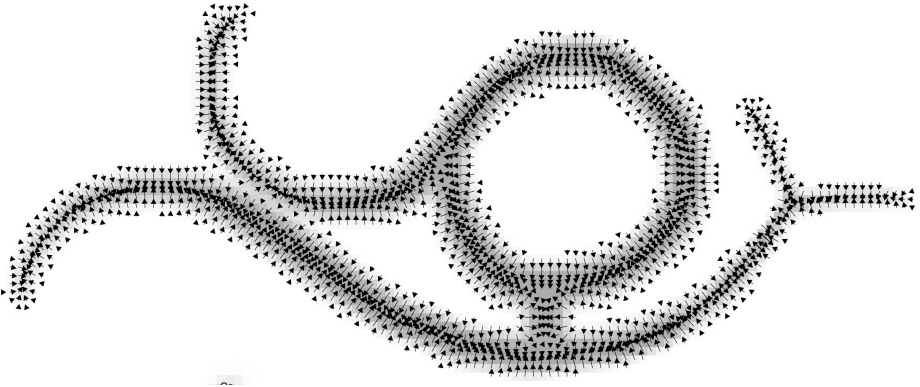


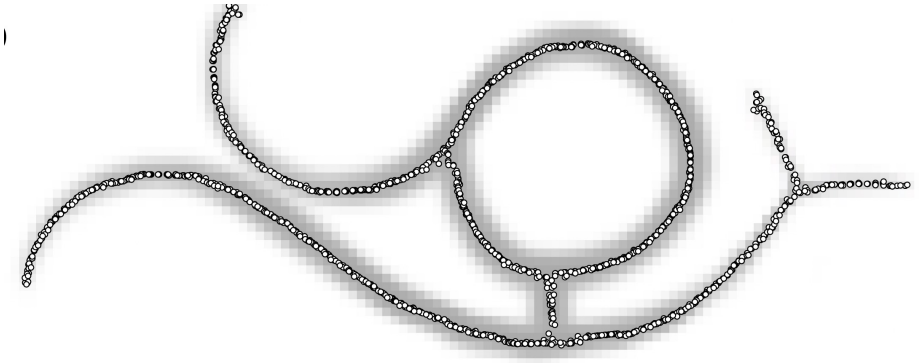
core challenges of sketches
and some solutions



Core challenge: Centerlines

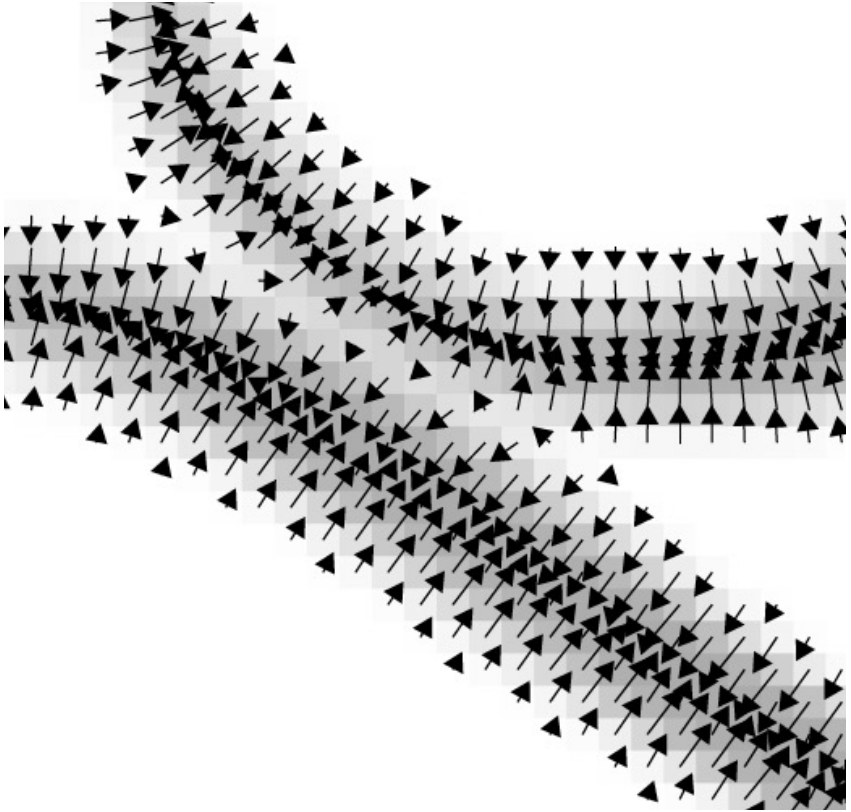
Find centerlines of a bitmap line drawing

