Skeletal models for shape understanding

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Computer Science
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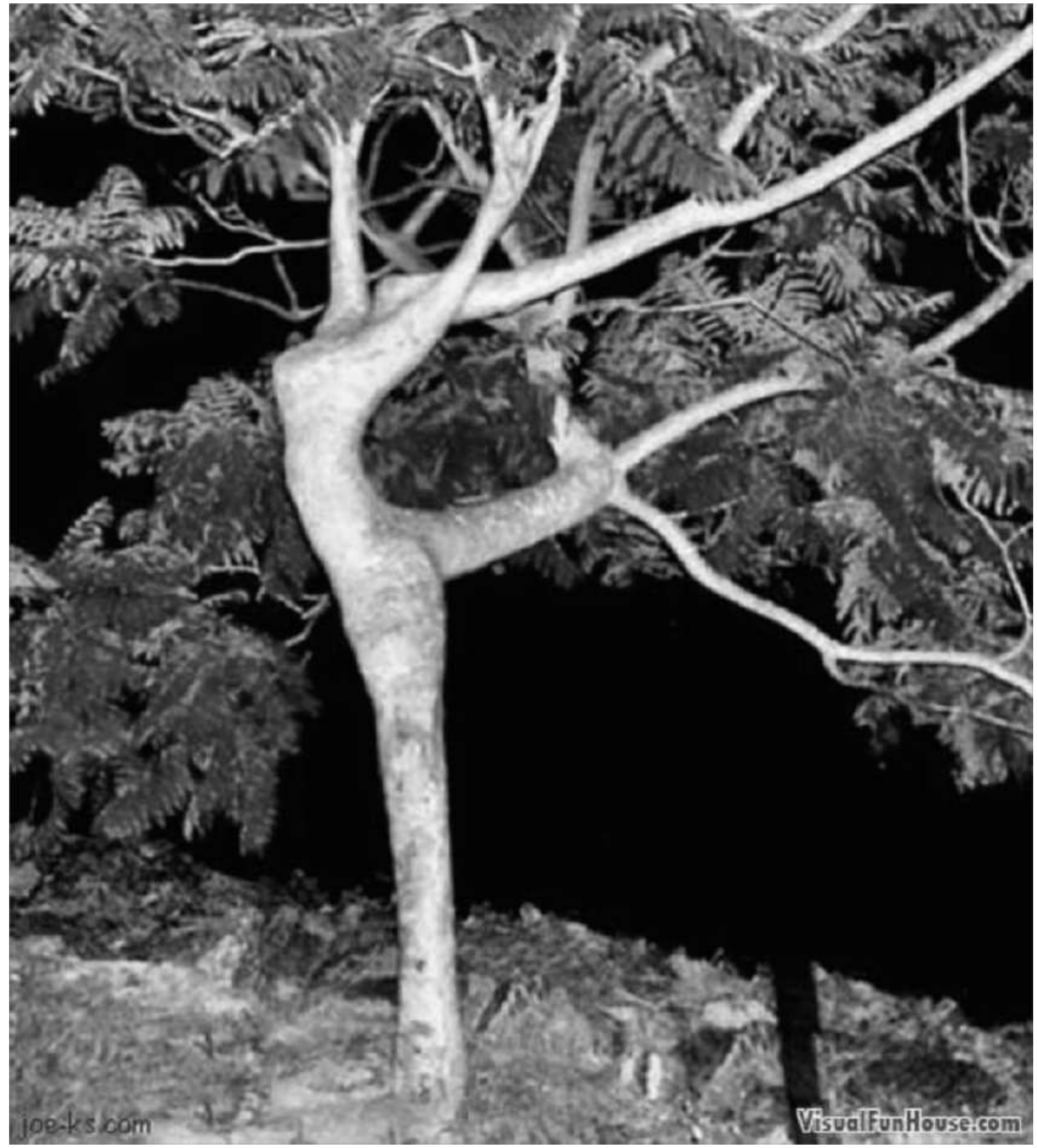
ORASIS 2021



MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROJECT MAC

Artificial Intelligence Group
Vision Memo. No. 100.

July 7, 1966

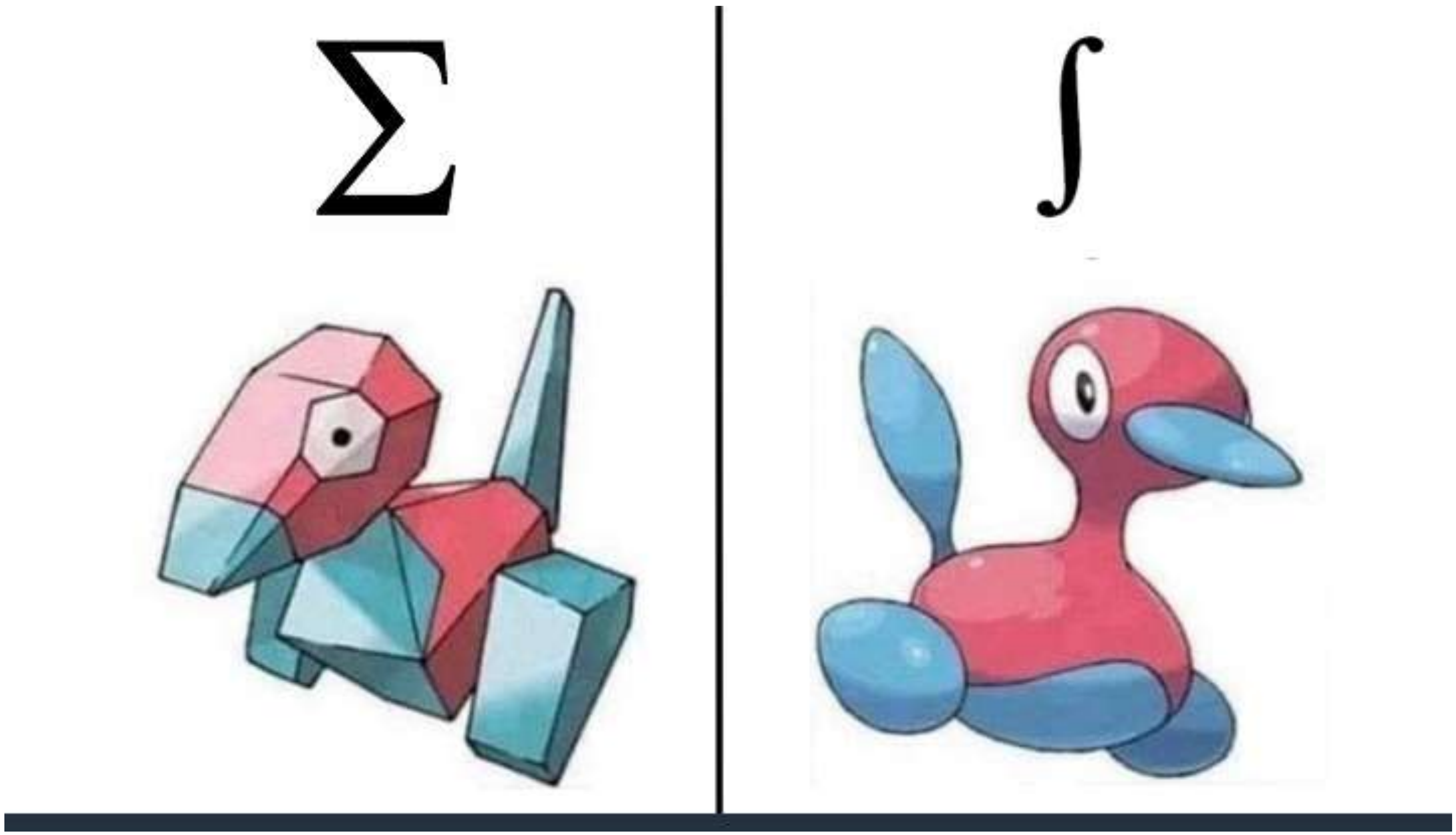
Half a century later, we're still working on it.

THE SUMMER VISION PROJECT

Seymour Papert

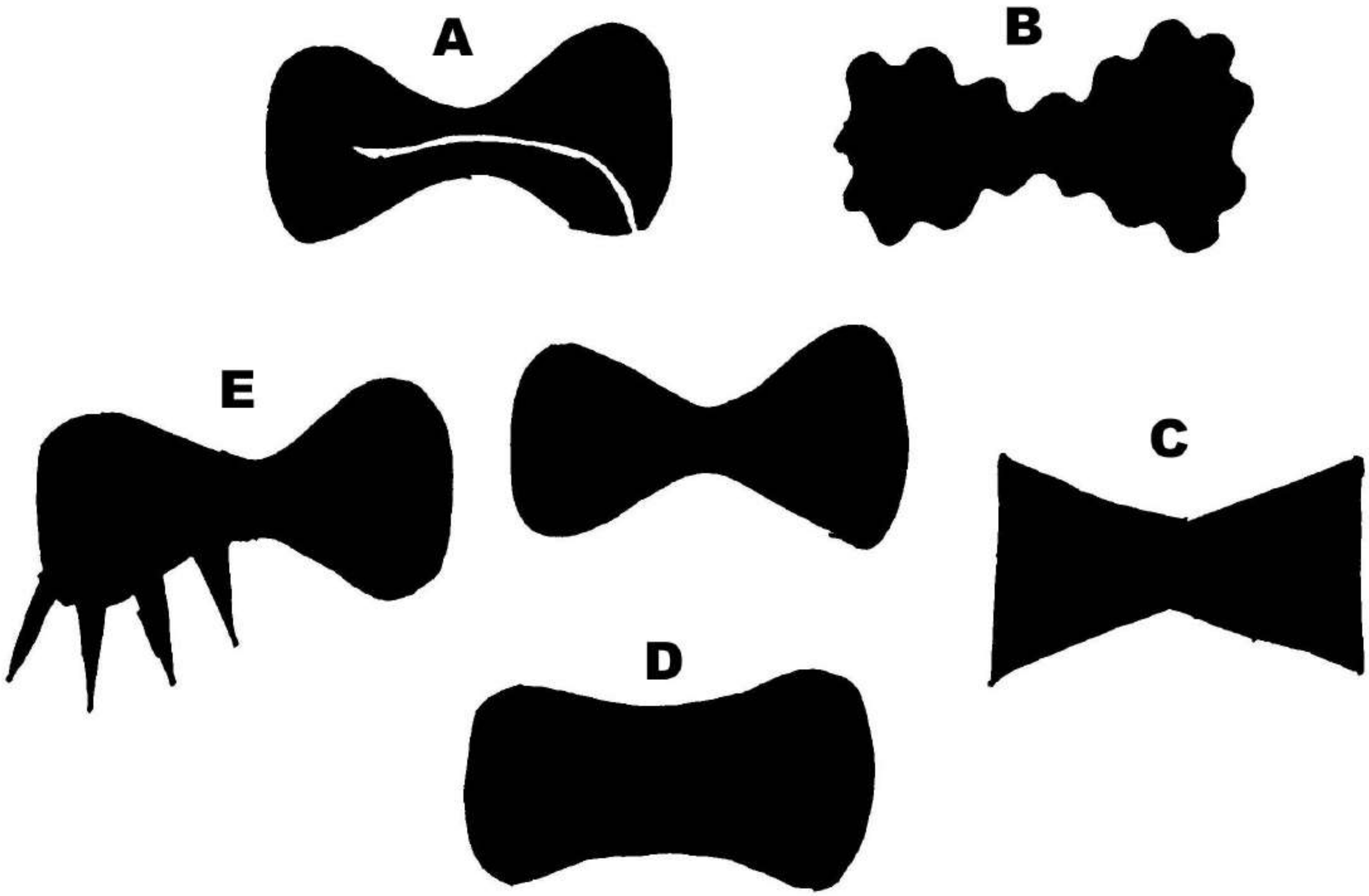
The summer vision project is an attempt to use our summer workers effectively in the construction of a significant part of a visual system. The particular task was chosen partly because it can be segmented into sub-problems which will allow individuals to work independently and yet participate in the construction of a system complex enough to be a real landmark in the development of "pattern recognition".

First known computer vision project



Shape approximation

Image credit: twitter math meme

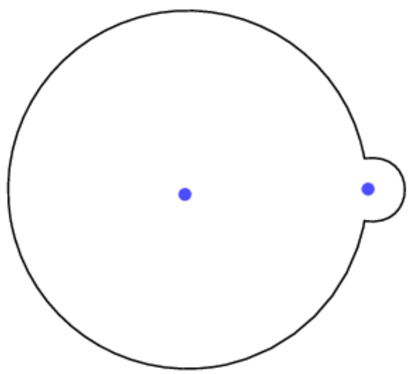


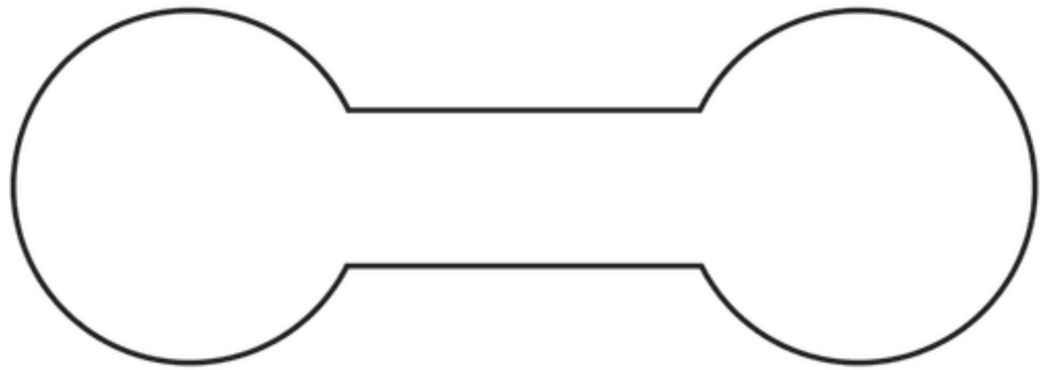
Perceptual approximation

Image credit: D. Mumford

Requires shape understanding

- How important is a shape feature to a shape?

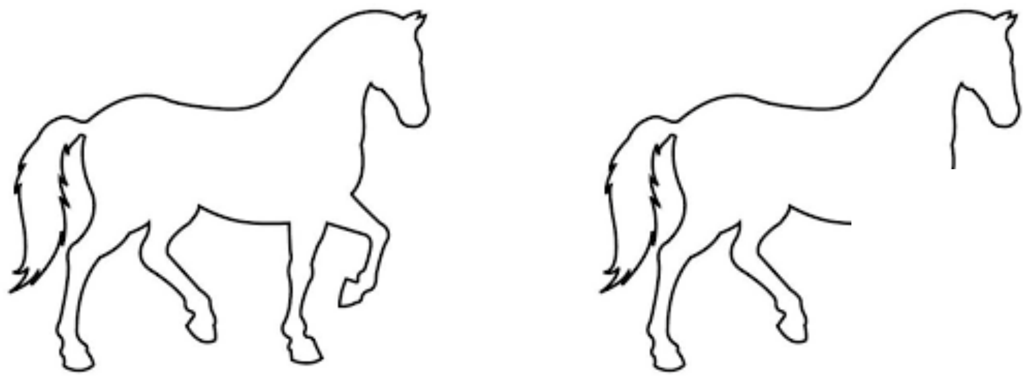




Perceptual
approximation

Requires shape understanding

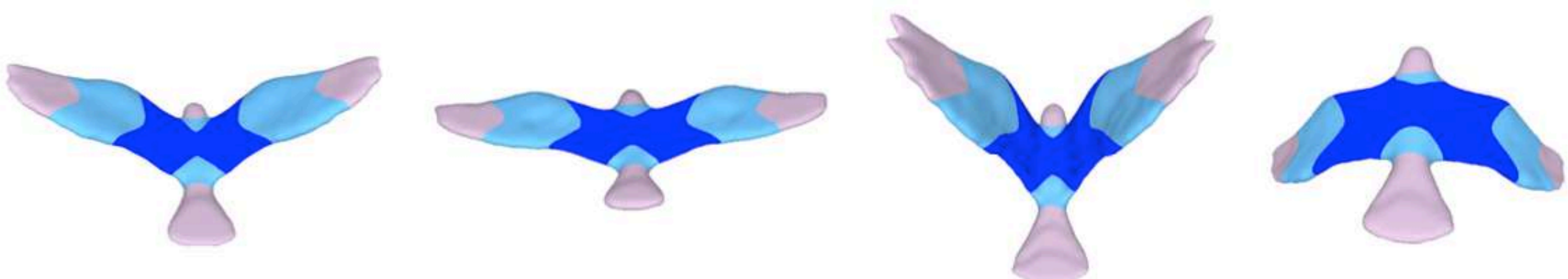
- How important is a shape feature to a shape?
- How can we handle occlusion?



Perceptual approximation

Requires shape understanding

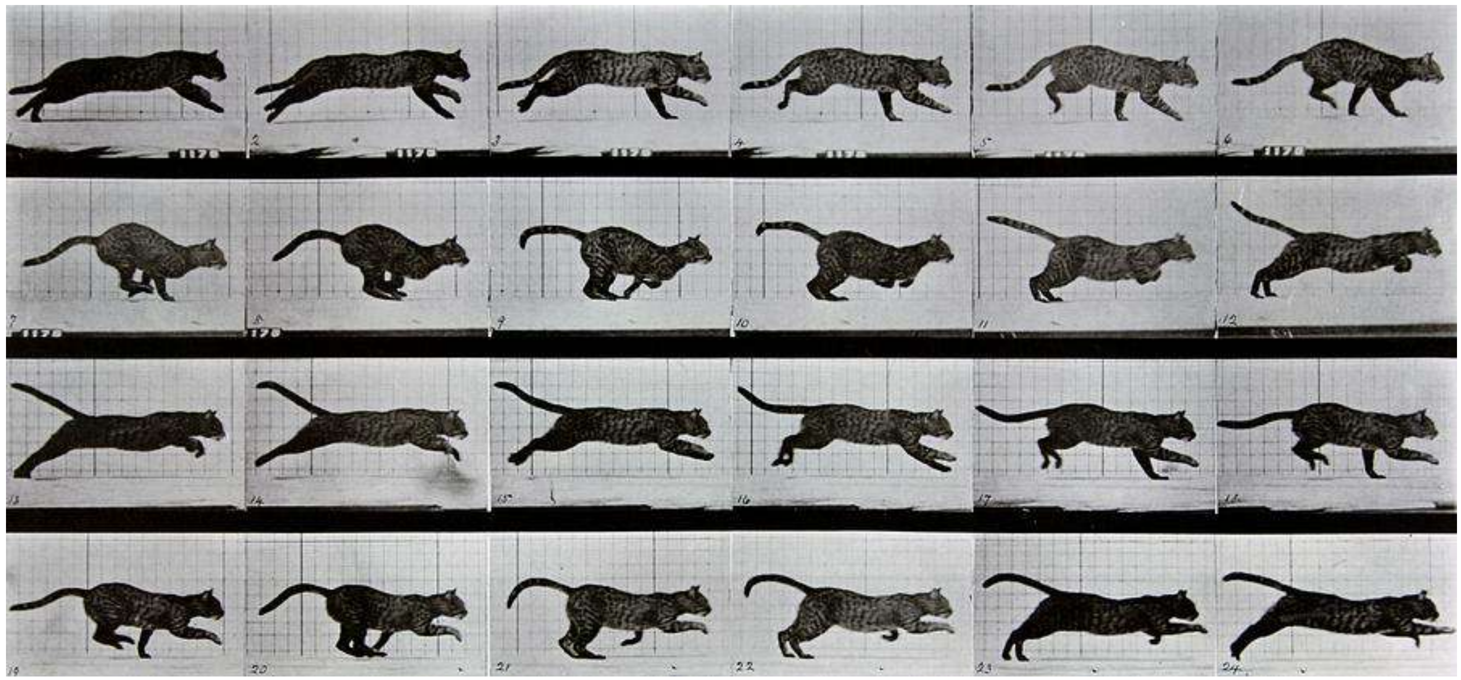
- How important is a shape feature to a shape?
- How can we handle occlusion?
- How can we match across different positions?



