Mapper can produce a topological model for fibres of failure modes.

Topology in the furnace:

TDA as a diagnostics tool for process control systems.

Mikael Vejdemo-Johansson
in transit KTH → CUNY

- Early work in progress
- Collaboration with
  Ayasdi Inc.
  Outukumpu Stainless AB
  KTH ITM (Industrial Engineering and Management)
- Plan: use TDA to understand, diagnose and improve industrial process control and engineering.

  First approach: diagnostics on existing control systems with Mapper.

What is mapper?

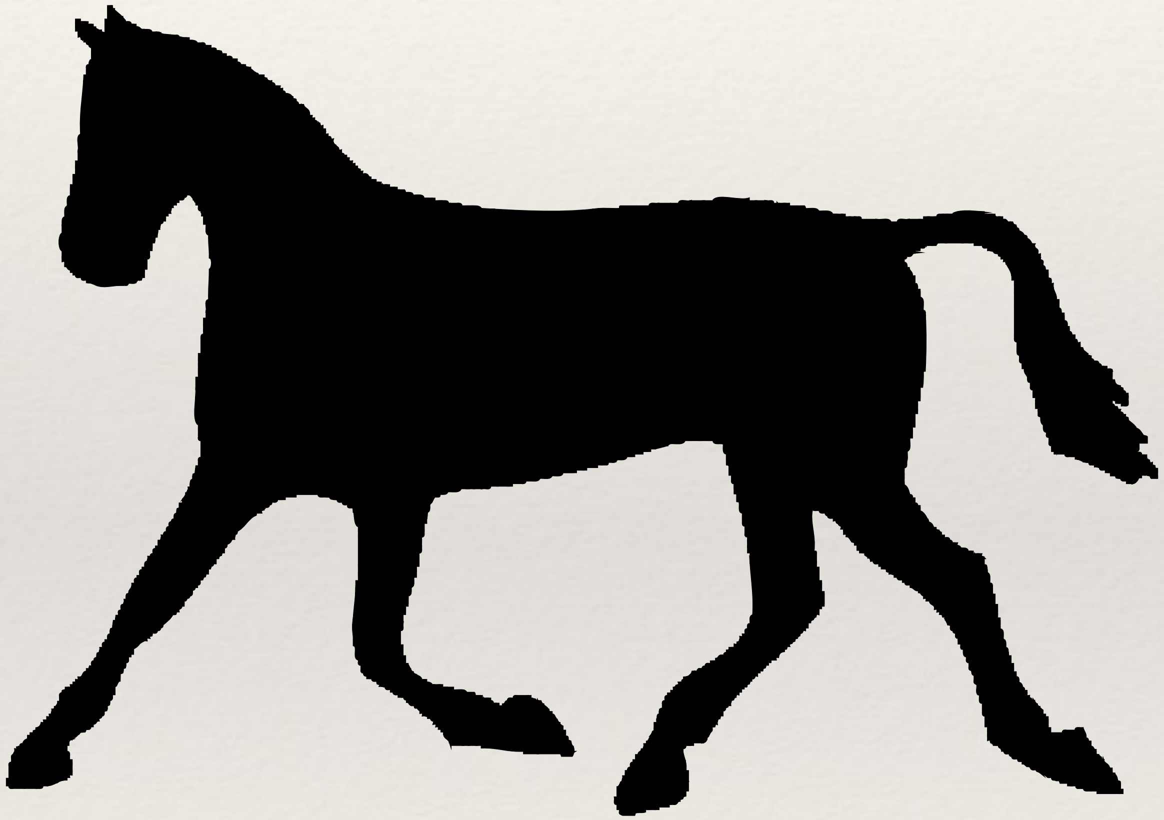
The Mapper algorithm

- Gurjeet Singh (2012)
- Built on a topological basic idea
- Creates intrinsic simplicial complex model of arbitrary data