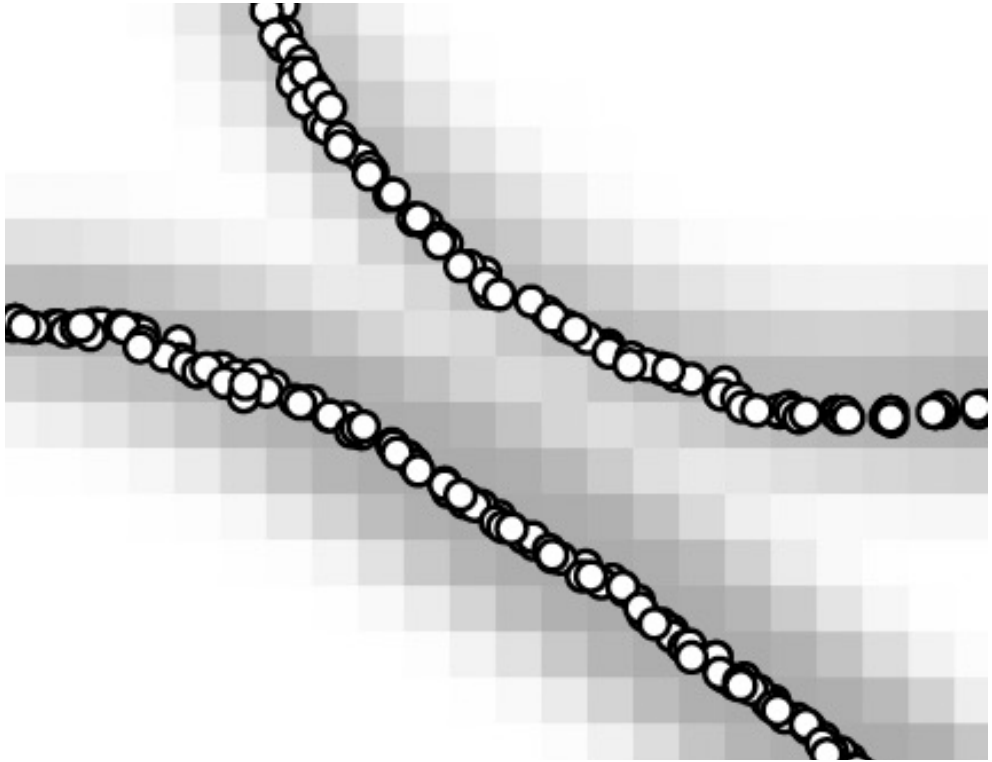




[Noris et al., 2012]

Centerlines | Solution: Gradient descent





[Noris et al., 2012]

Centerlines | Solution: Unsigned distance field

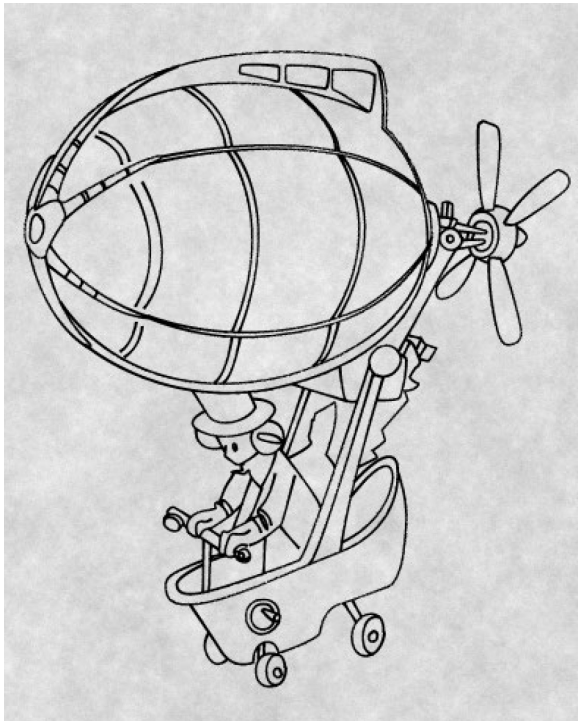


Image © David Revoy CC-BY-4.0

[Yan et al. 2024]