Perceptual approximation

Shape understanding helps with tasks

- Matching
- Tracking
- Animating



Perceptual approximation

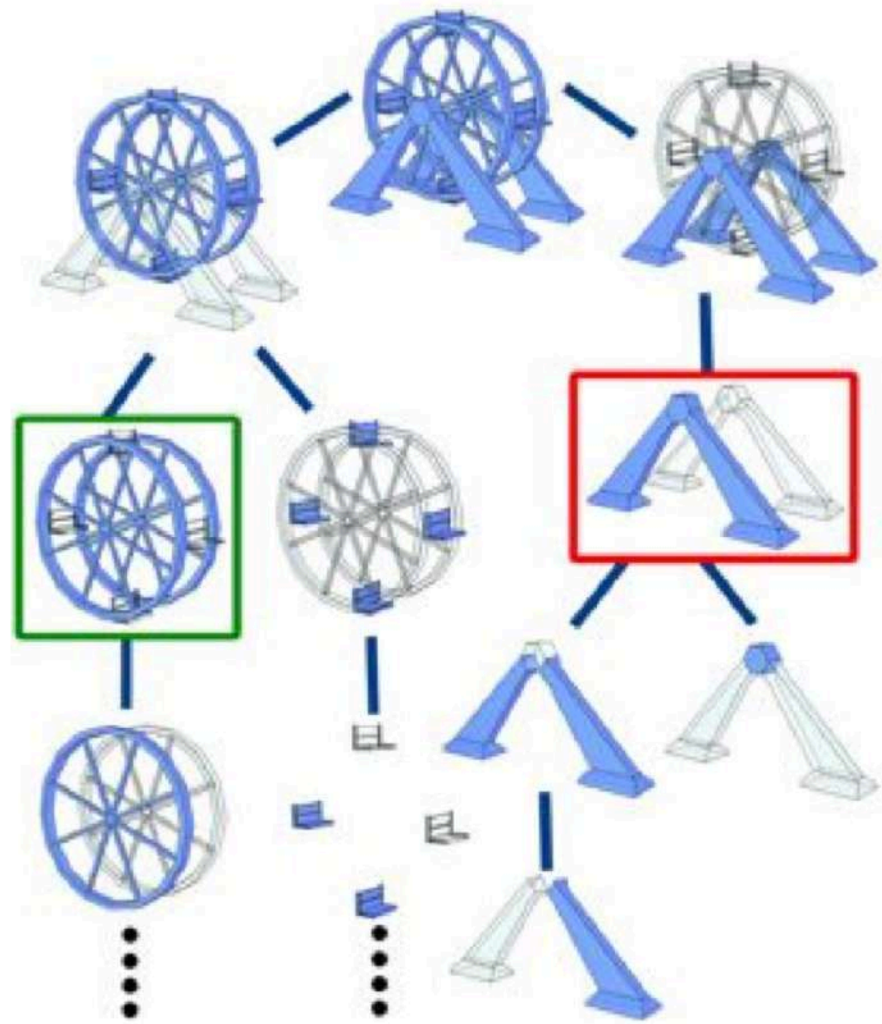
Image credit: Edweard Muybridge

- *Composition of parts*
- *Parameters on parts*
- *Relationships between parts*

hierarchy

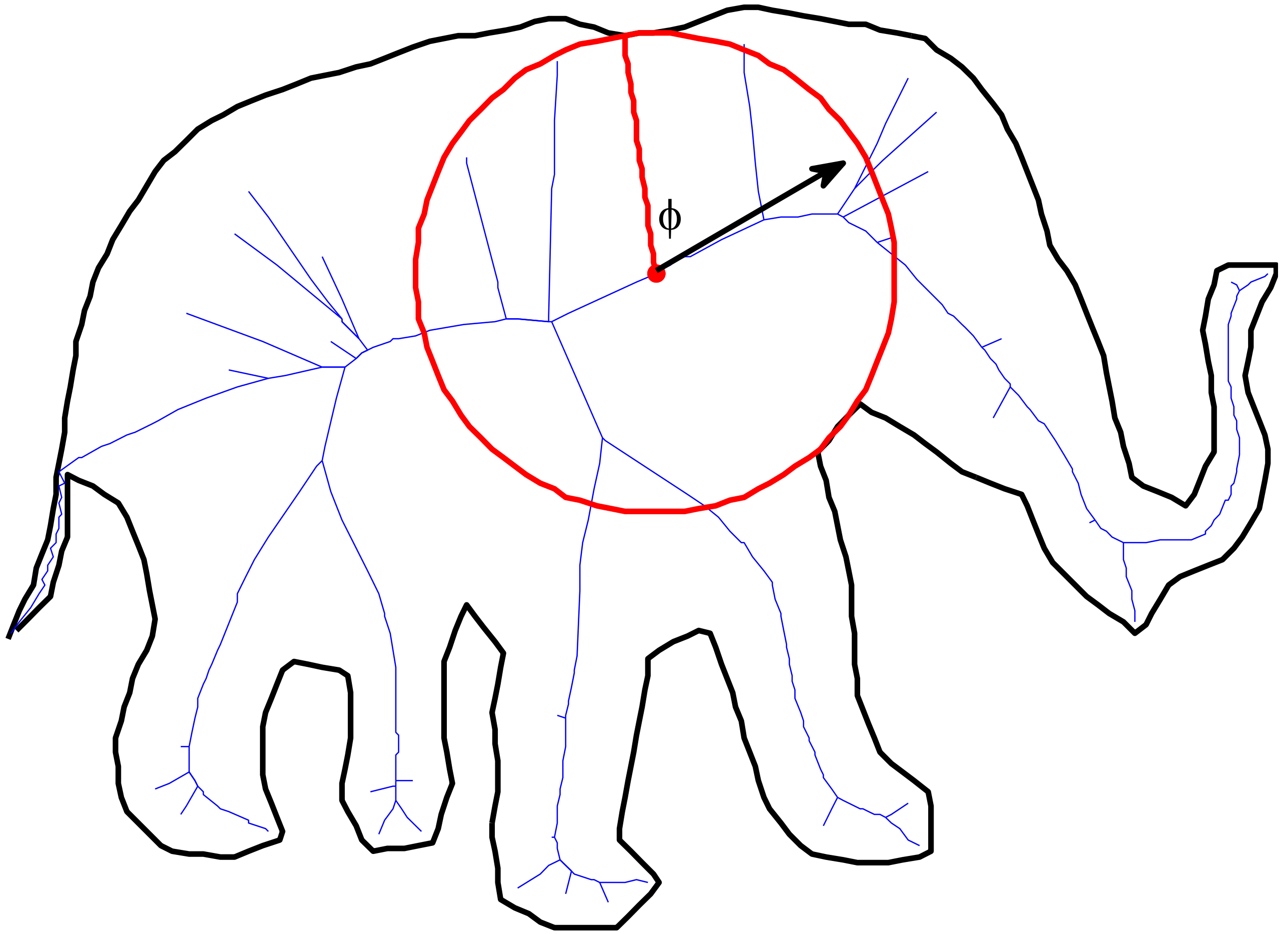
geometry

similarity

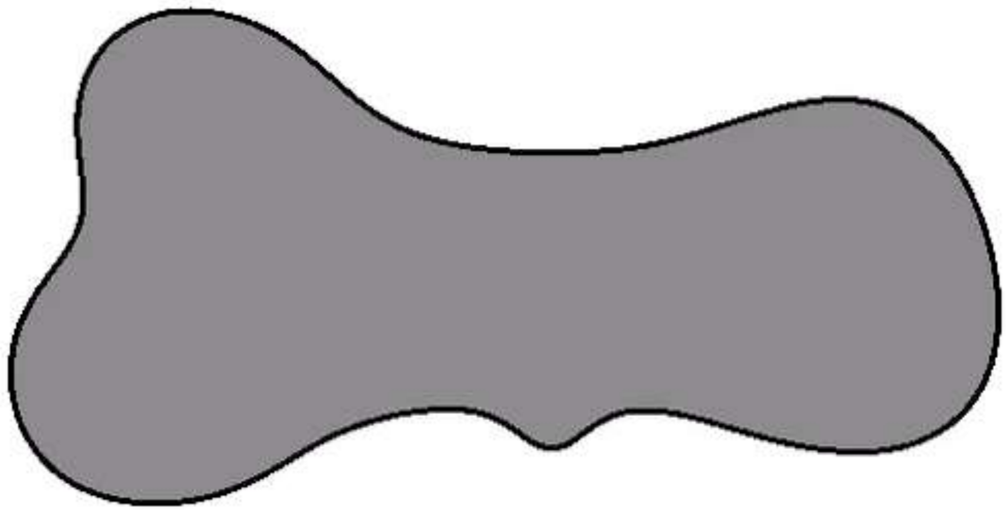


Shape understanding

N. J. Mitra, M. Pauly, M. Wand, and D. Ceylan. Symmetry in 3d geometry: Extraction and applications. In Computer Graphics Forum, volume 32. Wiley Online Library, 2013

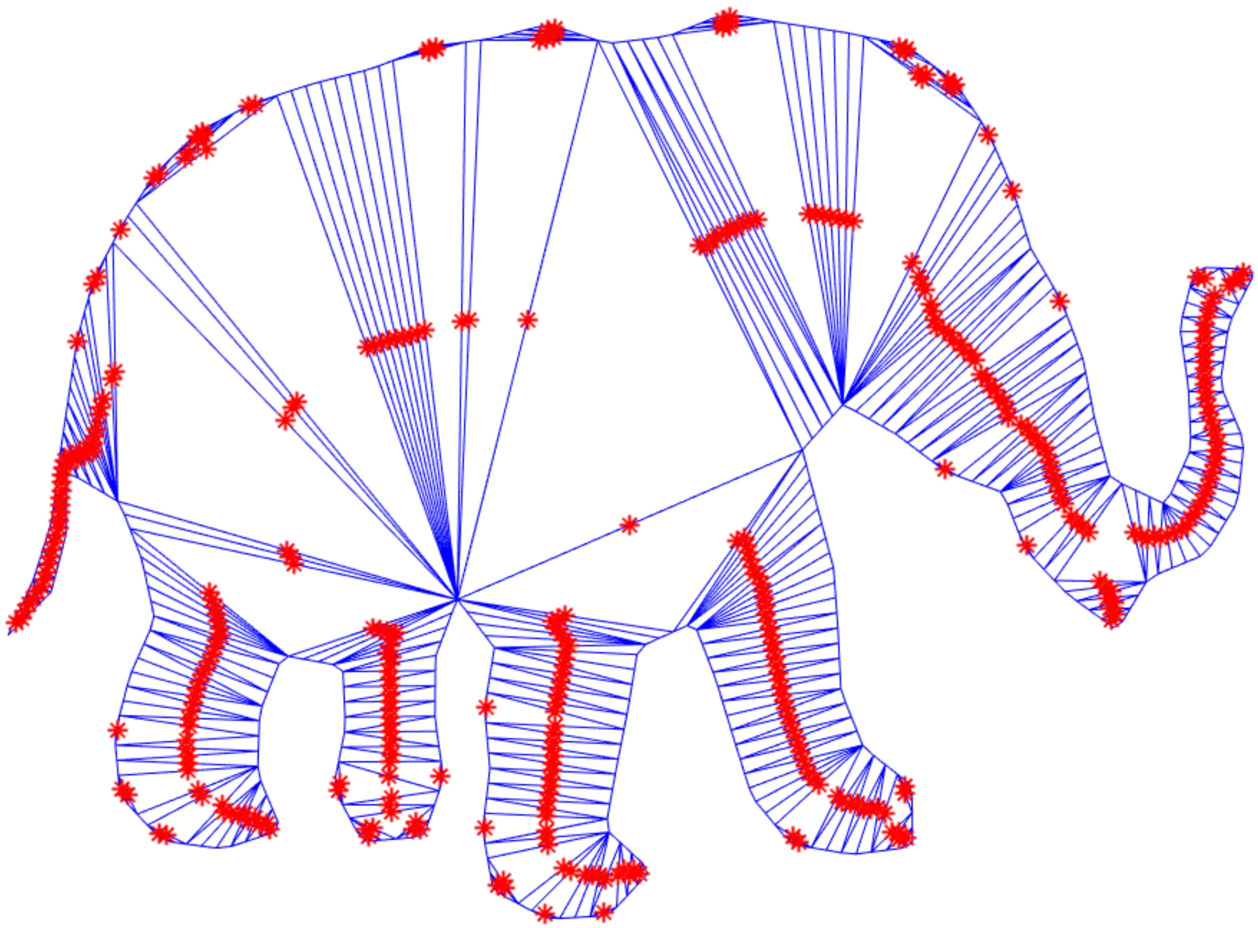


Understanding & representation: Blum medial axis



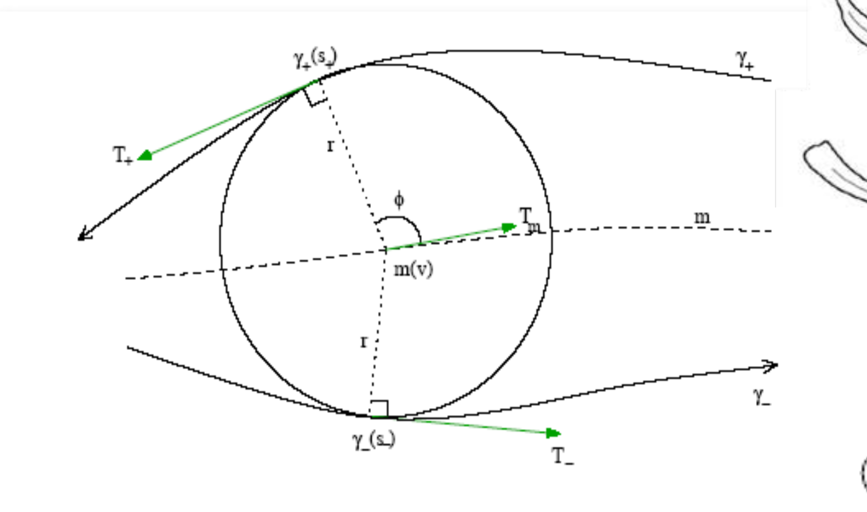
- set of quench sites of a fire started on the boundary of the shape which burns inward at uniform speed

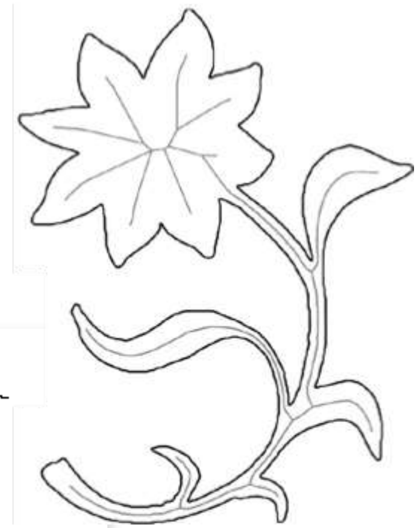
A tool for understanding:
Blum medial axis

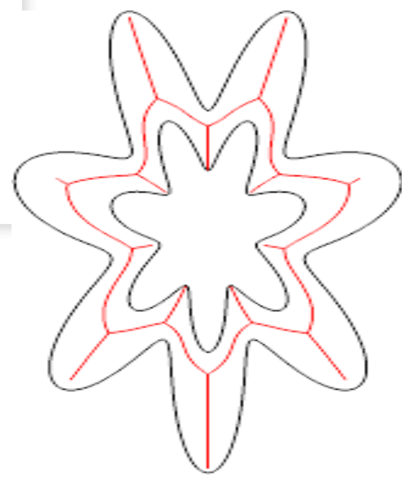


Discretization

Nice mathematical properties

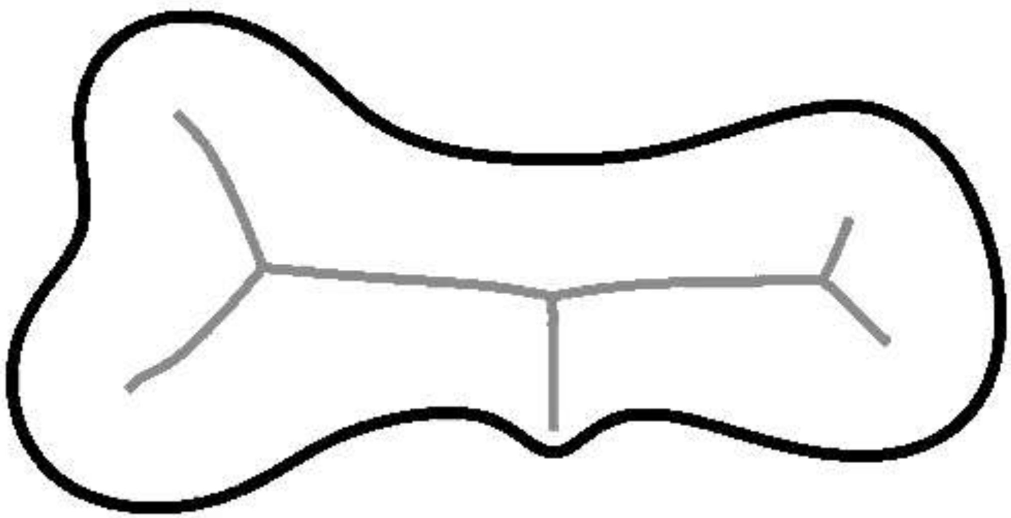


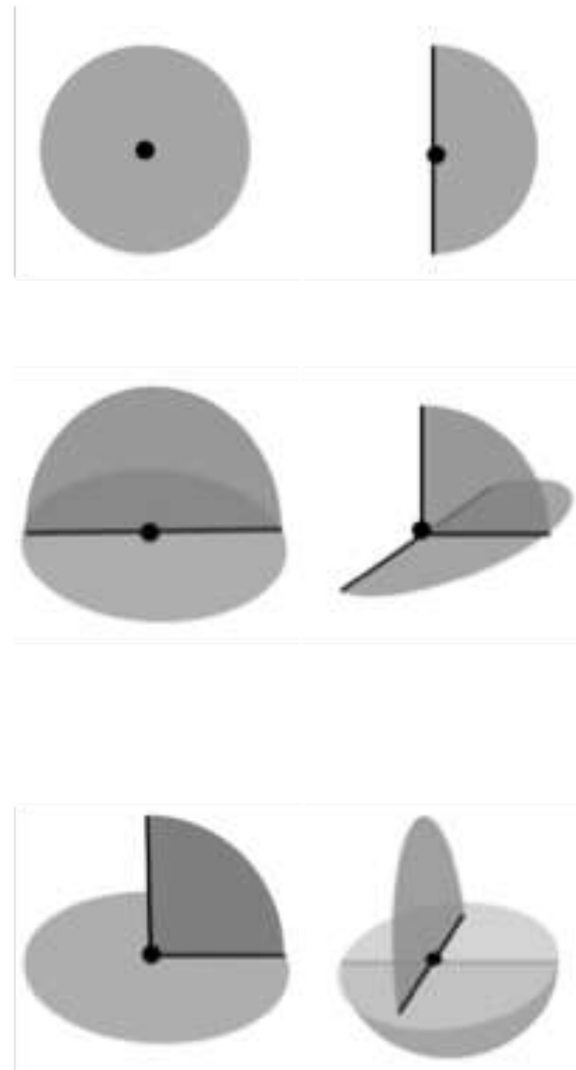




- topologically equivalent to boundary
- reduces dimensionality
- efficient as encoding representation (metric)
- explicit formulas relate boundary/ BMA loci and geometry
- same smoothness within branches as boundary