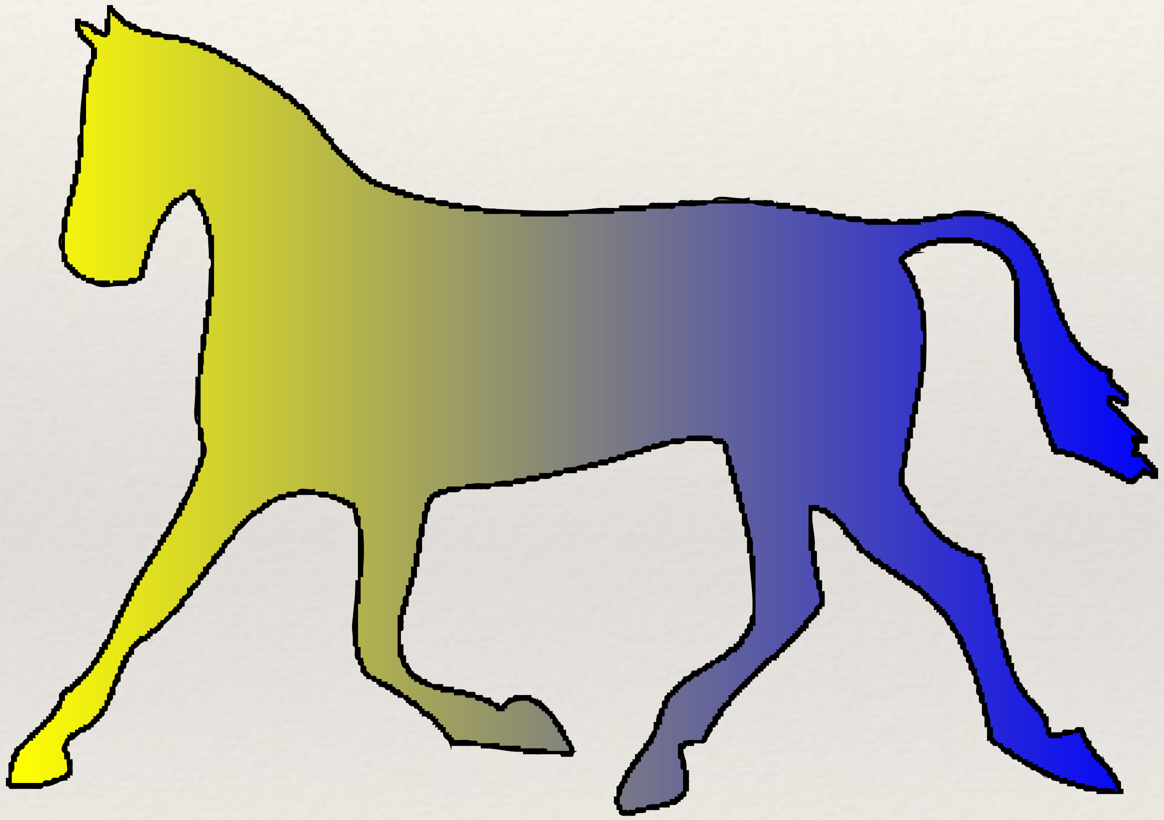
Topological background

- Consider:
    - Spaces X, Y
    - Continuous map $f: X \to Y$
    - Cover $Y = \cup Y_i$
- The cover pulls back to a cover $X = \cup f^{-1} Y_i$
- Refine cover to connected components $X = \cup X_j; X_j \in \pi_0 f^{-1} Y_i$
- If each X_j is contractible, Nerve lemma → nerve complex ≃ X.

Topological background



Topological background



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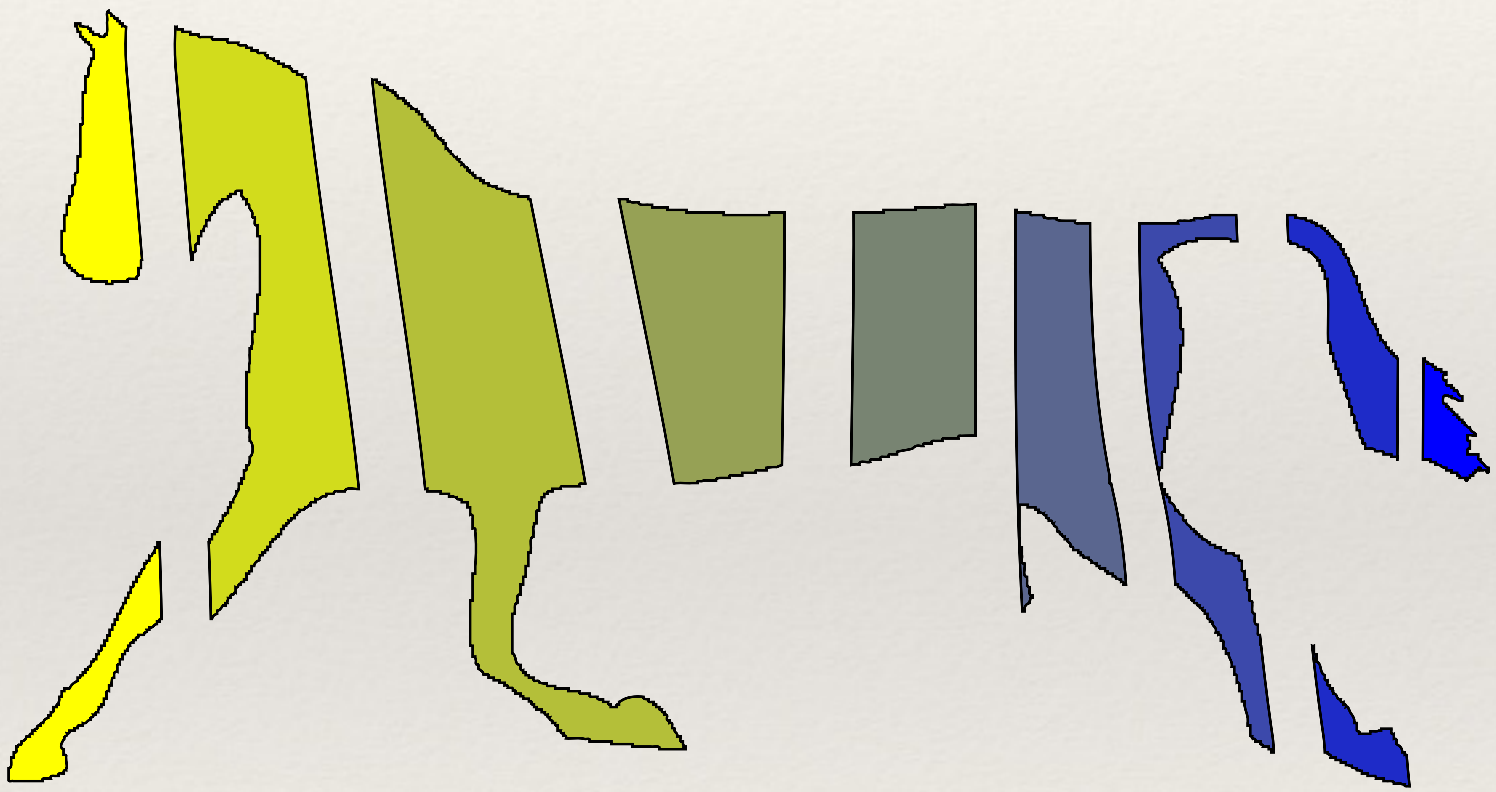