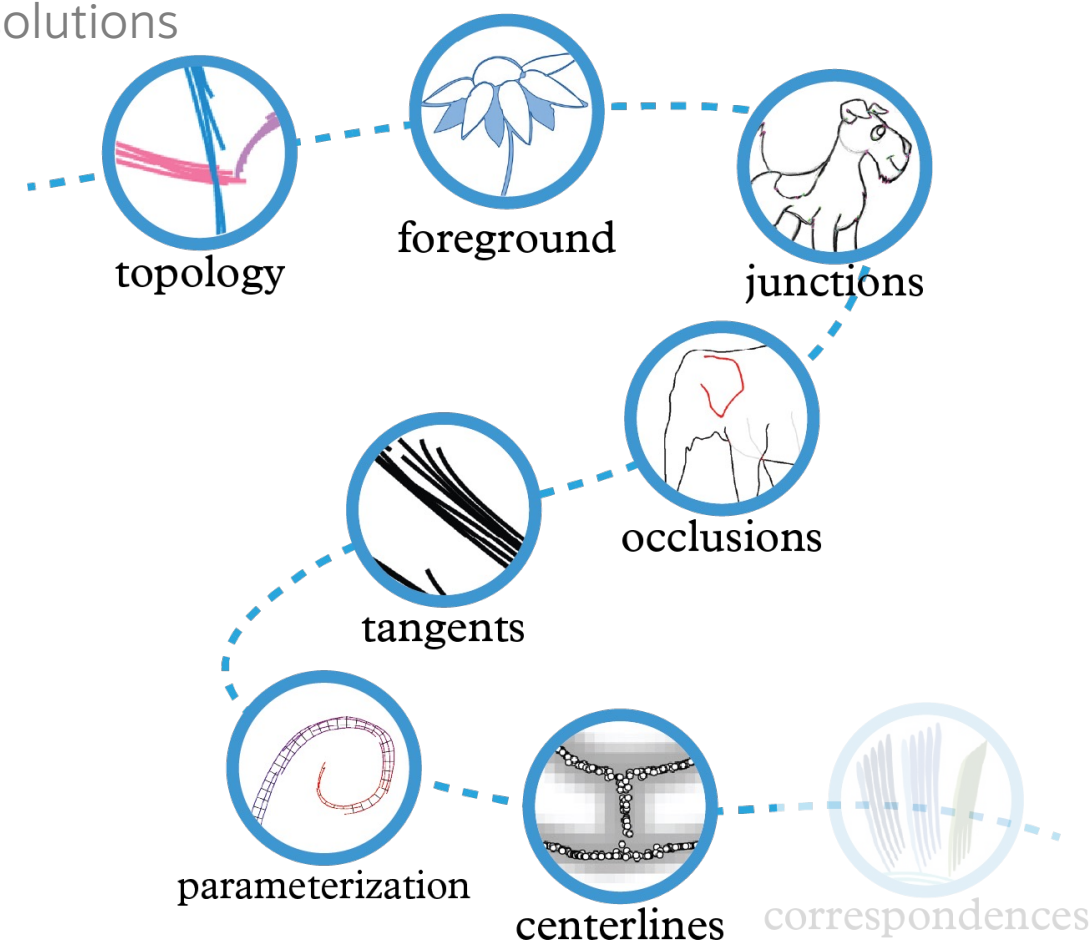
Core challenge: Stroke vs Fill?