a long list of people, including me

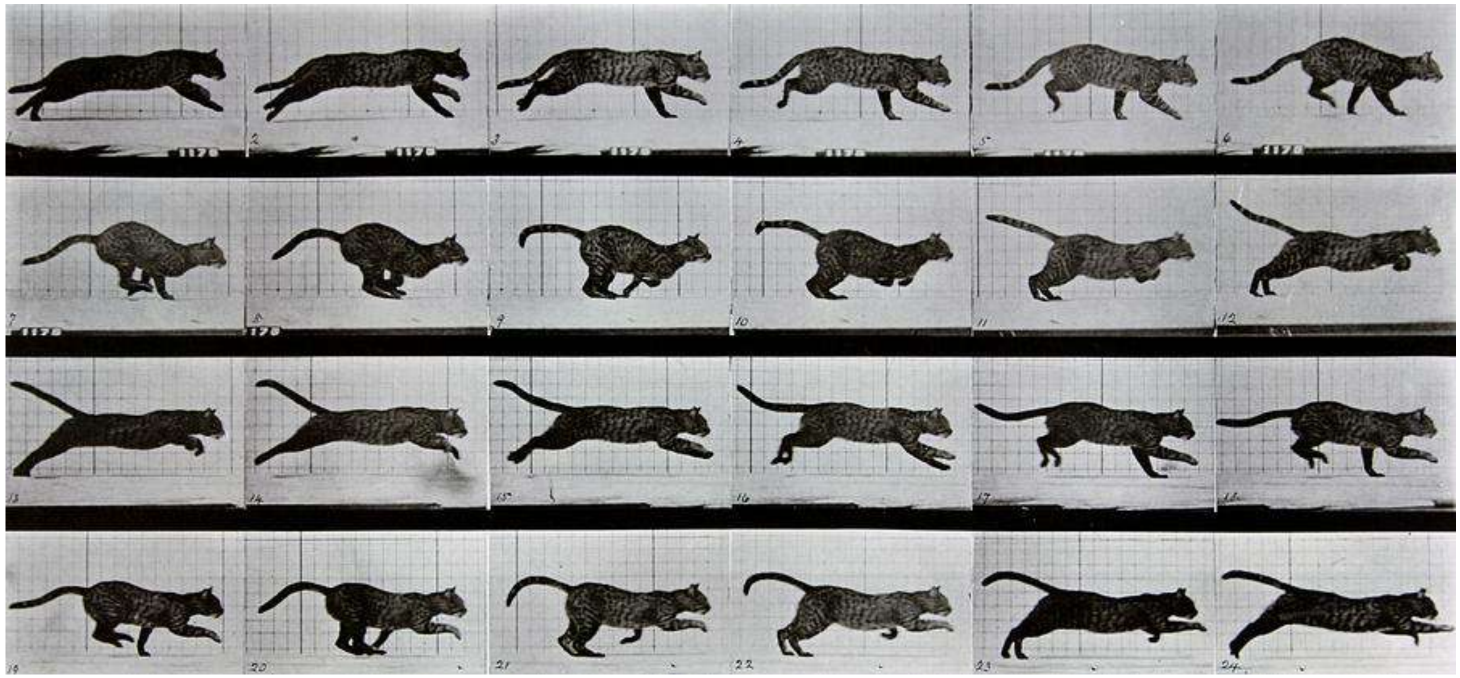




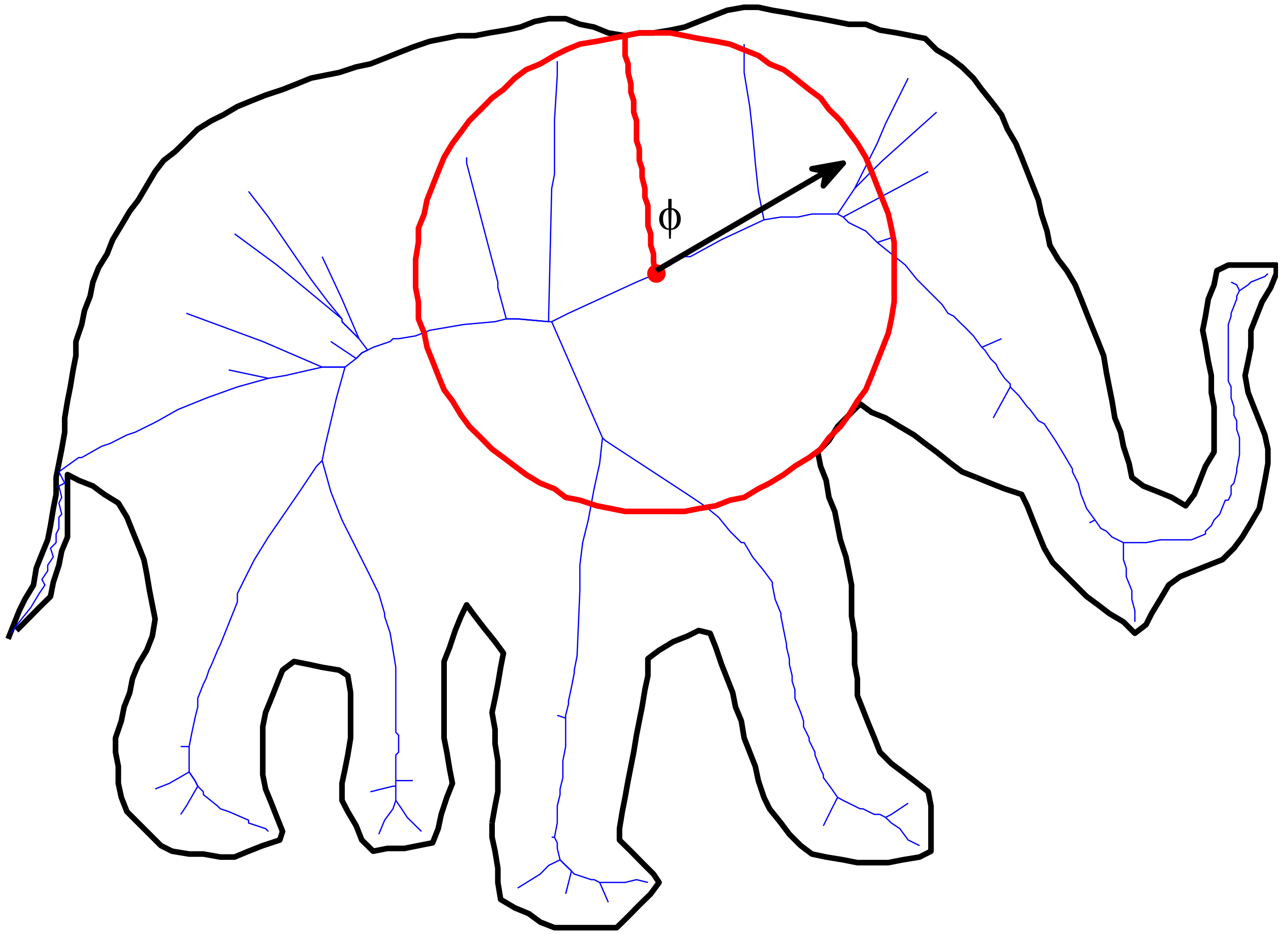
Well-understood singularities

Giblin, Kimia, Damon, Pizer

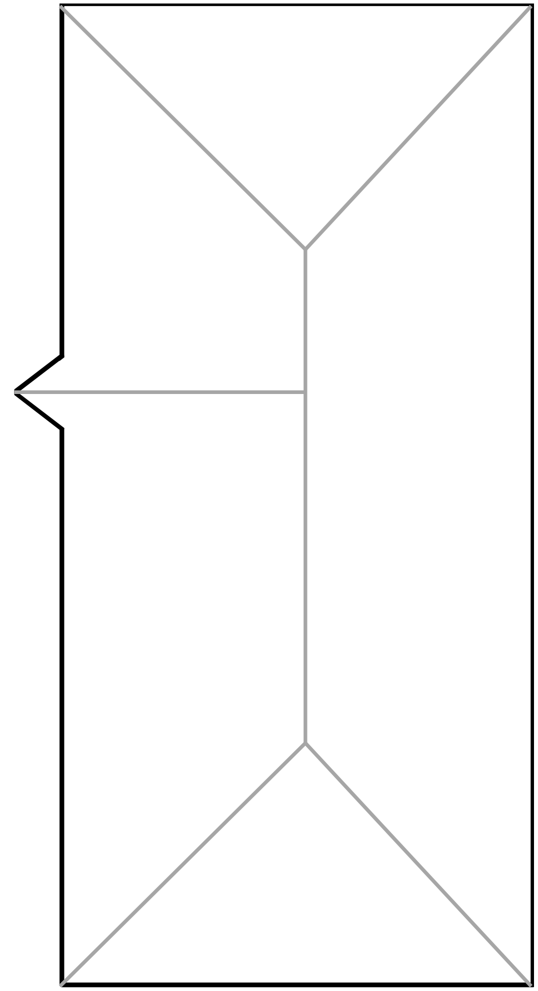
- Matching
- Tracking
- Animating



Tasks we'd like to do



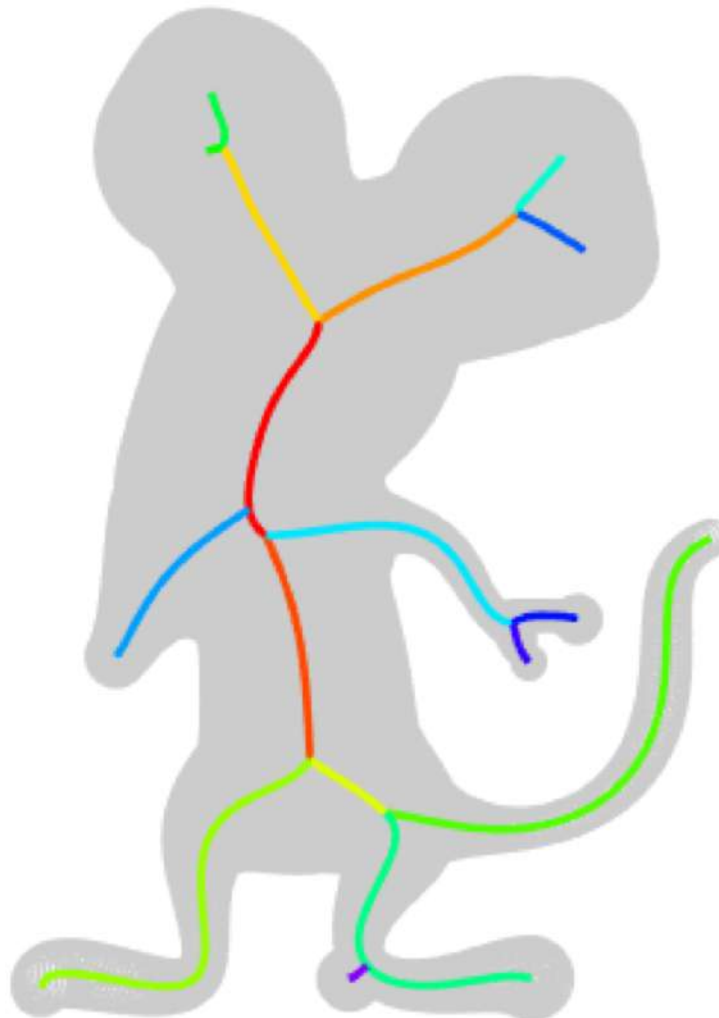
Challenge:
branches aren't parts



Challenge:
Noisy branches

Solutions

- Connect branches across junctions to find parts
- Figure out which branches are meaningful and which aren't
- Relate BMA to boundary features



Solutions

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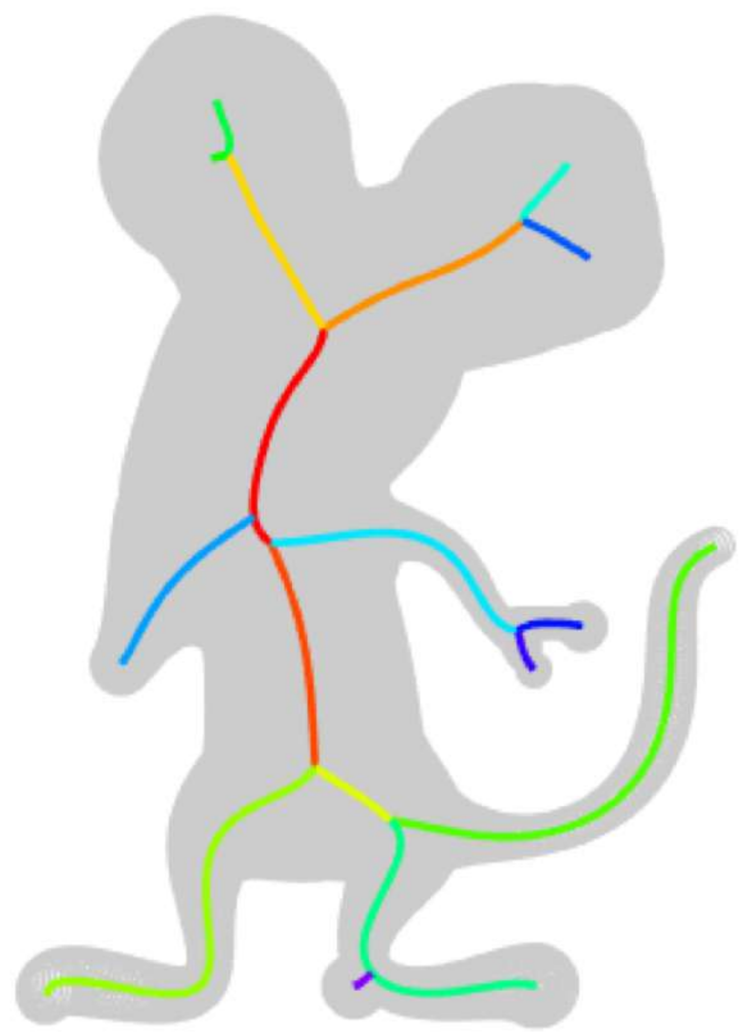
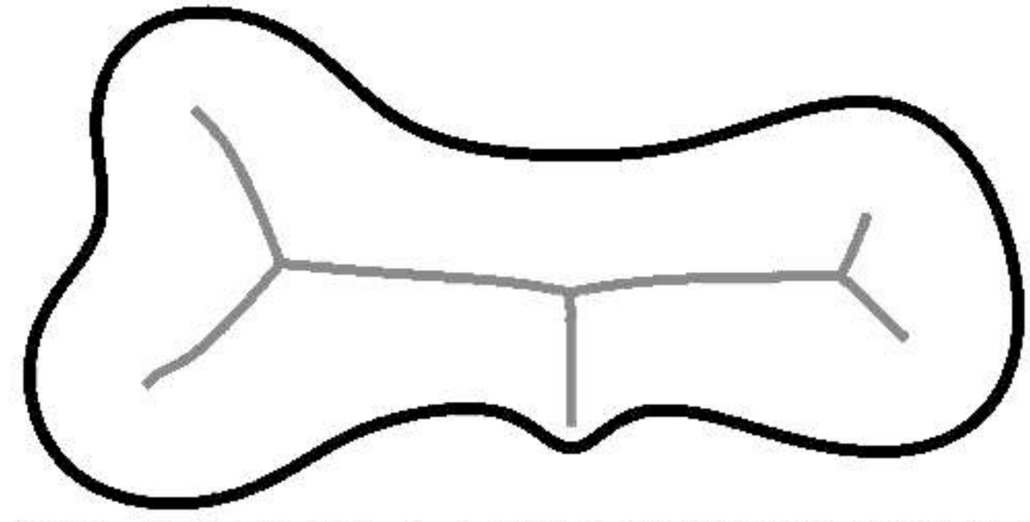


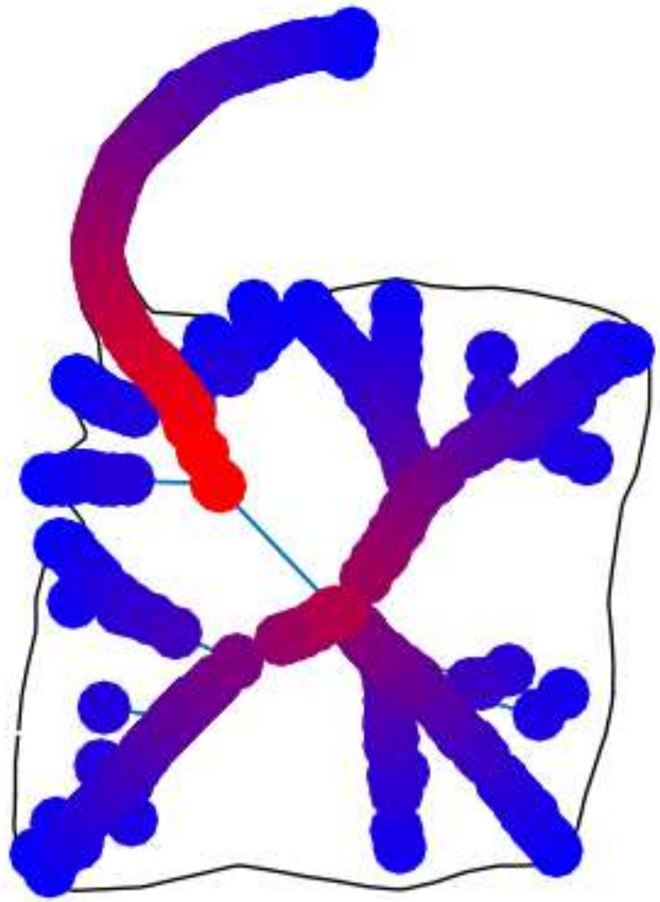
TOOL: Functions defined on BMA



burn time (formerly extended distance function (EDF)): *shortest distance to boundary on longest path along axis containing x*

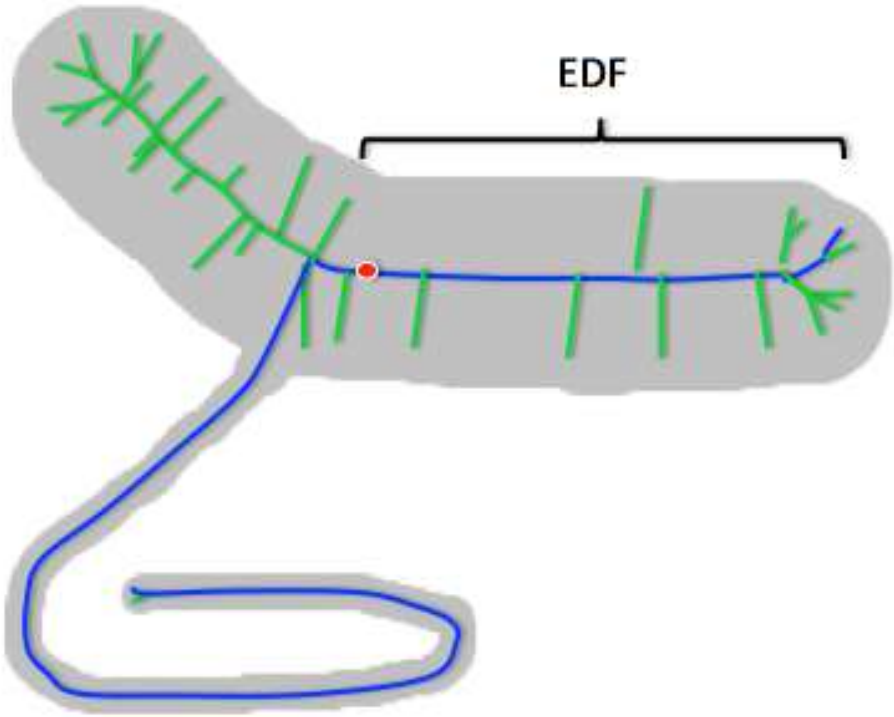
A useful measure on the BMA: Burn time (EDF)