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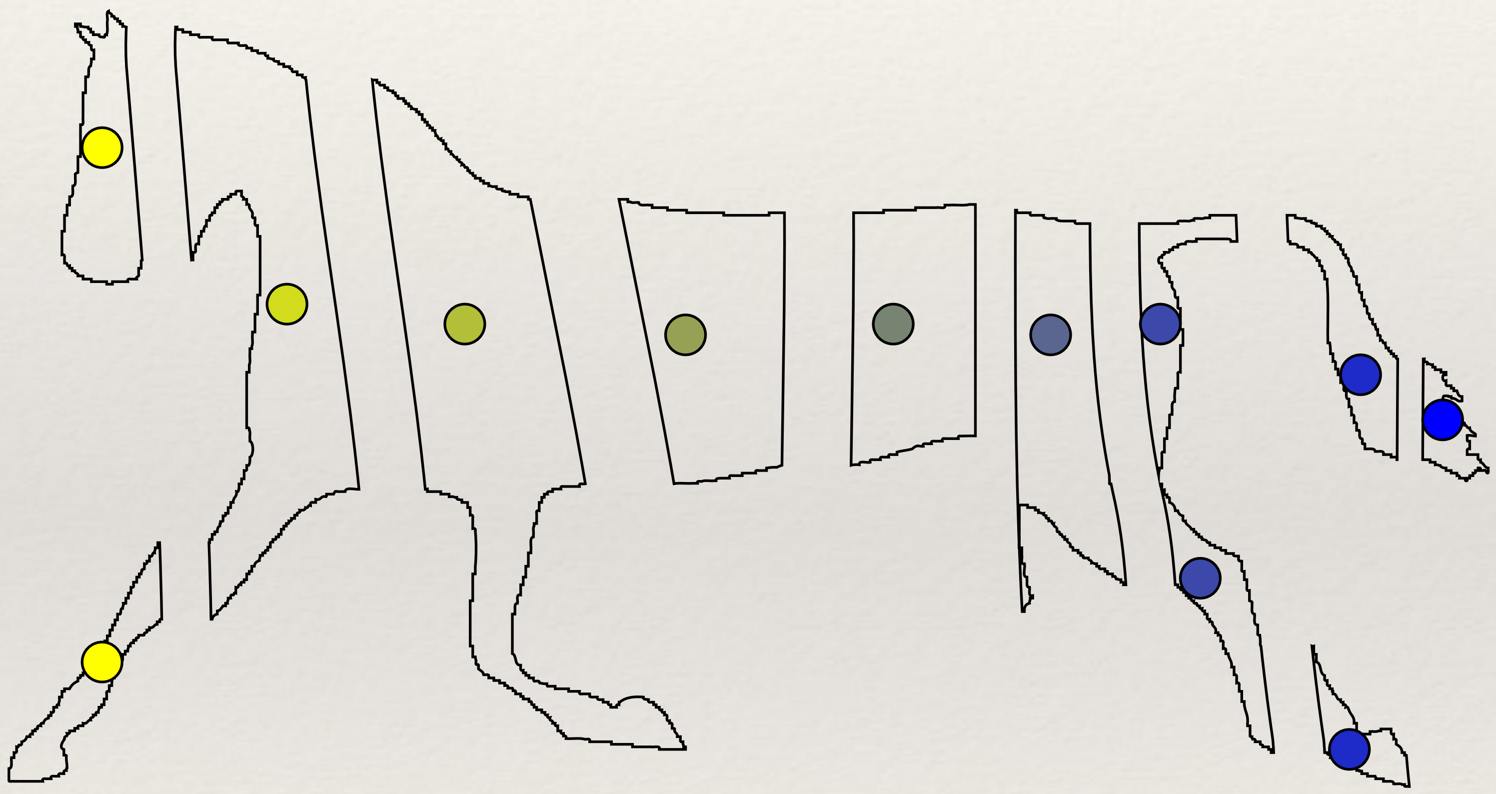