Image © Andreas von Buddenbrock

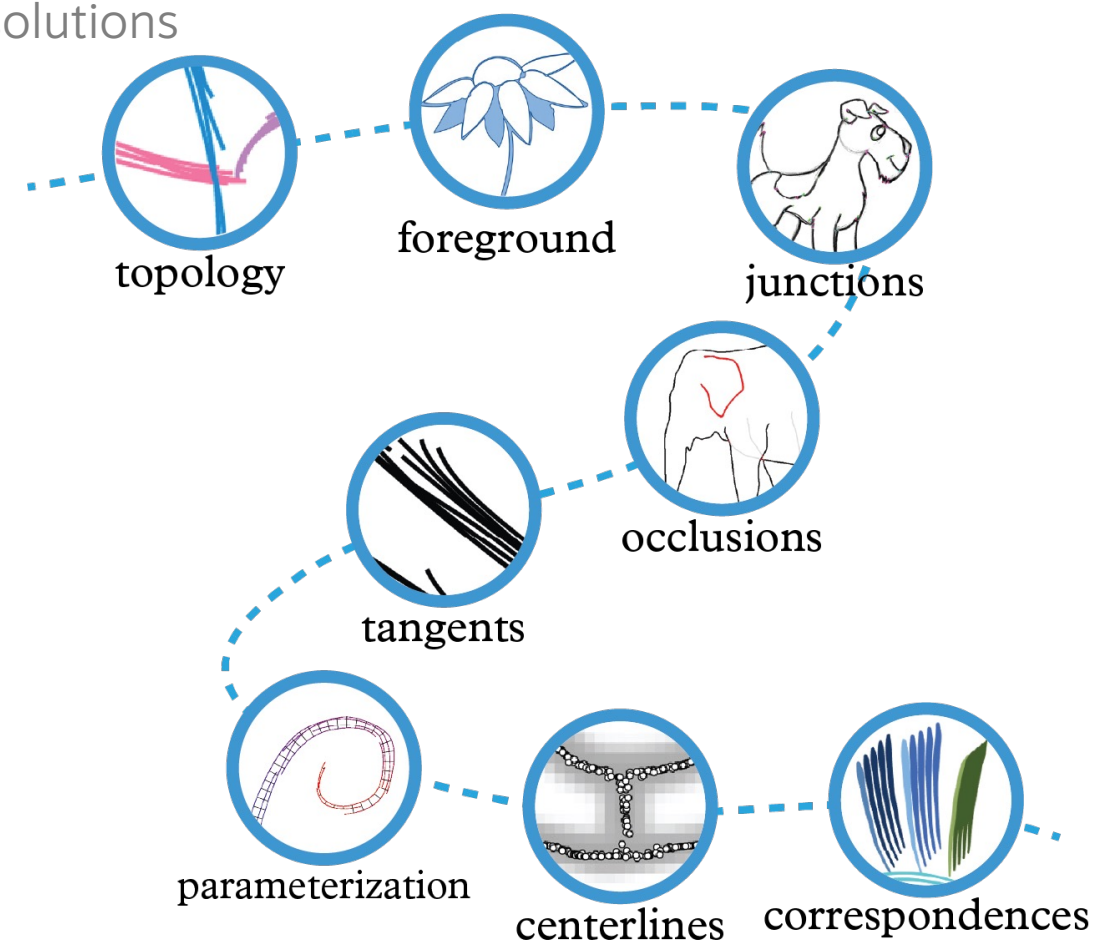
Core challenge: Stroke vs Fill?