Liu, et al, 2011



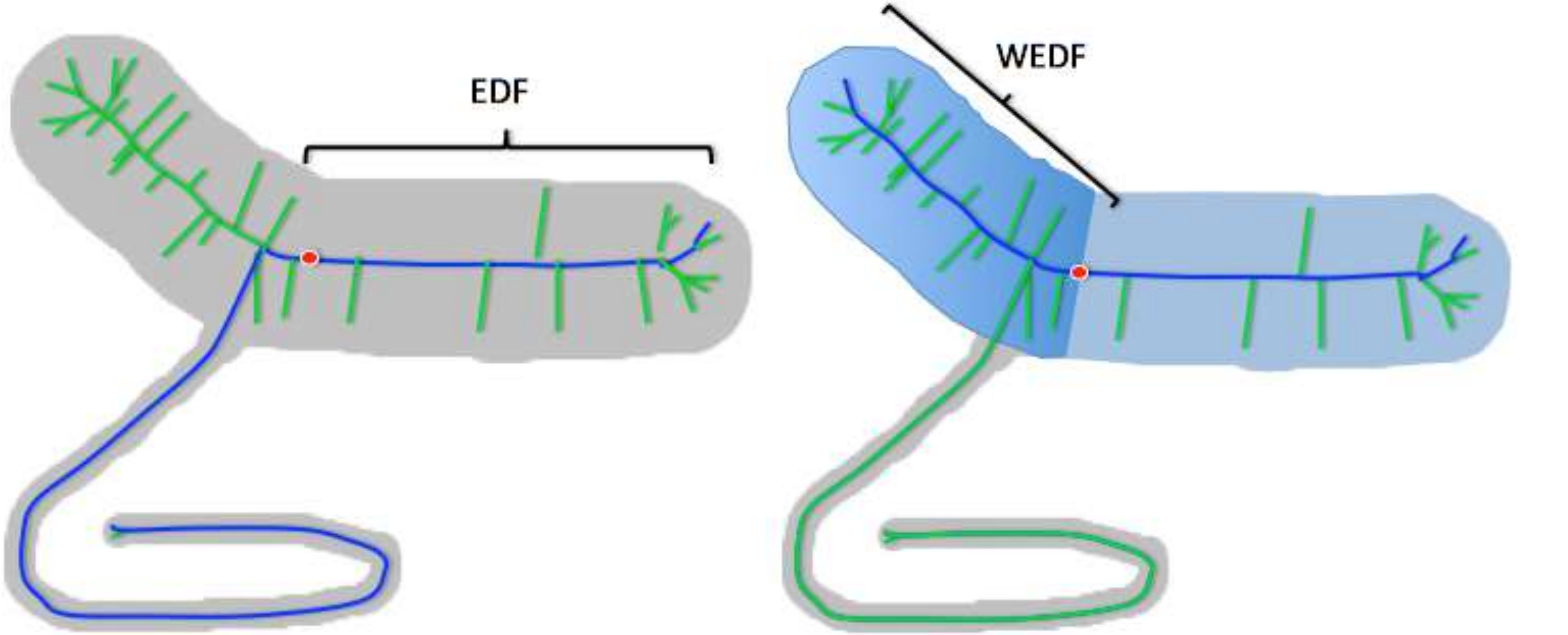
BT/EDF heat map

Drawback of depth-based measure



Another function on the BMA: WEDF

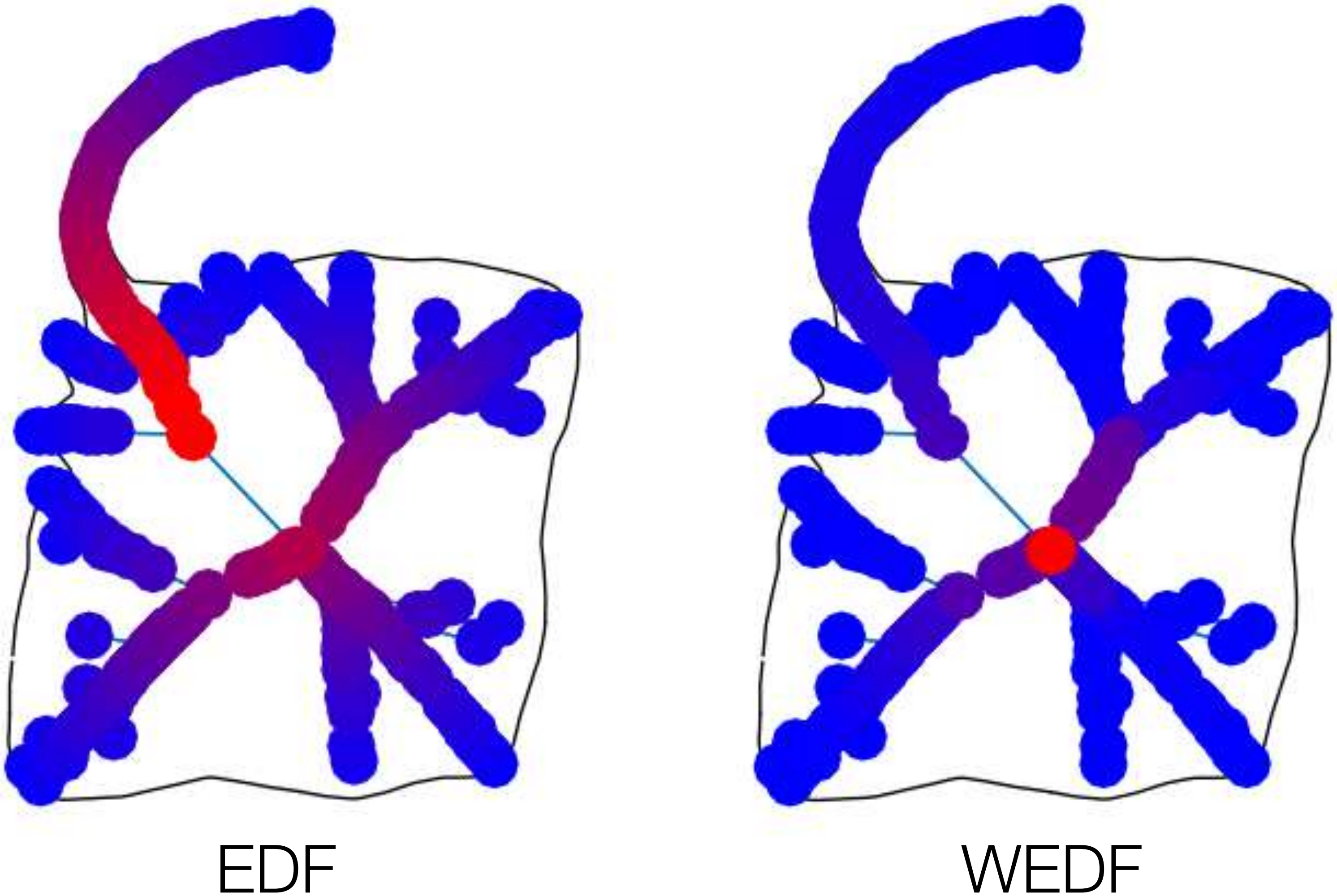
Morin, et al, 2015



$$WEDF(x) = \sup_{f|x \in f} A_f(x).$$

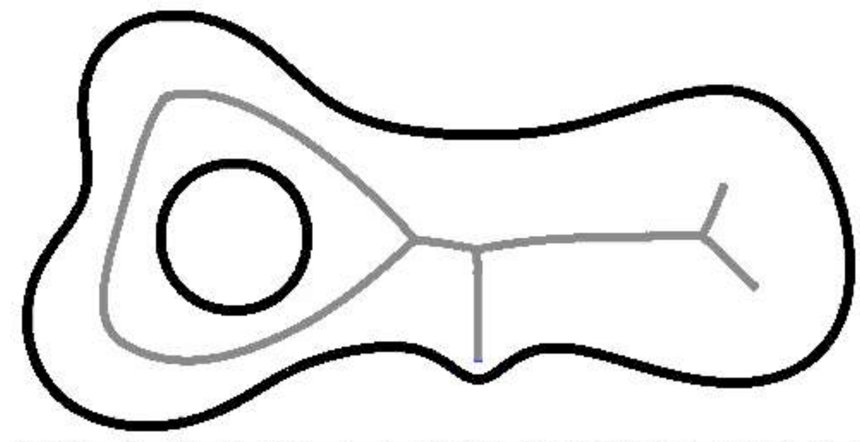
Another measure on the axis:
WEDF

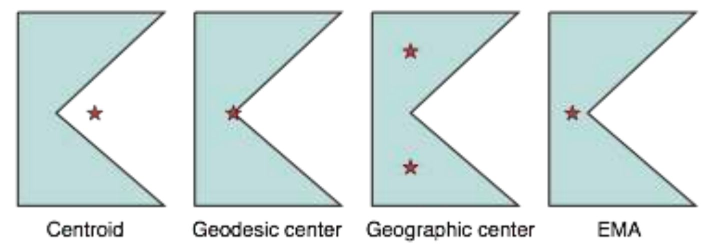
Morin, et al, 2015

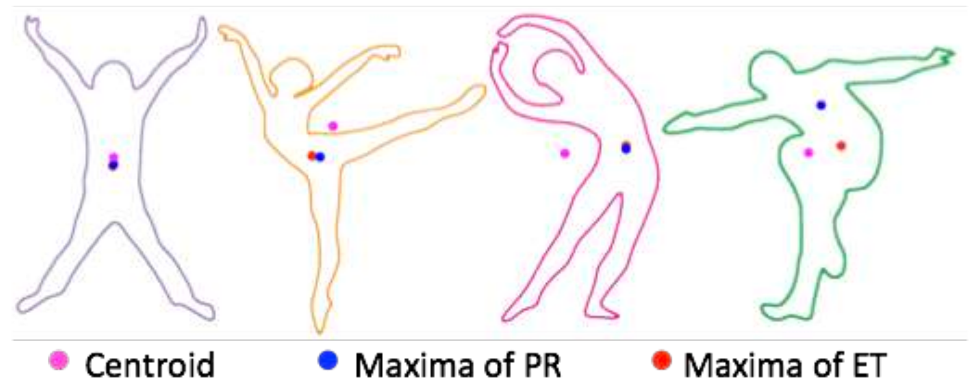


EDF/BT & WEDF

- finite except maximally closed sub-complex
- monotonically decreasing moving toward endpoints
- continuous within branches
- continuous across branches that have already burned

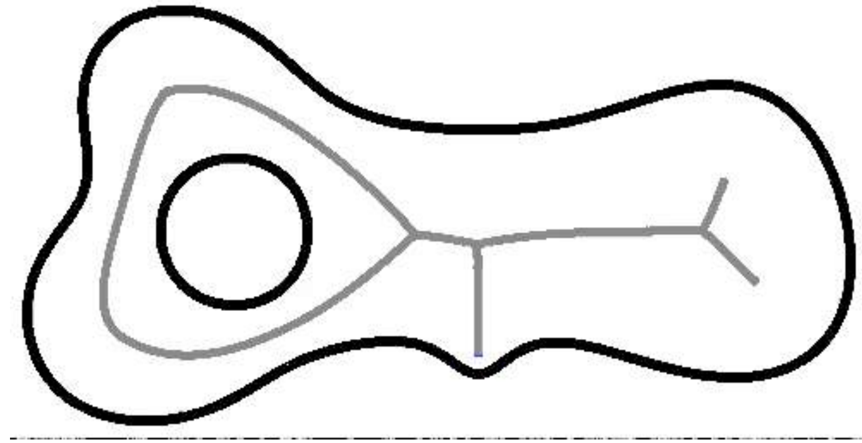


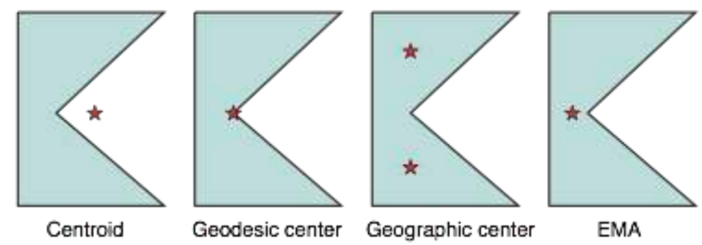


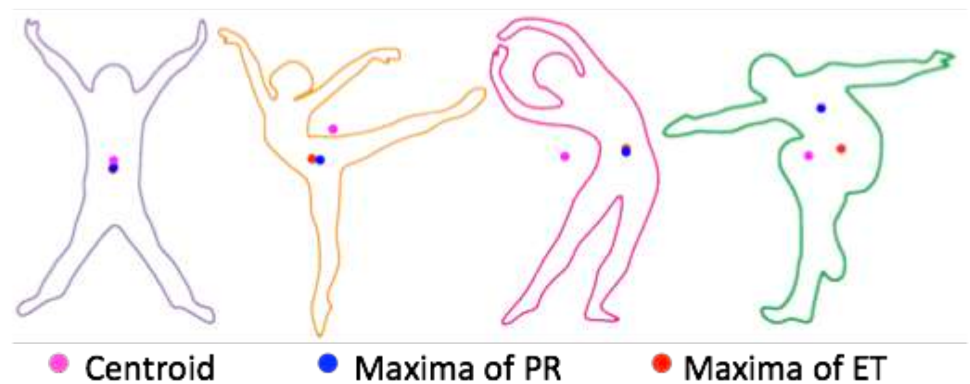


BT/EDF/WEDF properties in 2D

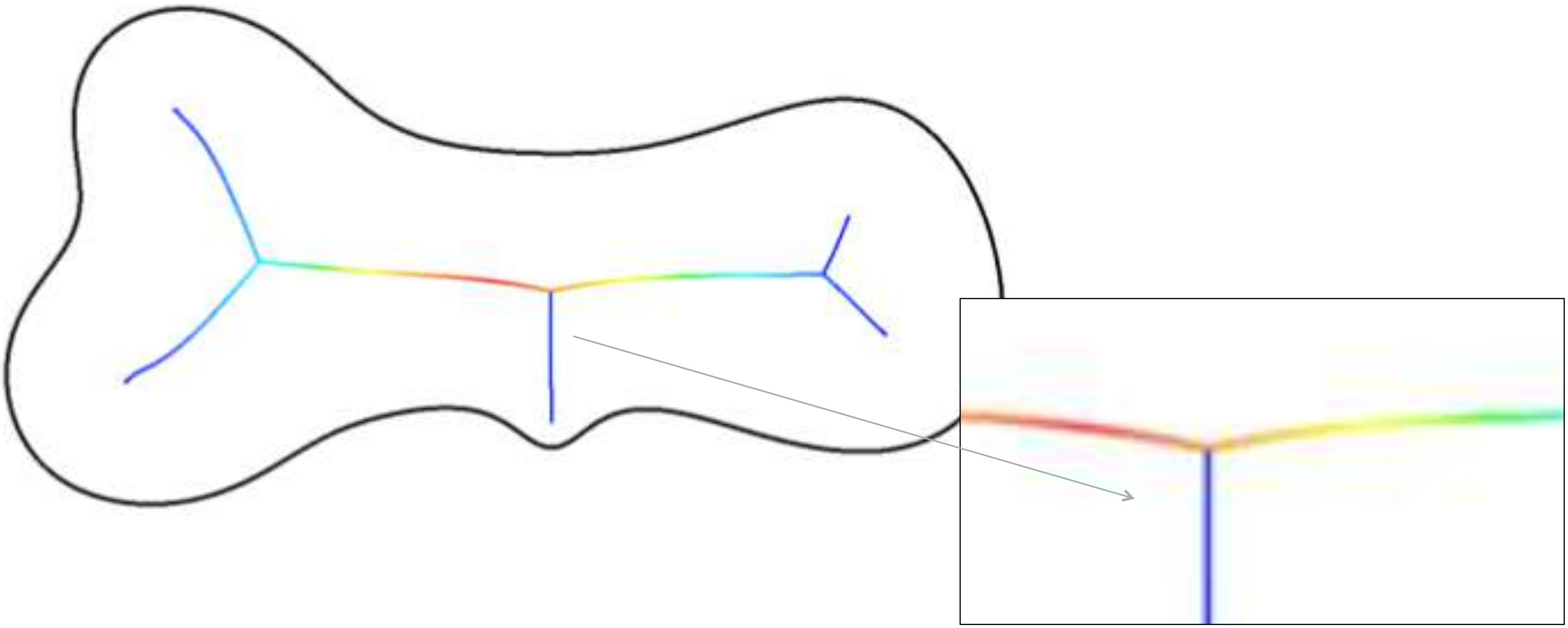
- finite except maximally closed sub-complex
- monotonically decreasing moving toward endpoints
- continuous within branches
- continuous across branches that have already burned



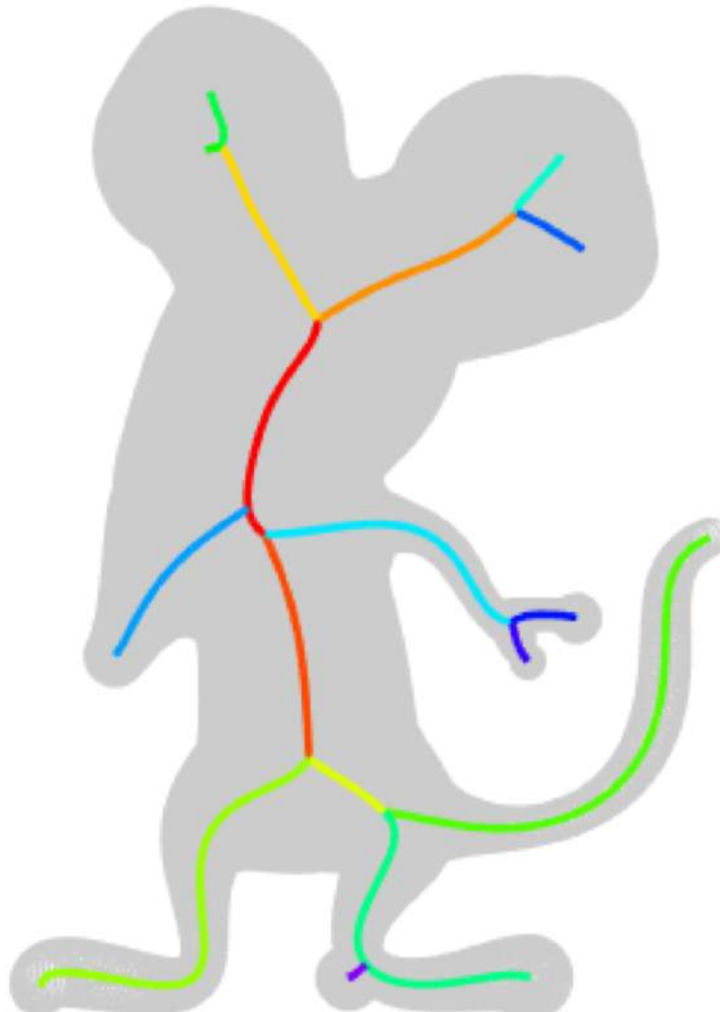




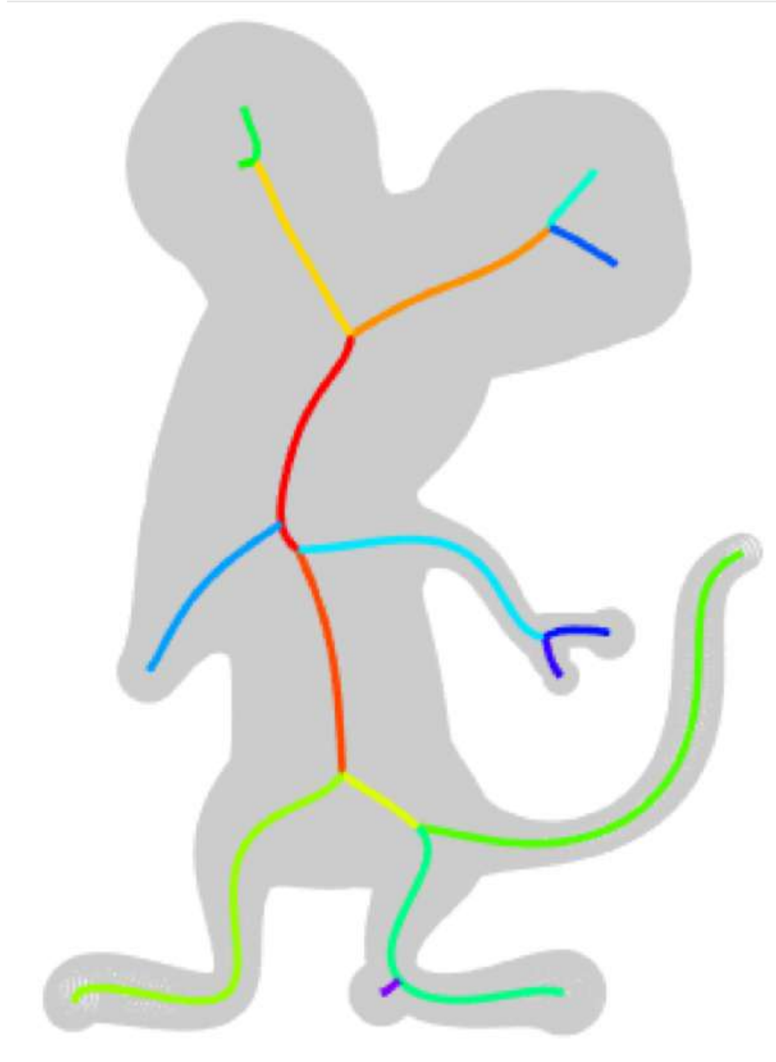
BT/EDF/WEDF properties in 2D



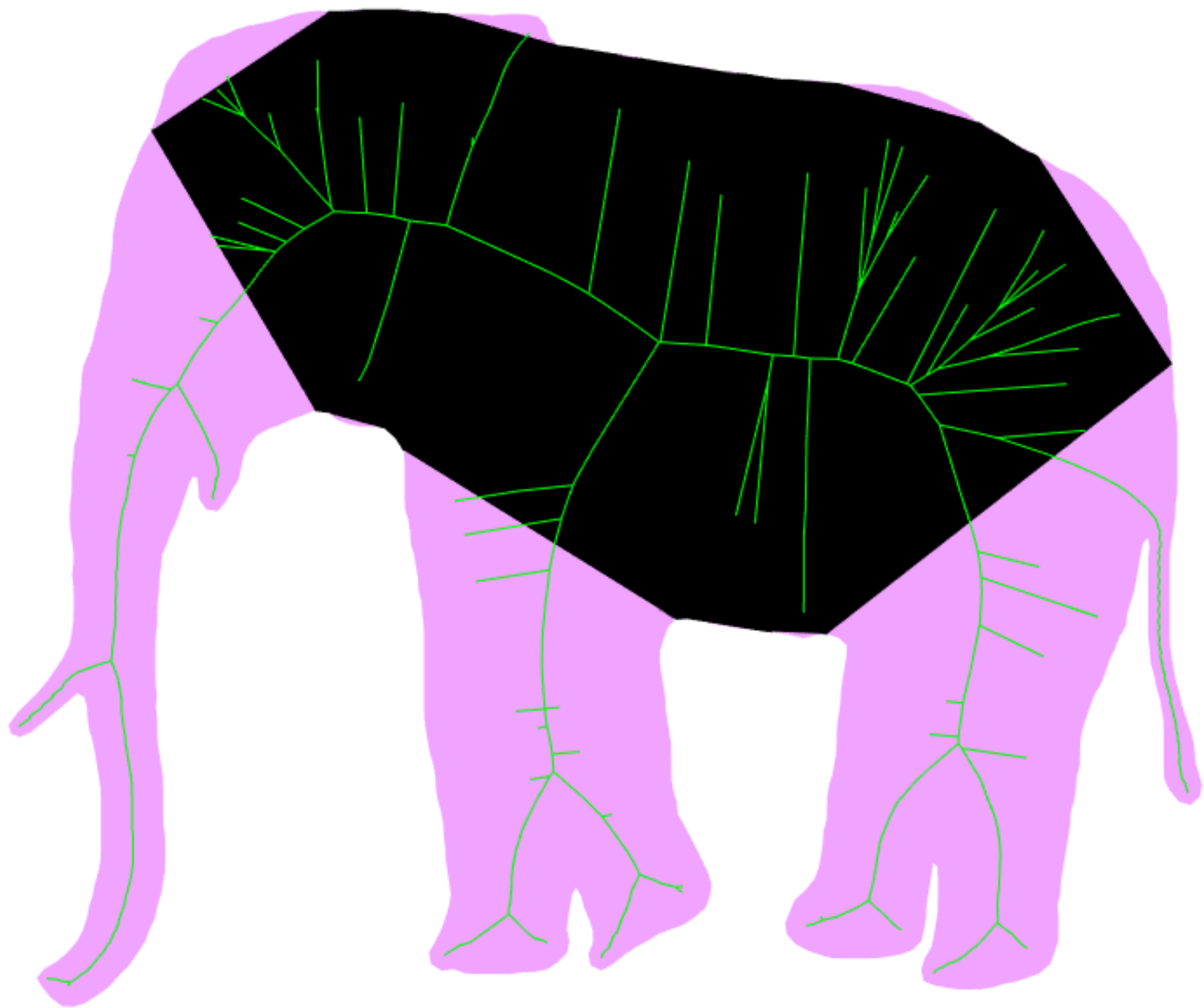
EDF/WEDF & branch continuity



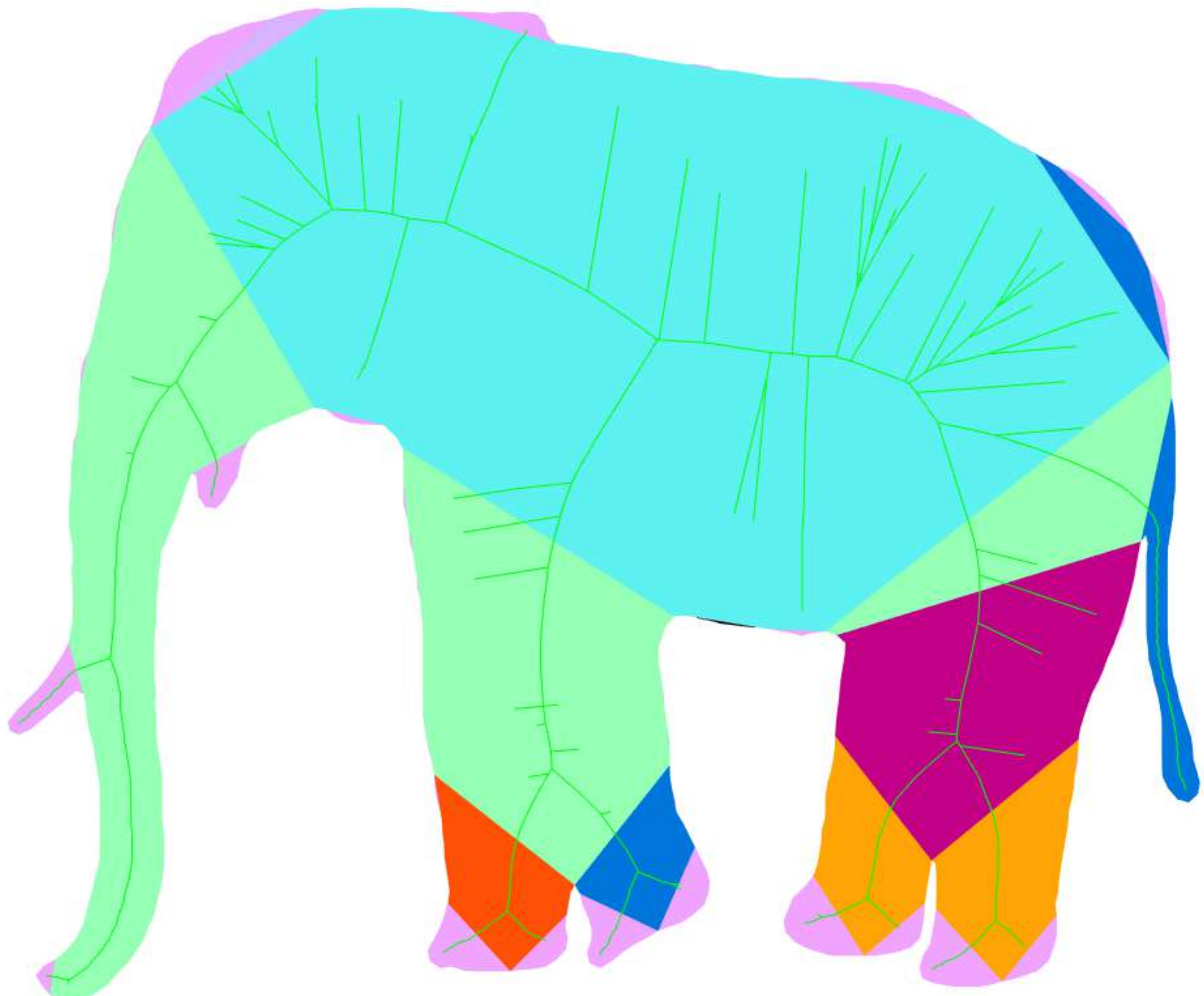
EDF, WEDF & parts



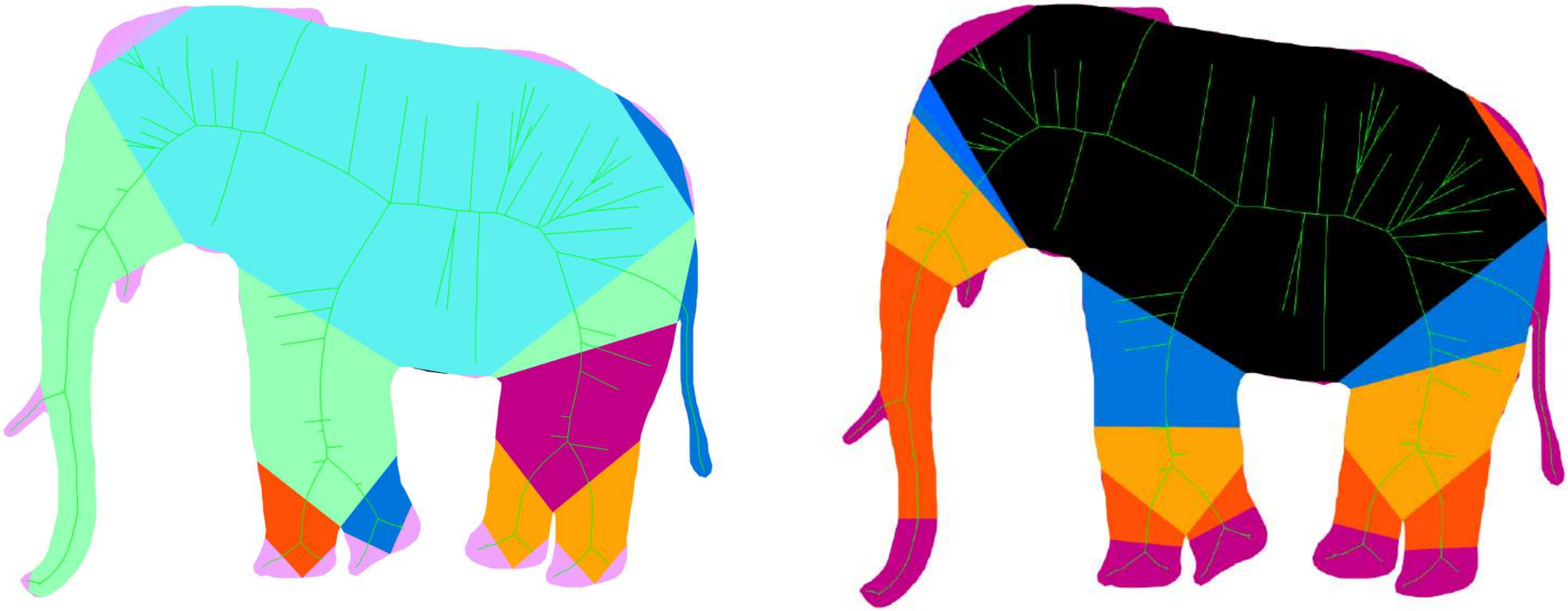
EDF, WEDF & parts hierarchy



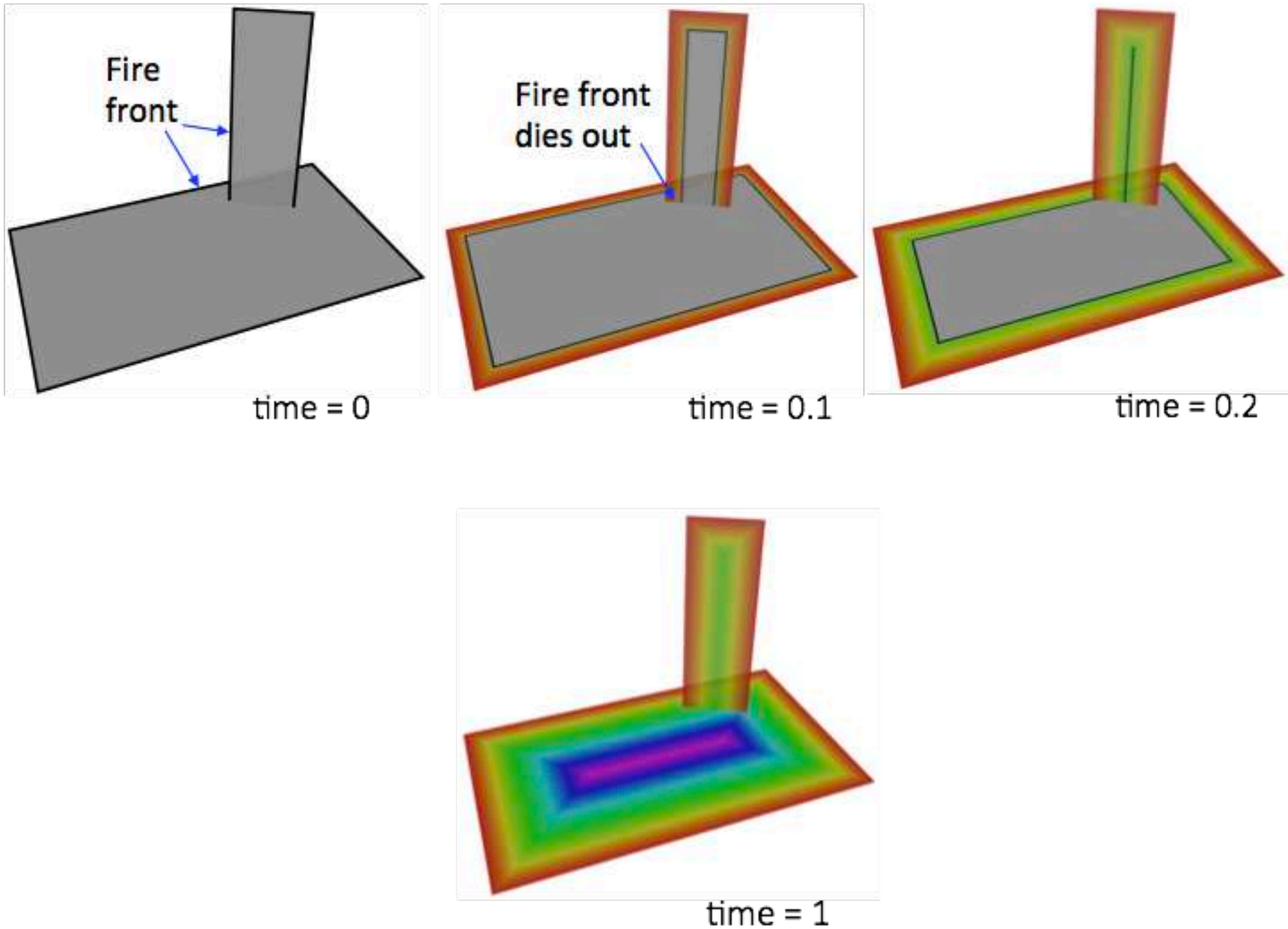
Hierarchy: Core shape



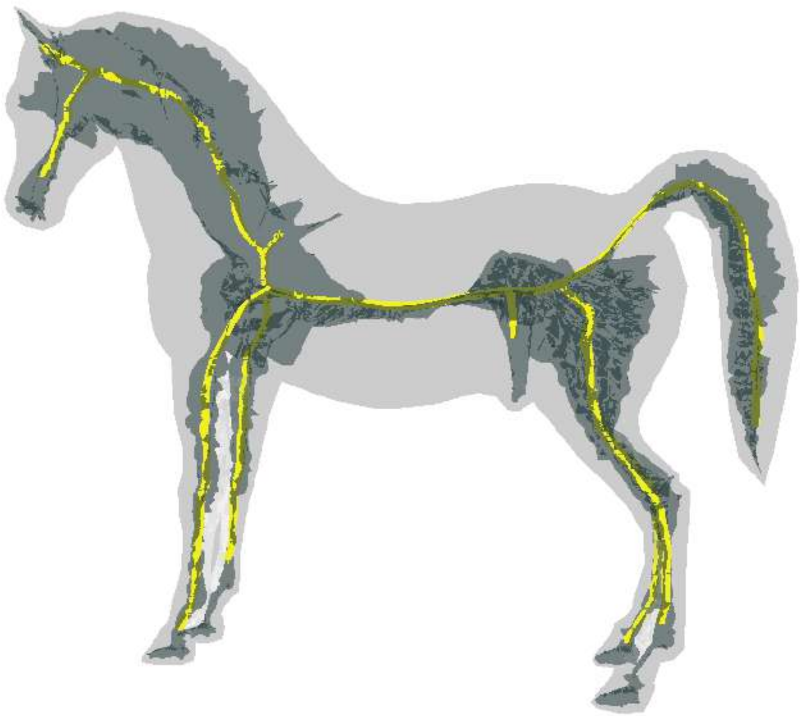
Parts

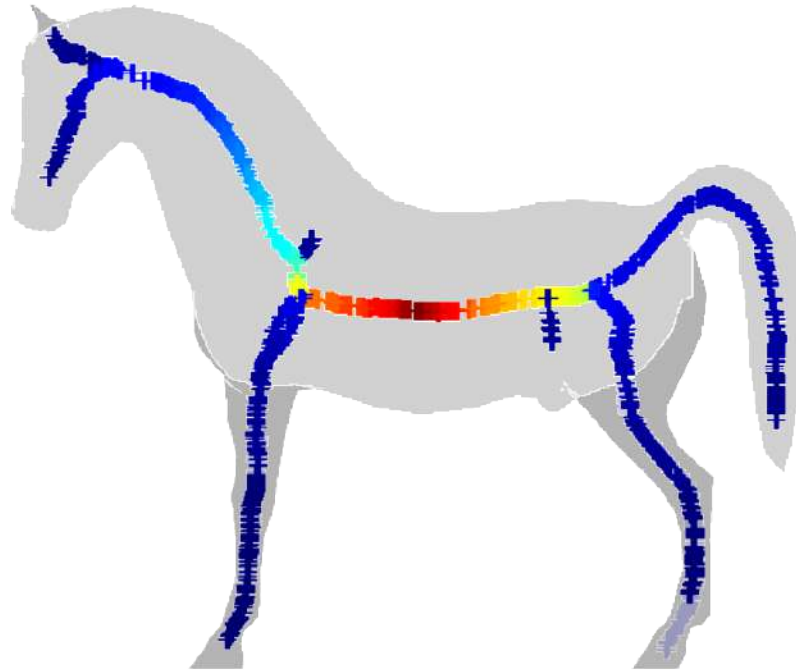


Parts correspondence:
spreading the hierarchy



3D discrete BT example

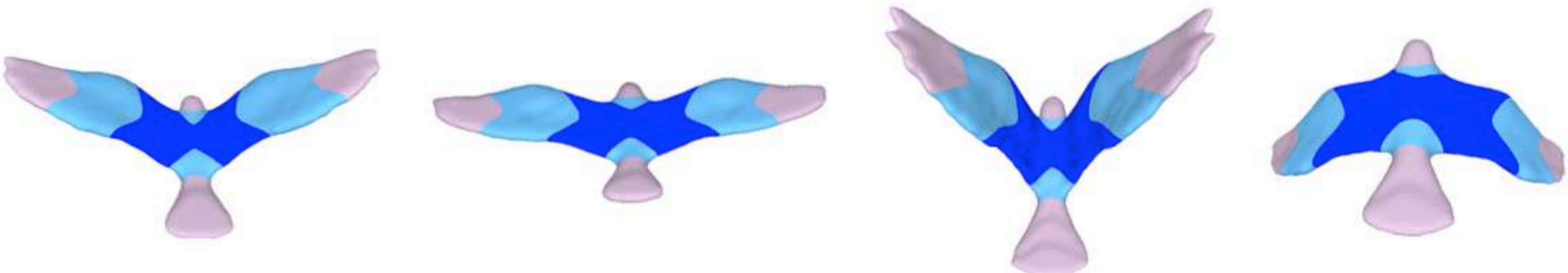




3D WEDF & parts

Blanc-Beyne, et al, 2019

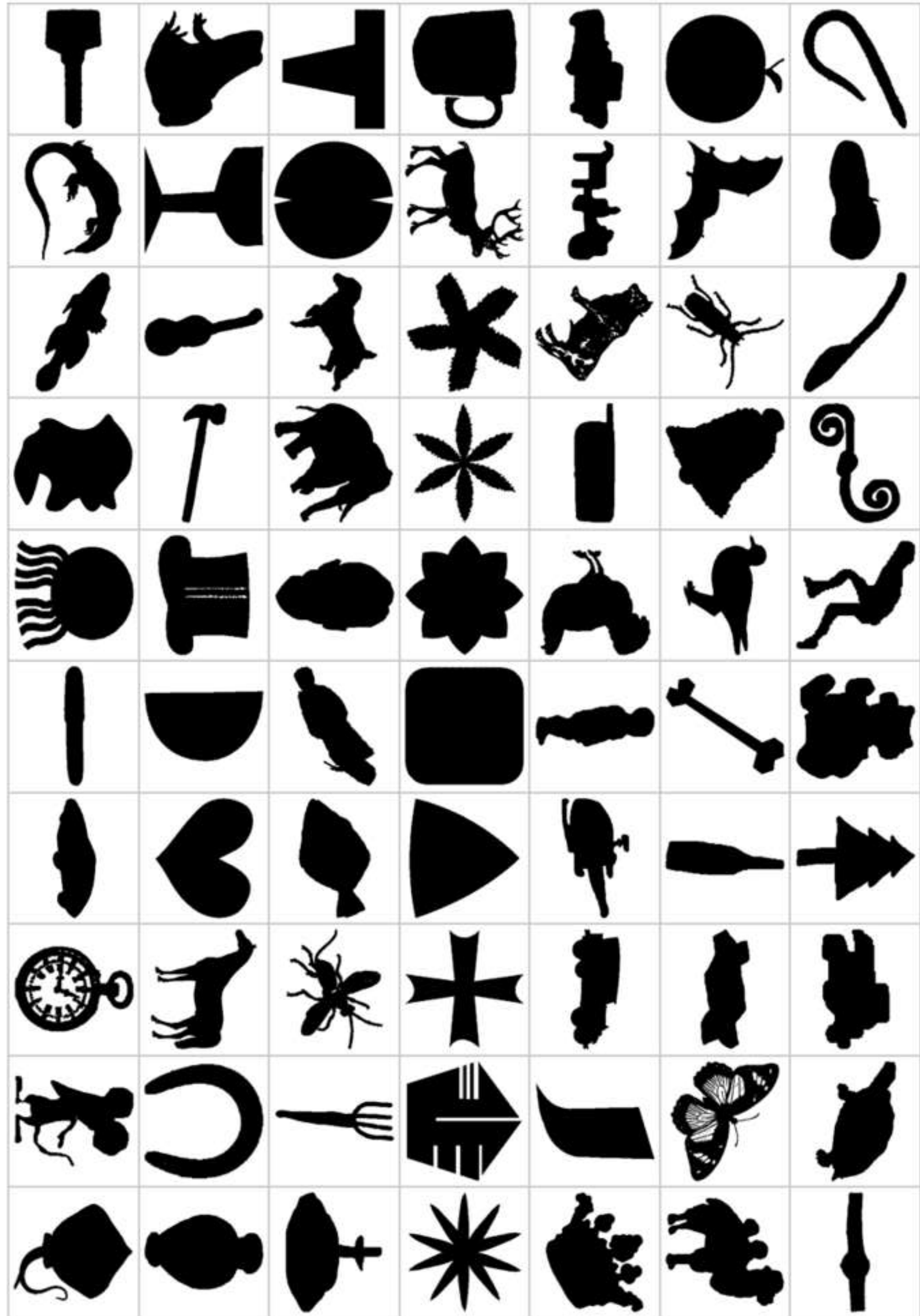
3D WEDF & parts



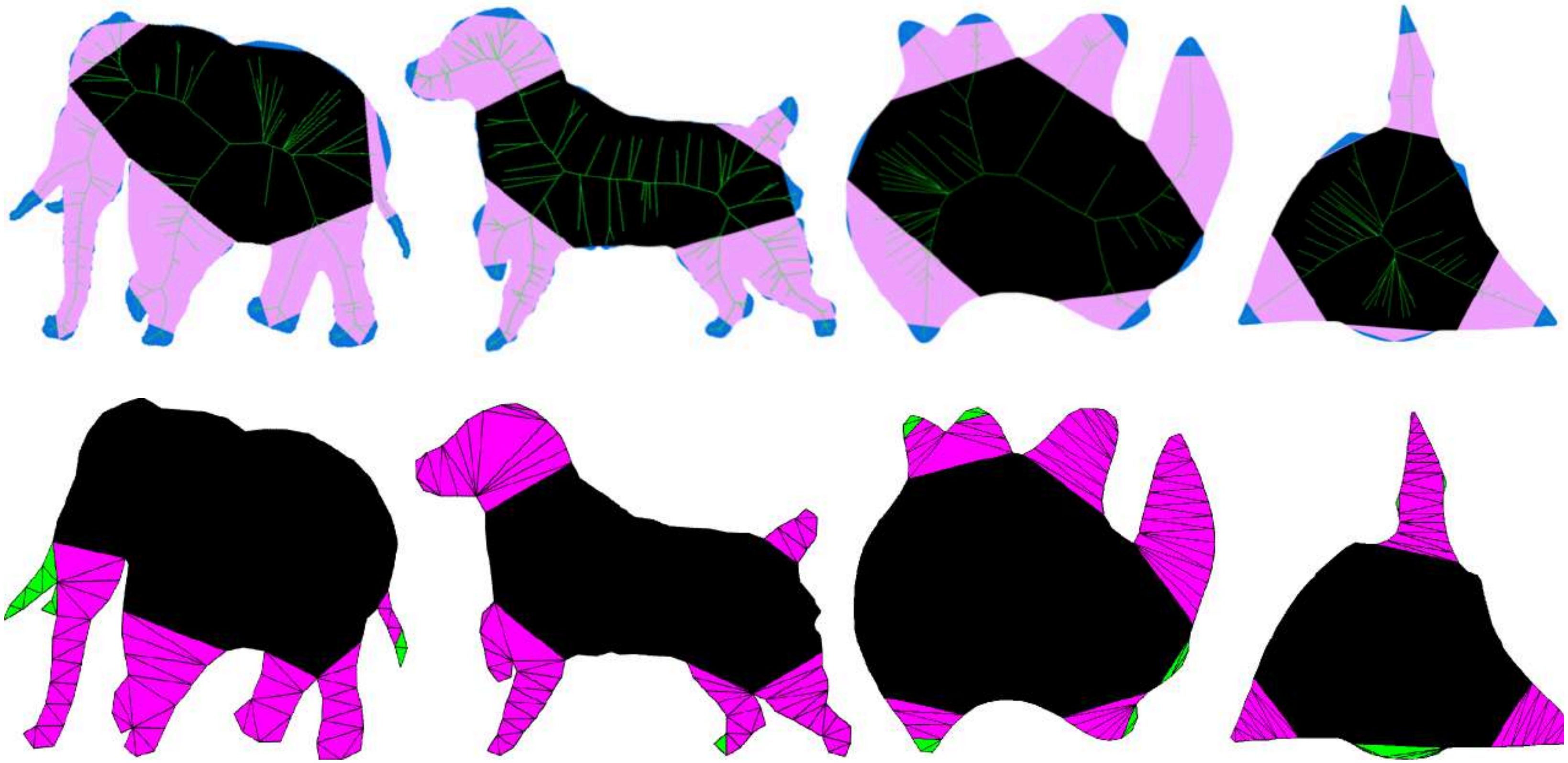
Things we want to do:
tracking

MPEG-7 database
70 classes, 1400 shapes

2000+ annotators
40,000+ shapes
24+ annotations/shape

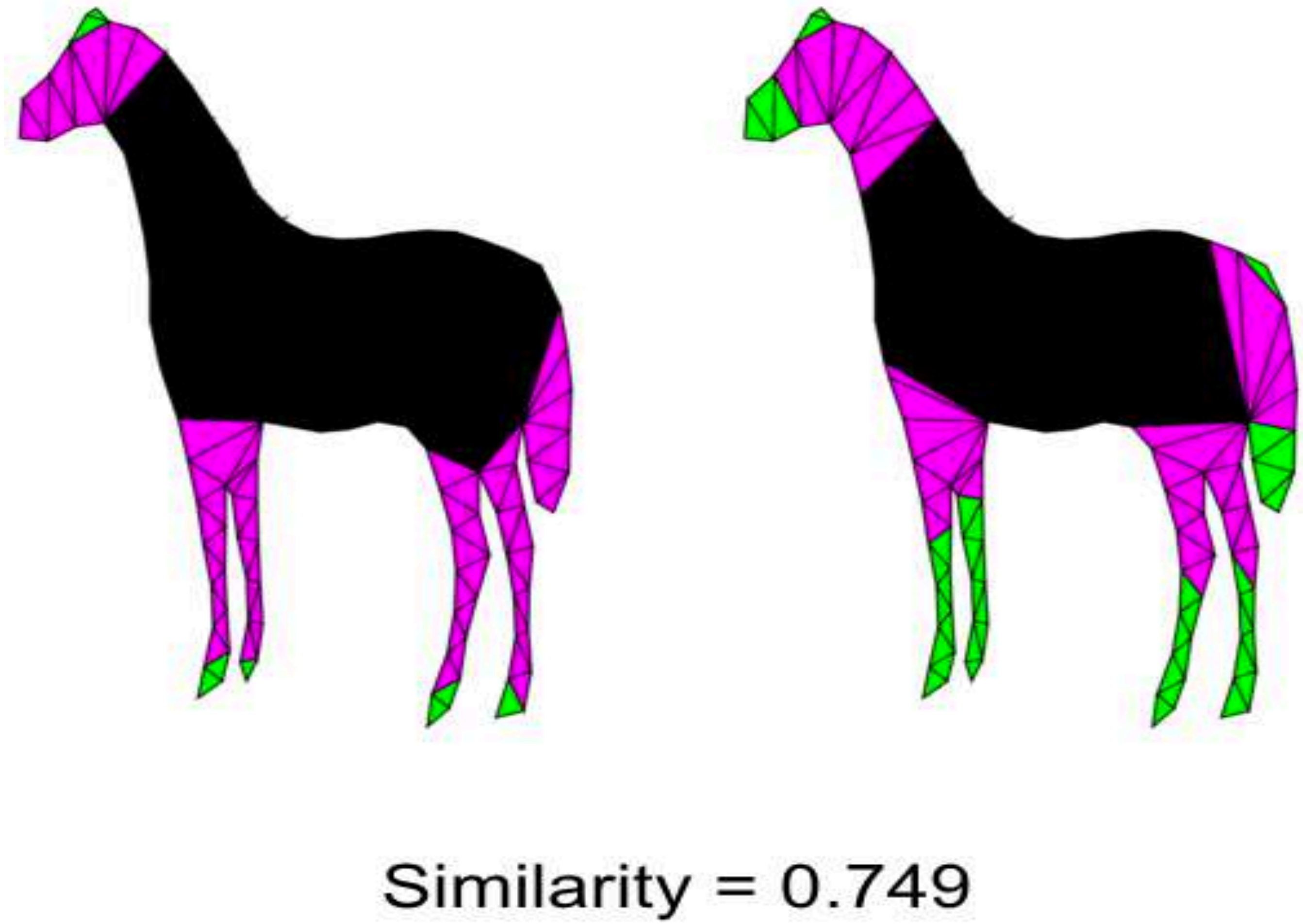


Median similarity score: 0.8
Average: 0.765
Std dev: 0.14

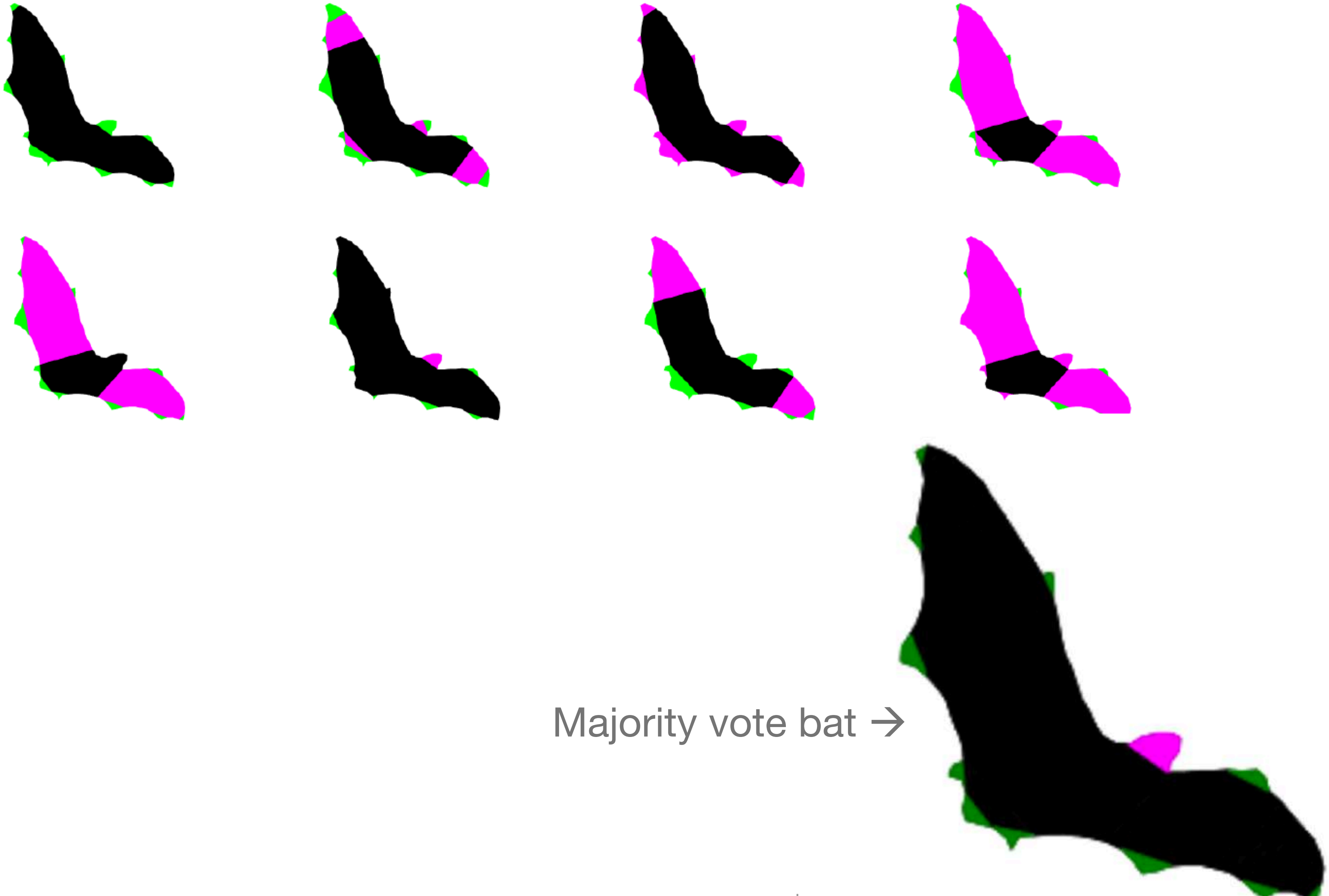


How to measure perception?
Comparison to user study

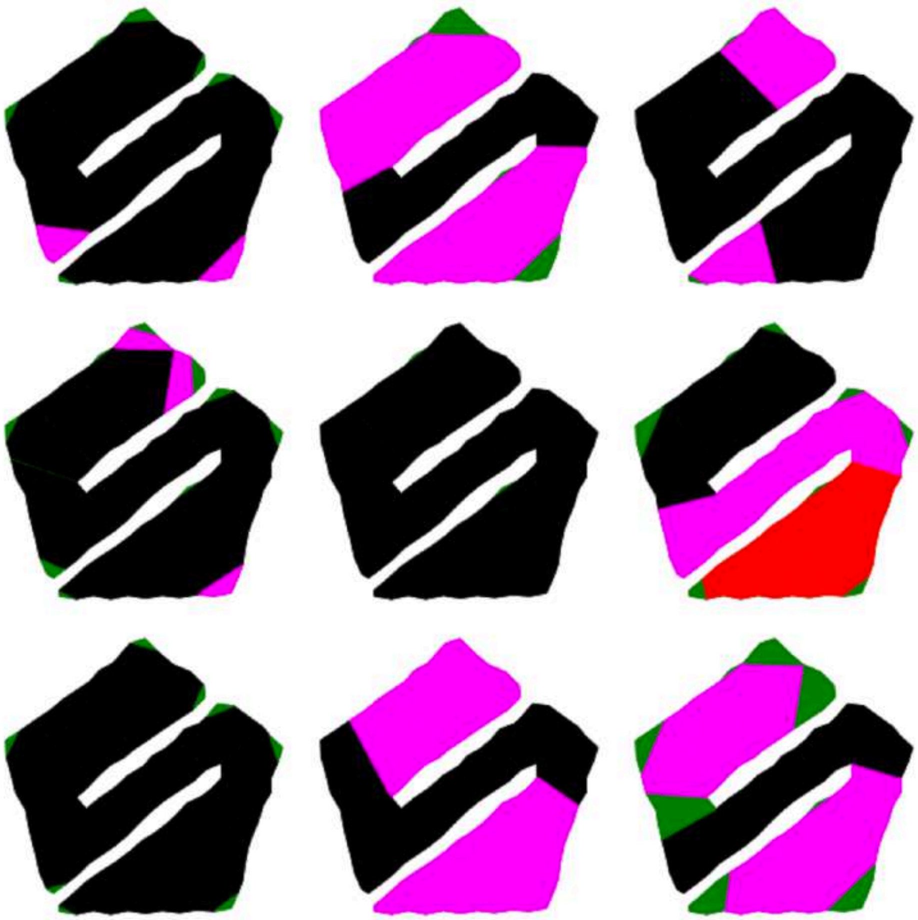
Carlier, et al, 2016

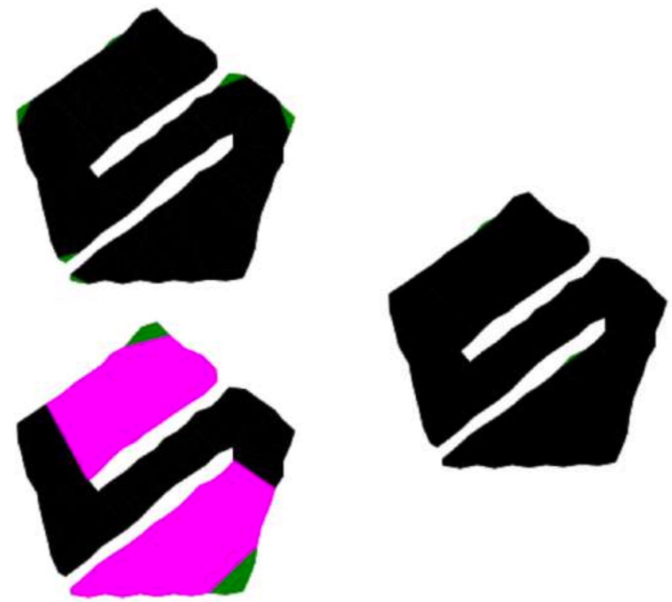


Evaluation:
Expected agreement



User annotations of bats





Two modes Majority vote

interesting data set!