Image © Andreas von Buddenbrock

core challenges of sketches and some solutions

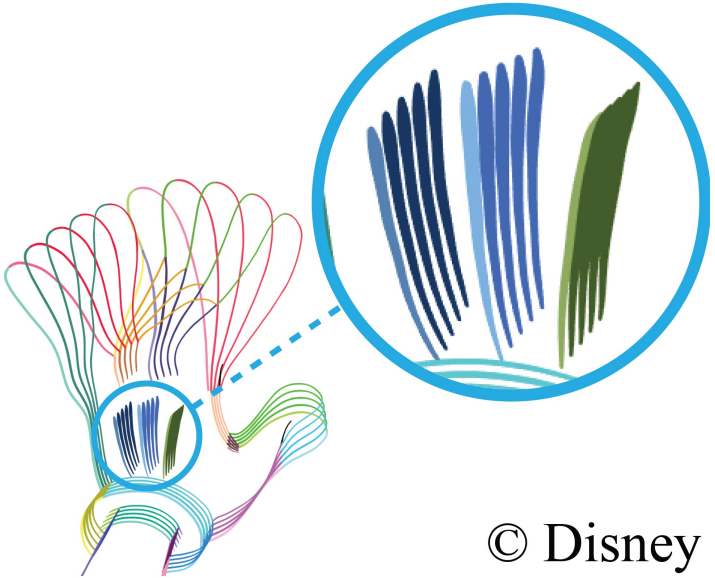


core challenges of sketches and some solutions



Core challenge: Correspondences

A correspondence **between strokes** suggests **pointwise correspondence**



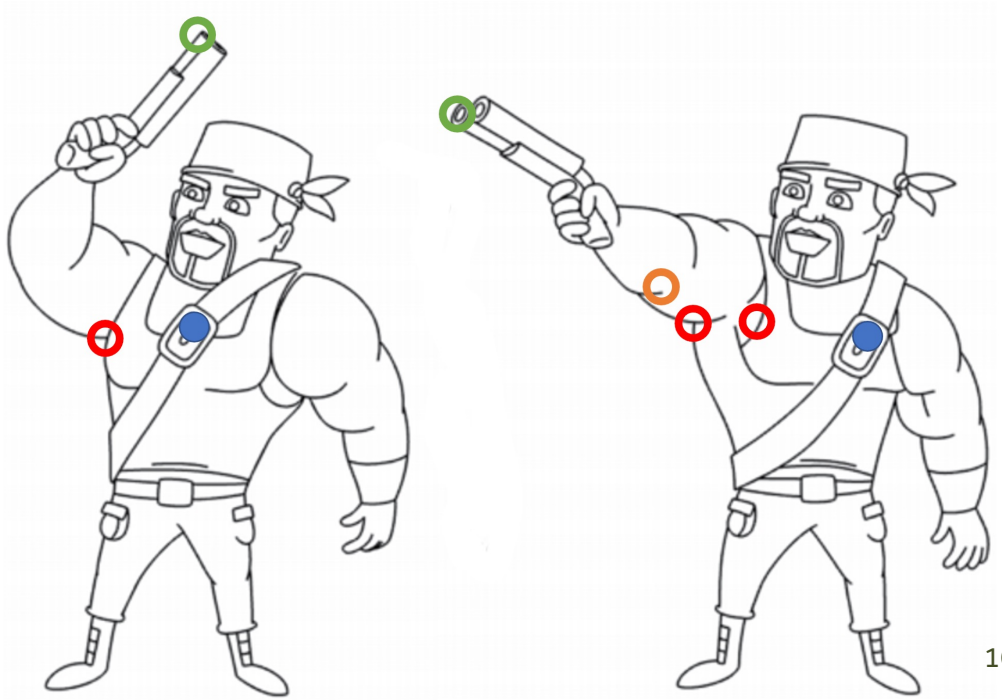
© Disney

[Whited et al. 2010]

Core challenge: Correspondences

Even more complex when there are occlusions

One-to-many, one-to-nothing



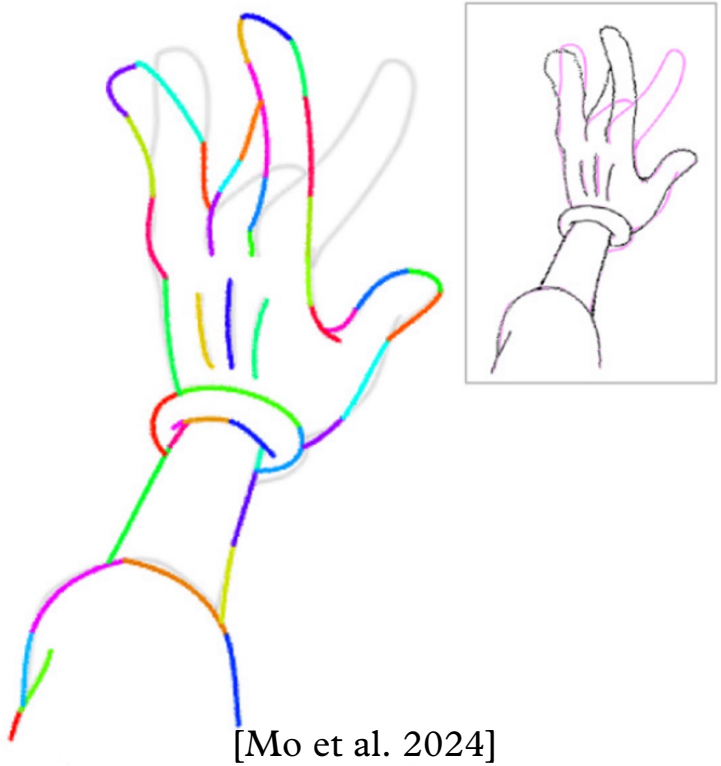
Correspondences | Solution: Joint Tracing