The 2D Shape Structure Dataset

Axel Carlier, Kathryn Leonard, Stefanie Hahmann, Géraldine Morin, Misha Collins

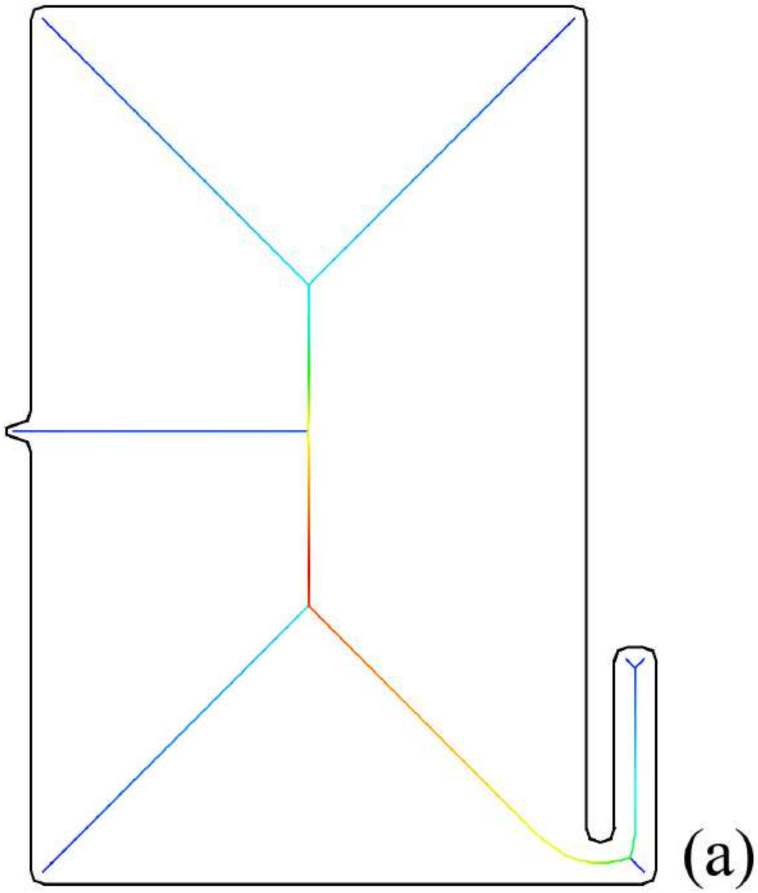
Abstract

On this web page, we present the 2D Shape Structure database, a public, user-generated dataset of 2D shape decompositions into a hierarchy of shape parts with geometric relationships retained. It is the outcome of a large-scale user study obtained by crowdsourcing, involving over 1200 shapes in 70 shape classes, and 2861 participants. A total of 41953 annotations has been collected with at least 24 annotations per shape. For each shape, user decompositions into main shape, one or more levels of parts, and a level of details are available. This database reinforces a philosophy that understanding shape structure as a whole, rather than in the separated categories of parts decomposition, parts hierarchy, and analysis of relationships between parts, is crucial for full shape understanding. We provide initial statistical explorations of the data to determine representative shape annotations and to determine the number of modes in the annotations. We release this rich and complex database and make it openly available so the shape community can access a ground truth of human perception of holistic shape structure.

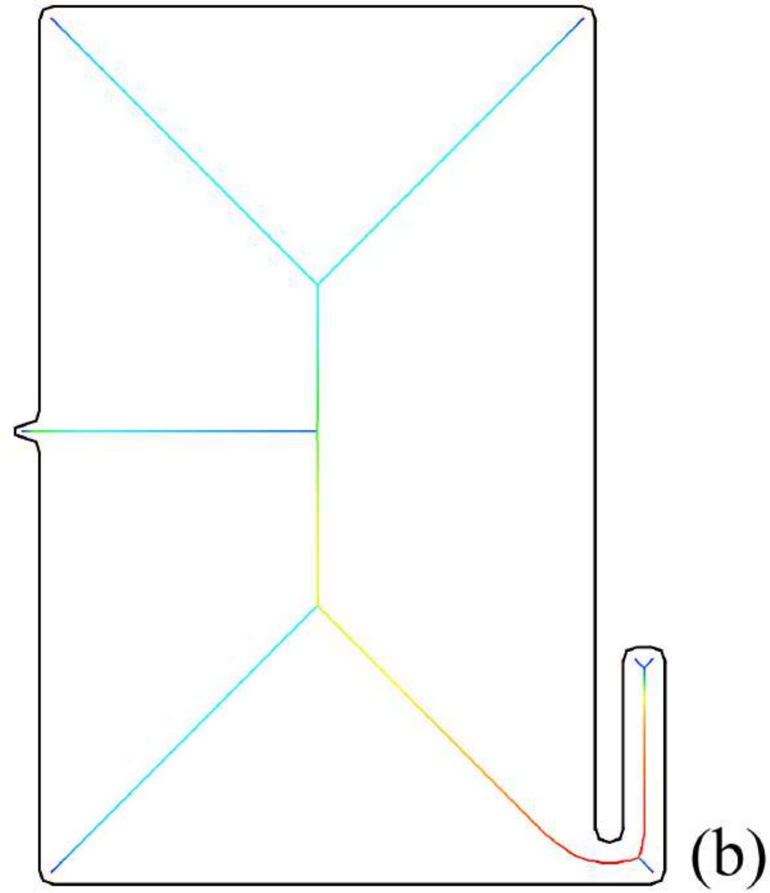
2D shape structure dataset

https://2dshapesstructure.github.io

Things we want to do: matching

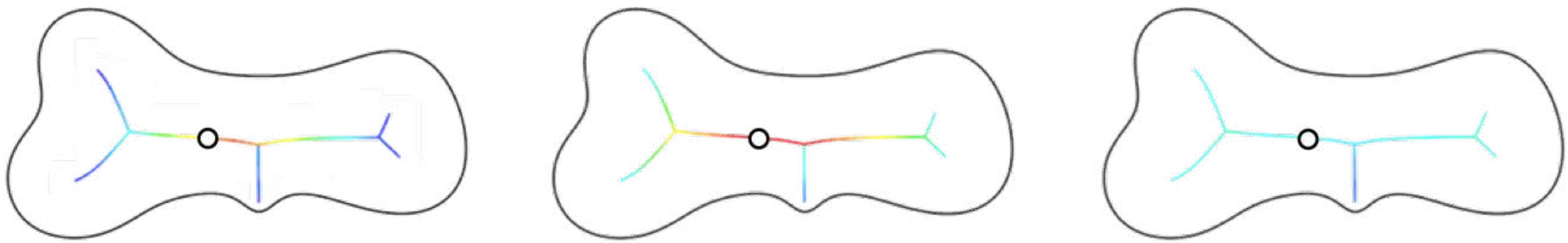


erosion thickness



shape tubularity

More functions on the BMA

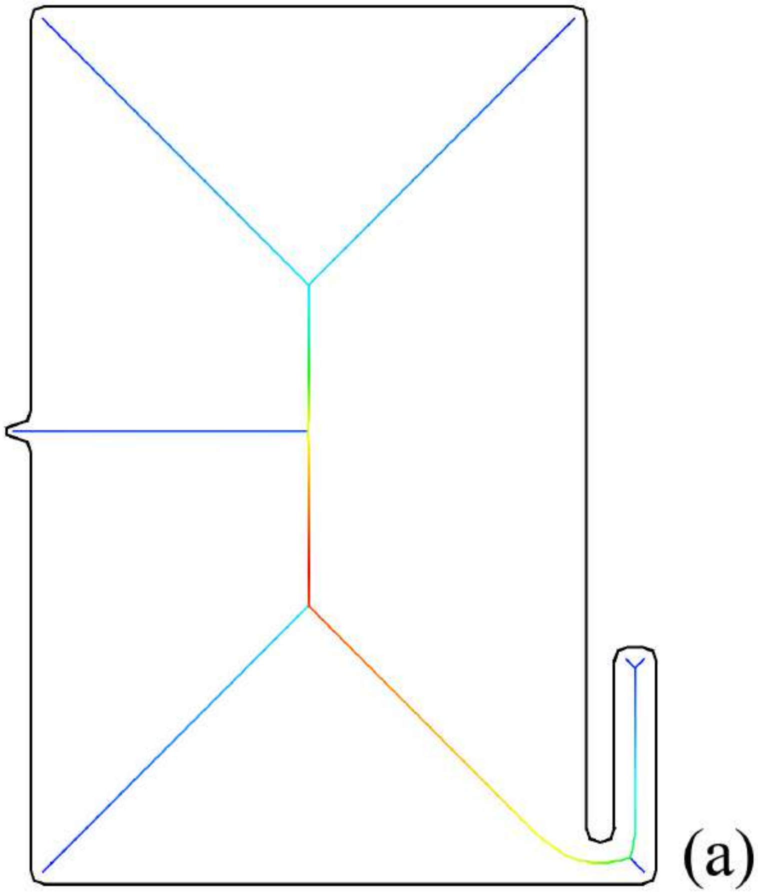


erosion thickness = burn time - radius

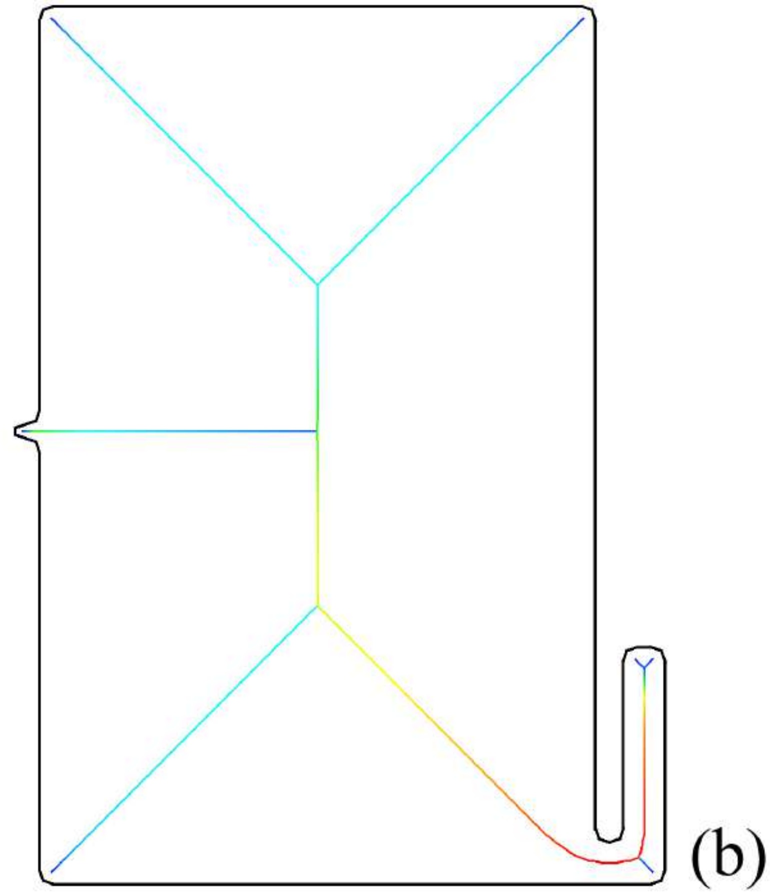
ET as a measure of blobbiness:

$BT - r$ = depth – width

erosion thickness &
BT/EDF



erosion thickness

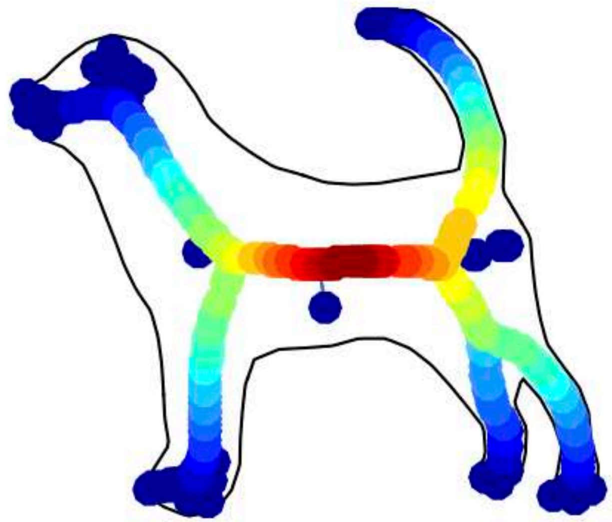


shape tubularity

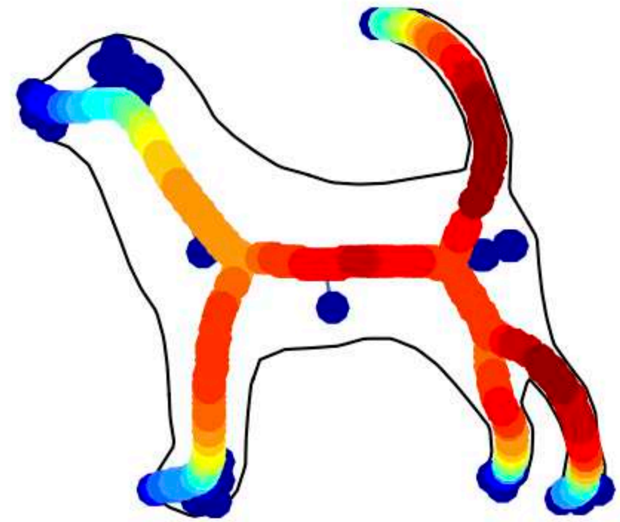
$$ST(x) = \frac{EDF(x) - r(x)}{EDF(x)} = 1 - \frac{r(x)}{EDF(x)}$$

shape tubularity

“tubiness” = blobbiness/depth

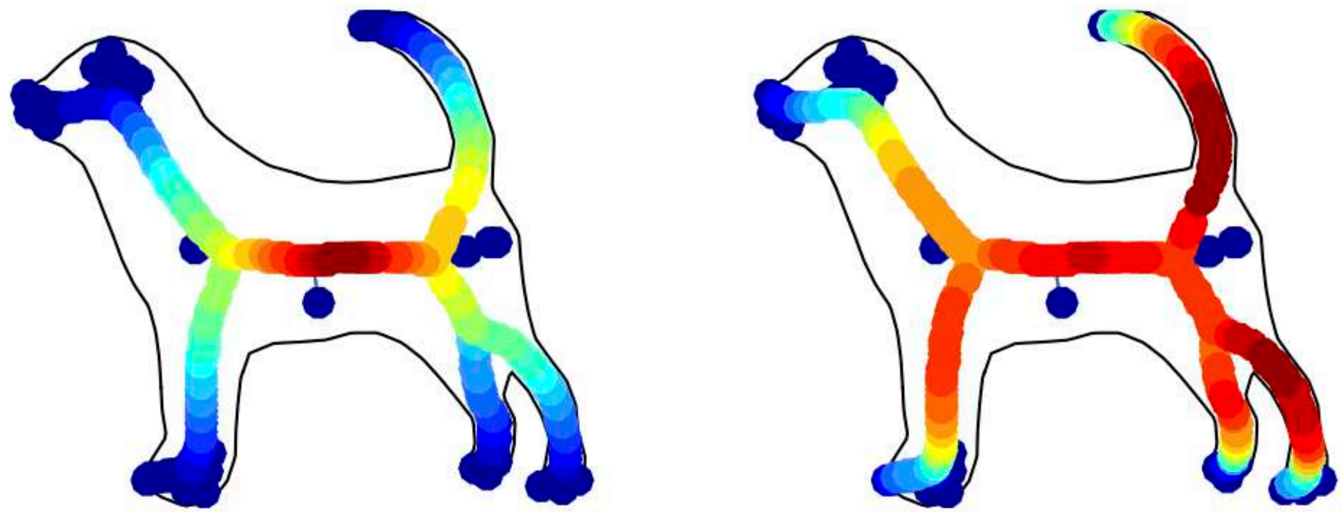


erosion thickness



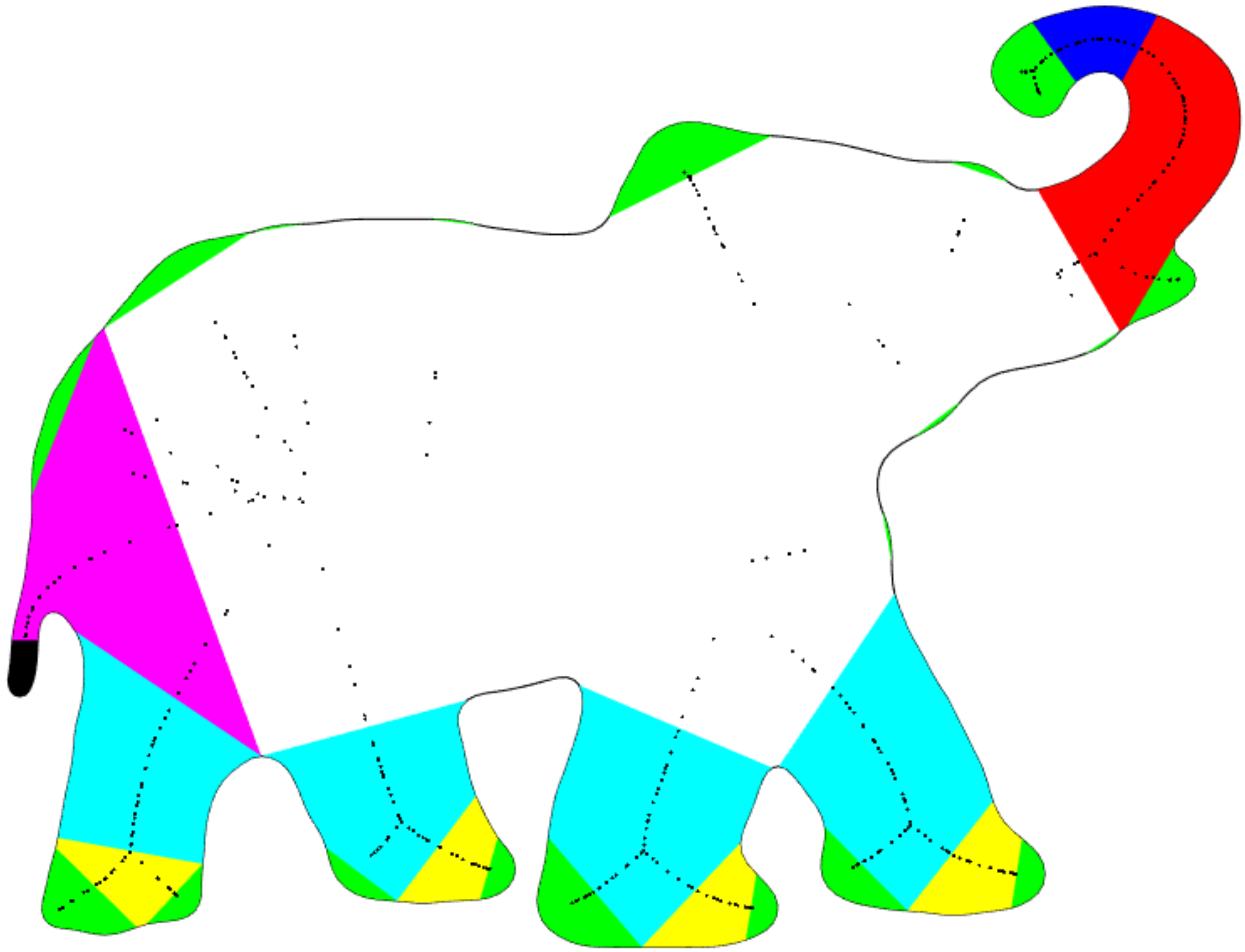
shape tubularity

ET and ST

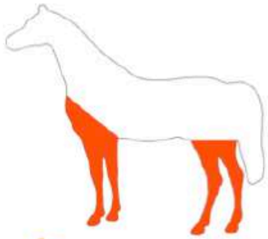


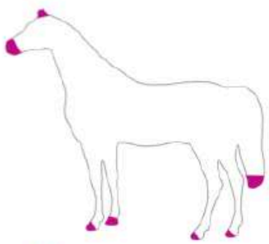
Theorem:
Up to articulation (radius-preserving embedding), the values of ET and ST uniquely determine the geometry of a shape part.

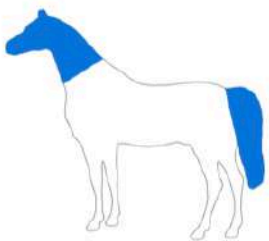
useful result for similarity

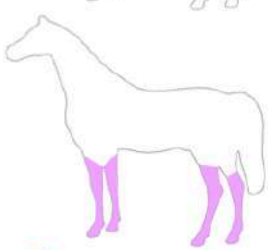


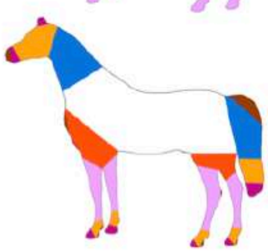
ET, ST similarity
clustering

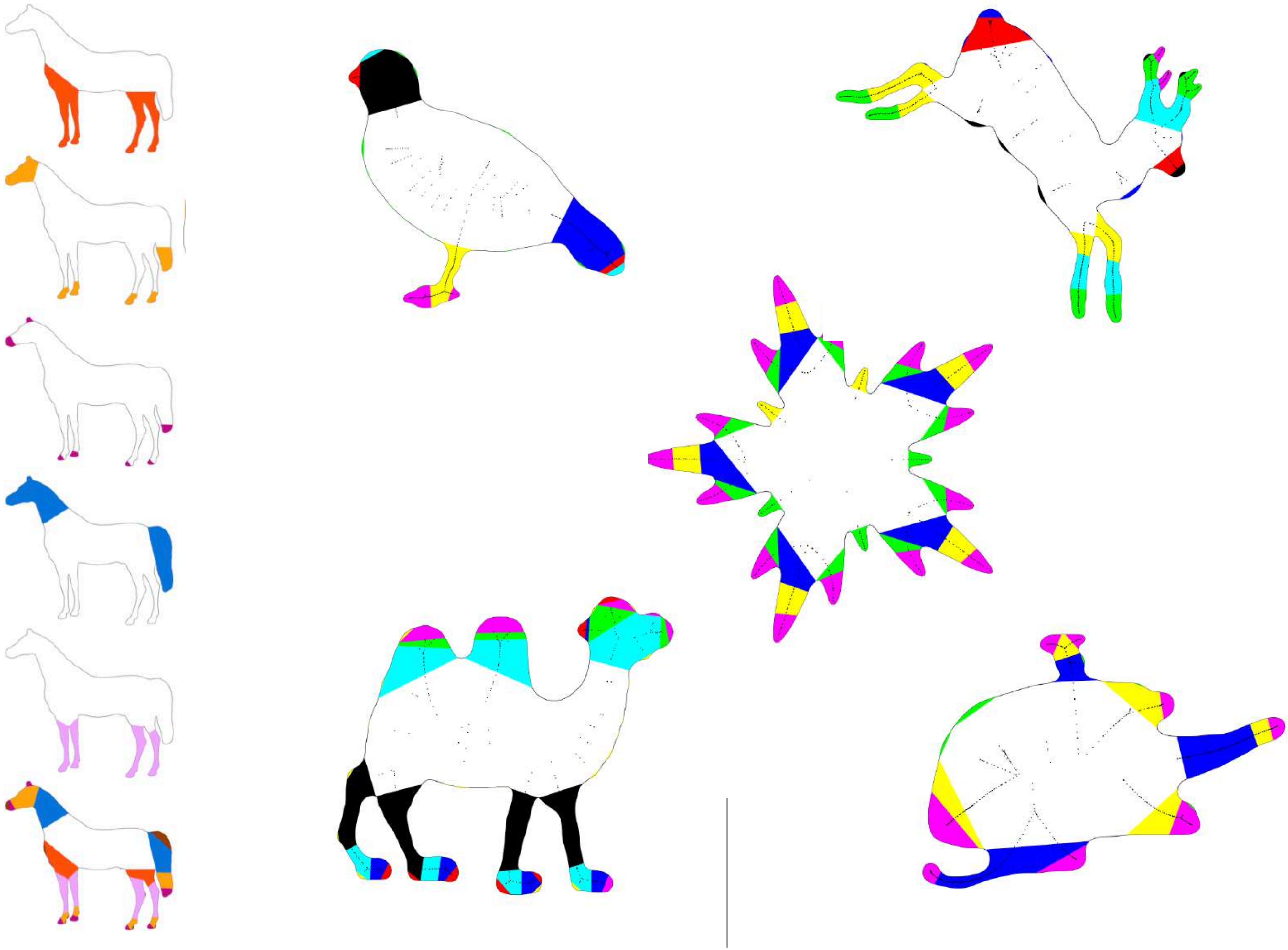










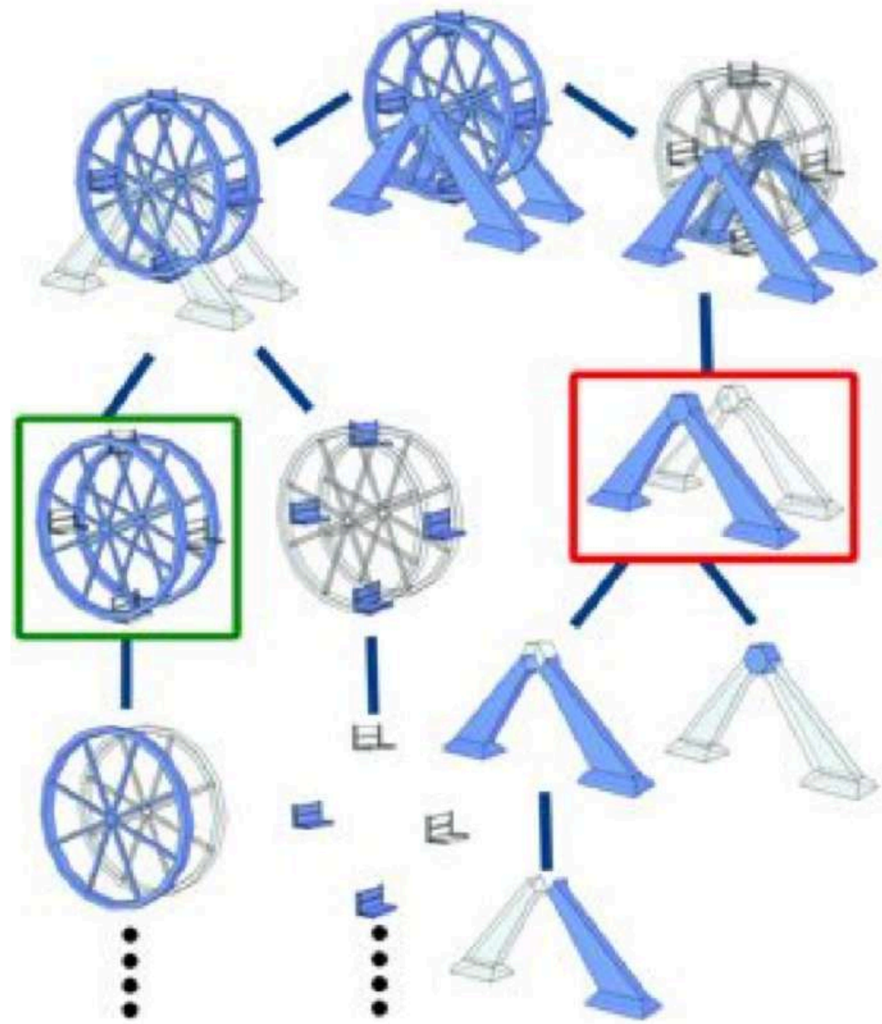


- *Composition of parts* ✔
- *Parameters on parts* ✔
- *Relationships between parts* ✔