Start with a vectorization of frame 1, try retracing it at frame 2

[Mo et al. 2024], a similar idea in [Noris et al. 2010]

Correspondences | Solution: Optical Flow

A vector field deforming Frame 1 into 2



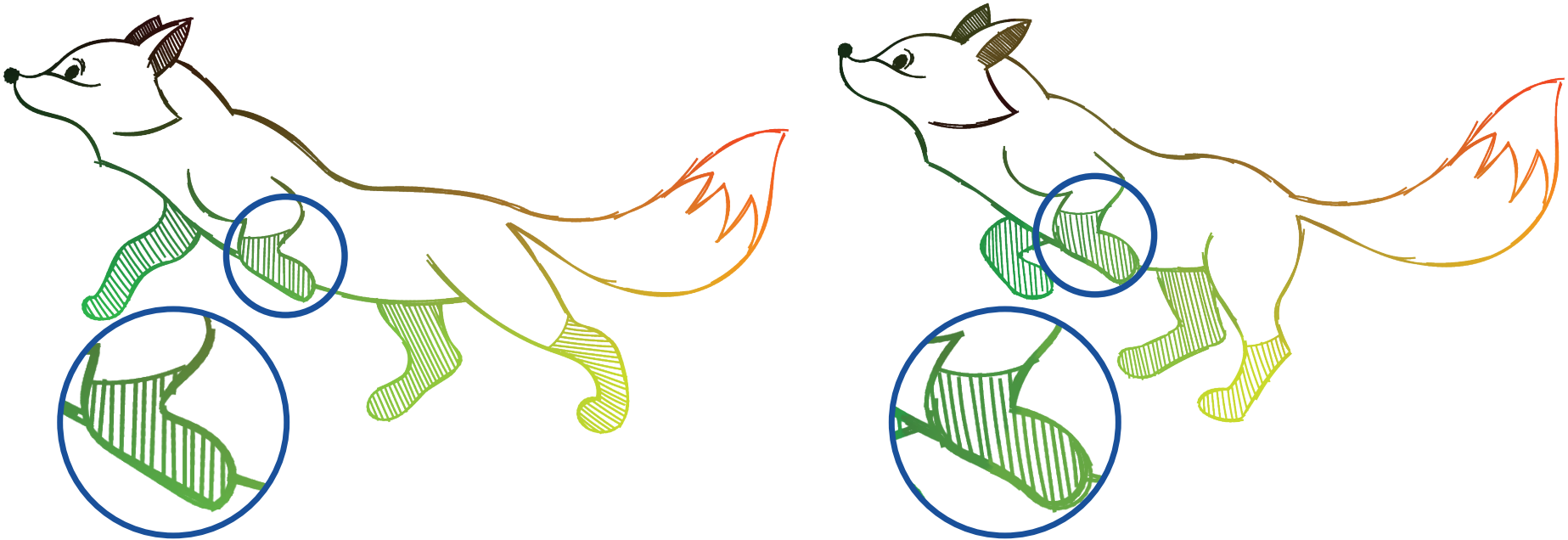
[Mo et al. 2024]

Correspondences | Solution: Deformation

Deform vector frame 1 into bitmap 2
Differential vector graphics + optimization

[Mo et al. 2024]

Correspondences | Solution: Functional maps



[Myronova et al. 2023]

Checkpoint

Some basic things are really hard for 2D and 3D sketches.

Having principled solution to these core challenges will be a big deal for applications

Fundamentals and applications of sketch processing

Lots of hard problems
Uncharted territories with topology and geometry ideas lurking
Not everything (yet) is deep learning

Fundamentals and Applications of Sketch Processing

Mikhail (Misha) Bessmeltsev & Chenxi Liu

Université de Montréal

UNIVERSITY OF TORONTO