hierarchy ✔

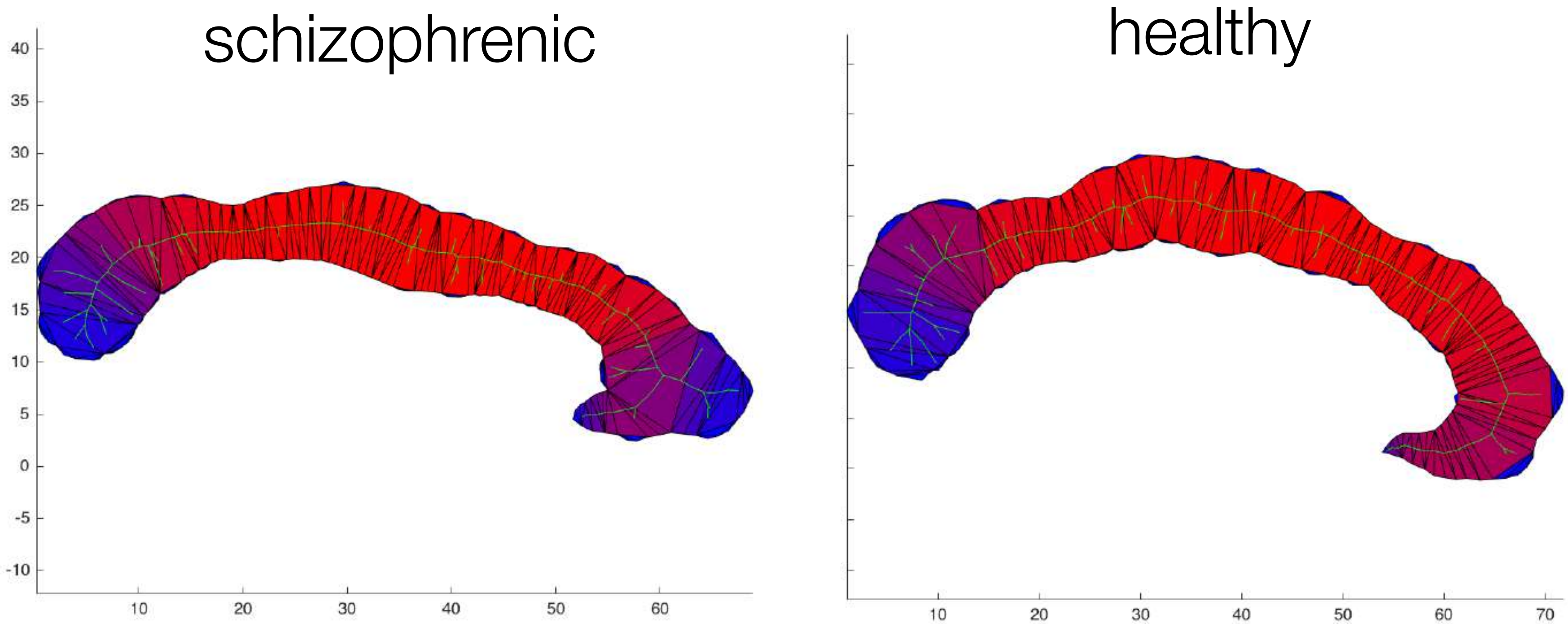
geometry ✔

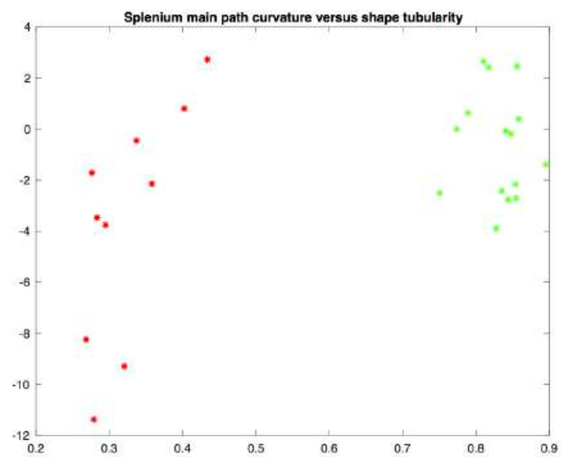
similarity ✔



Shape understanding

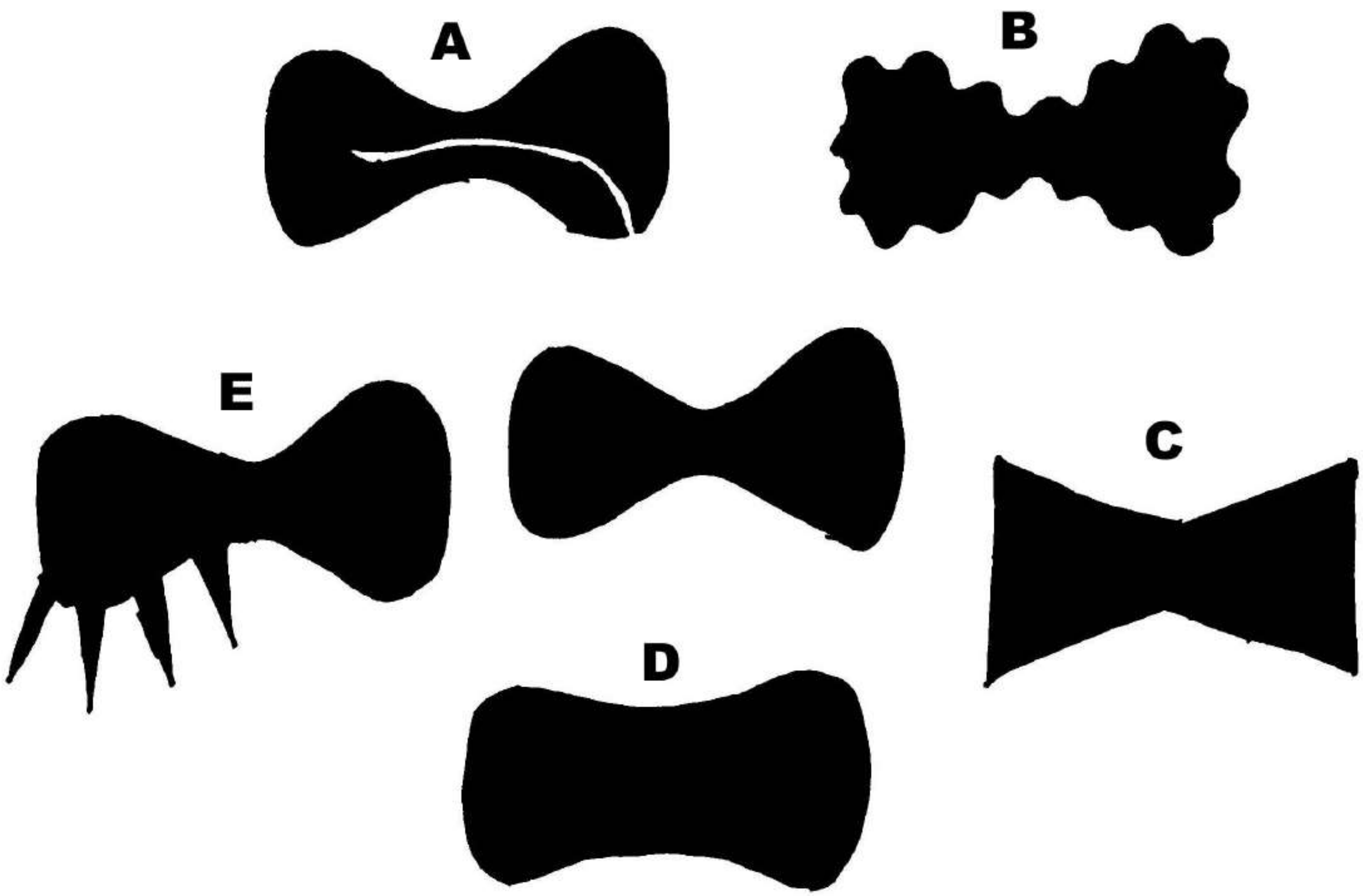
N. J. Mitra, M. Pauly, M. Wand, and D. Ceylan. Symmetry in 3d geometry: Extraction and applications. In Computer Graphics Forum, volume 32. Wiley Online Library, 2013





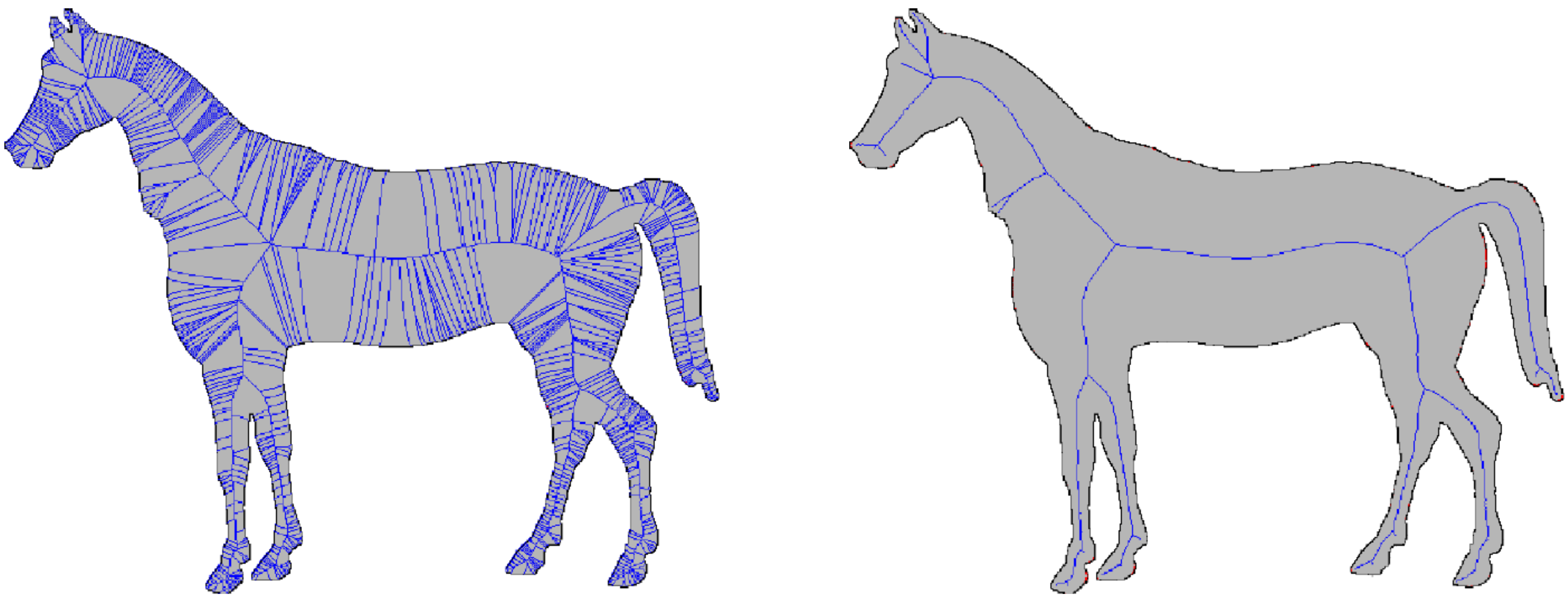
Application of ST: Schizophrenia diagnosis aid

Arountiounian, et al, 2015



Perceptual
approximation

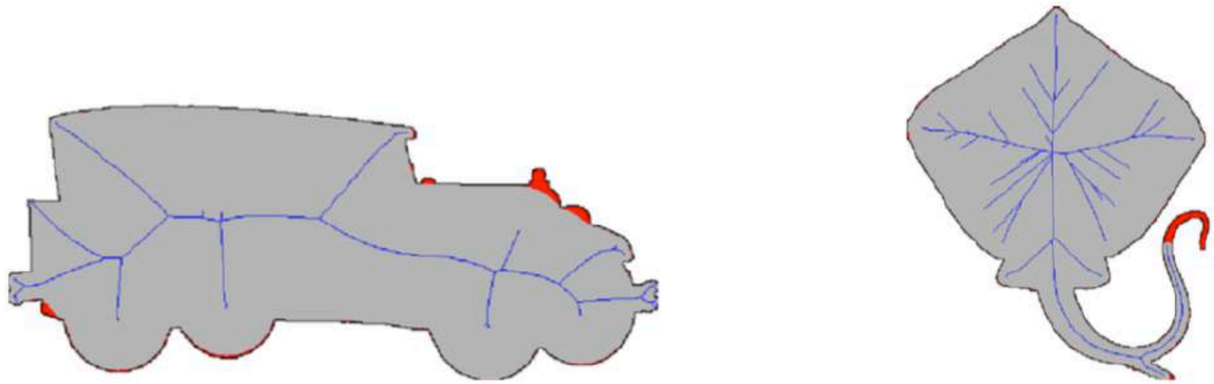
Image credit: D. Mumford



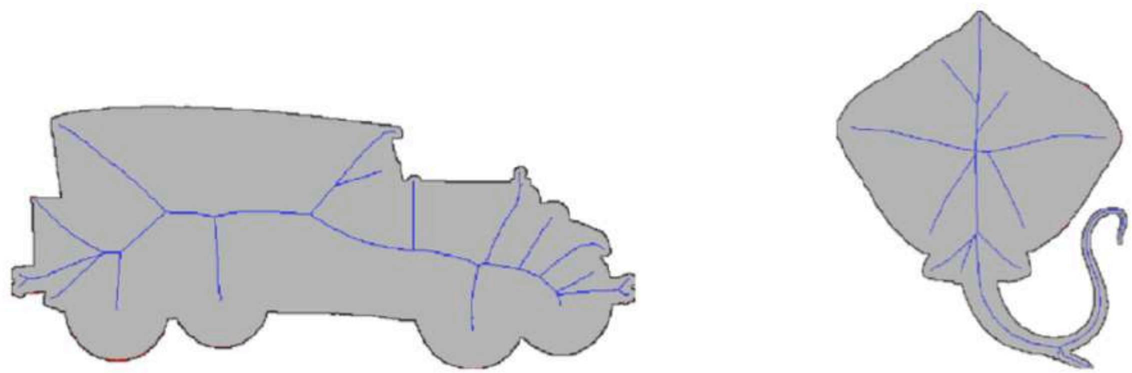
BMA with perceptual AND metric approximation guarantees

Clean BMA | *Durix, et al, 2019*

SAT method:

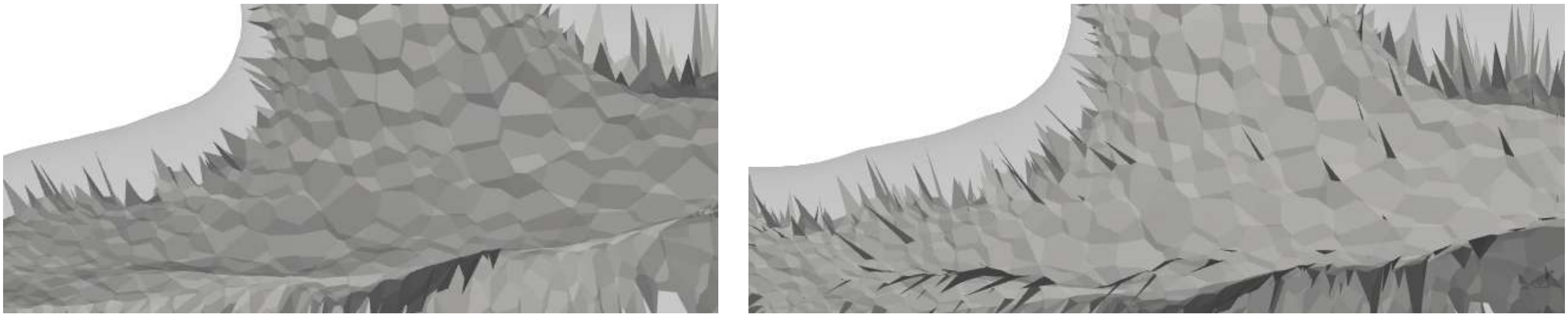


Our method:



BMA with perceptual AND metric approximation guarantees

Clean BMA | *Durix, et al, 2019*



BMA with perceptual AND metric approximation guarantees

Clean | *Durix, et al, 2022???*


Erin Chambers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Thibault Blanc-Beyne


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Axel Carlier


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Sylvie Chambon

Thank you!

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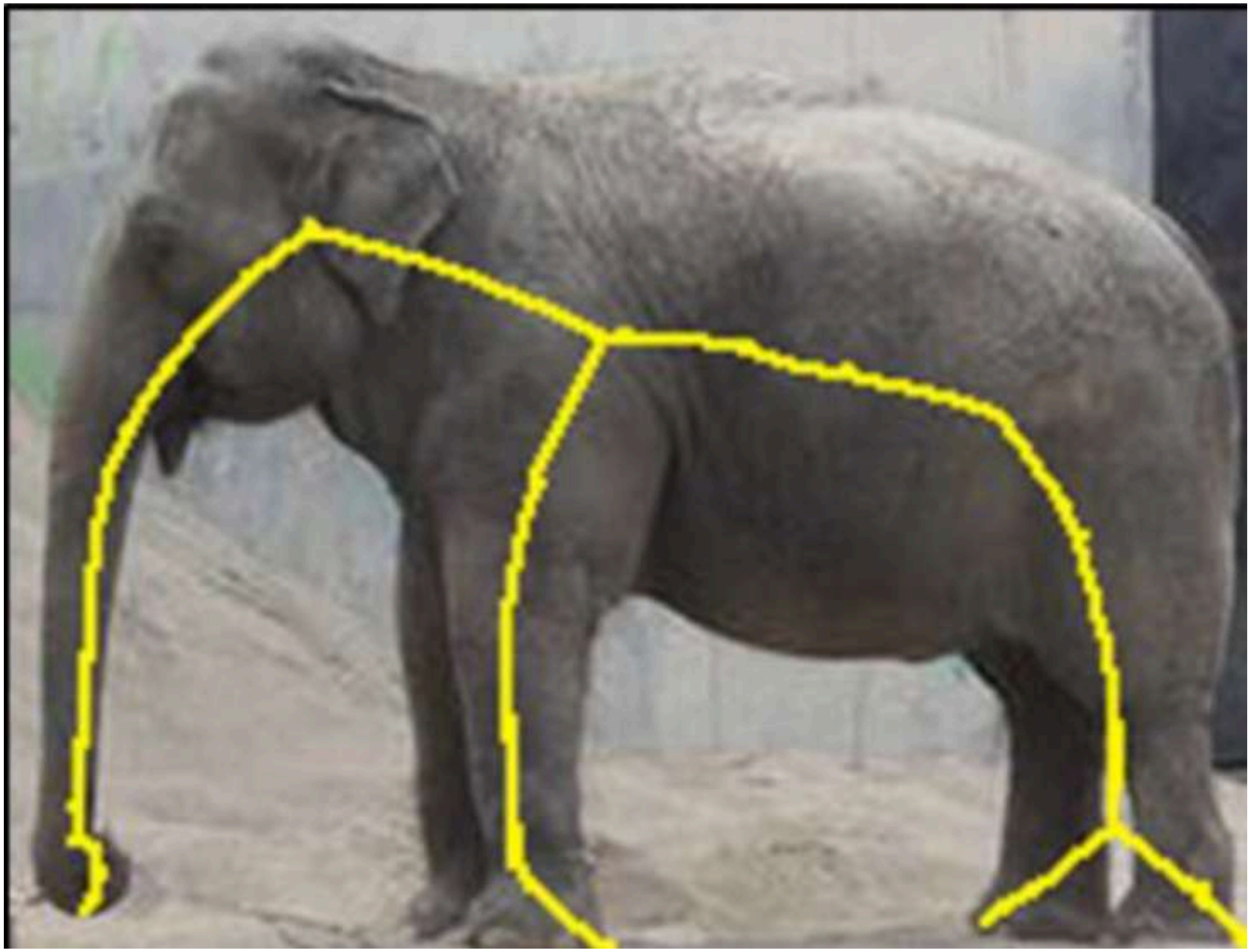

Neural networks for skeletons from natural images

Say Brown, Joaquin Madrid Larrañaga, OXY