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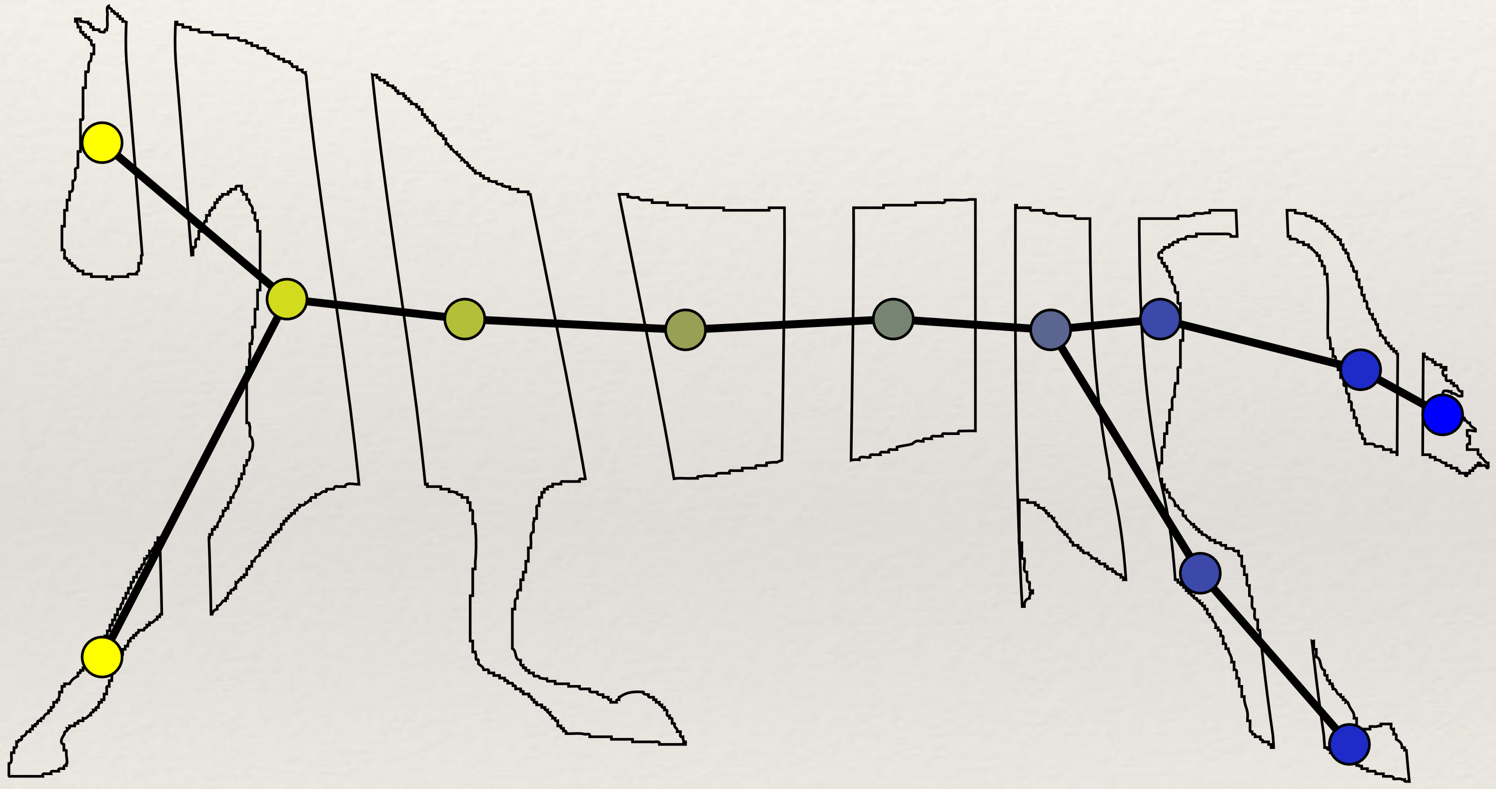
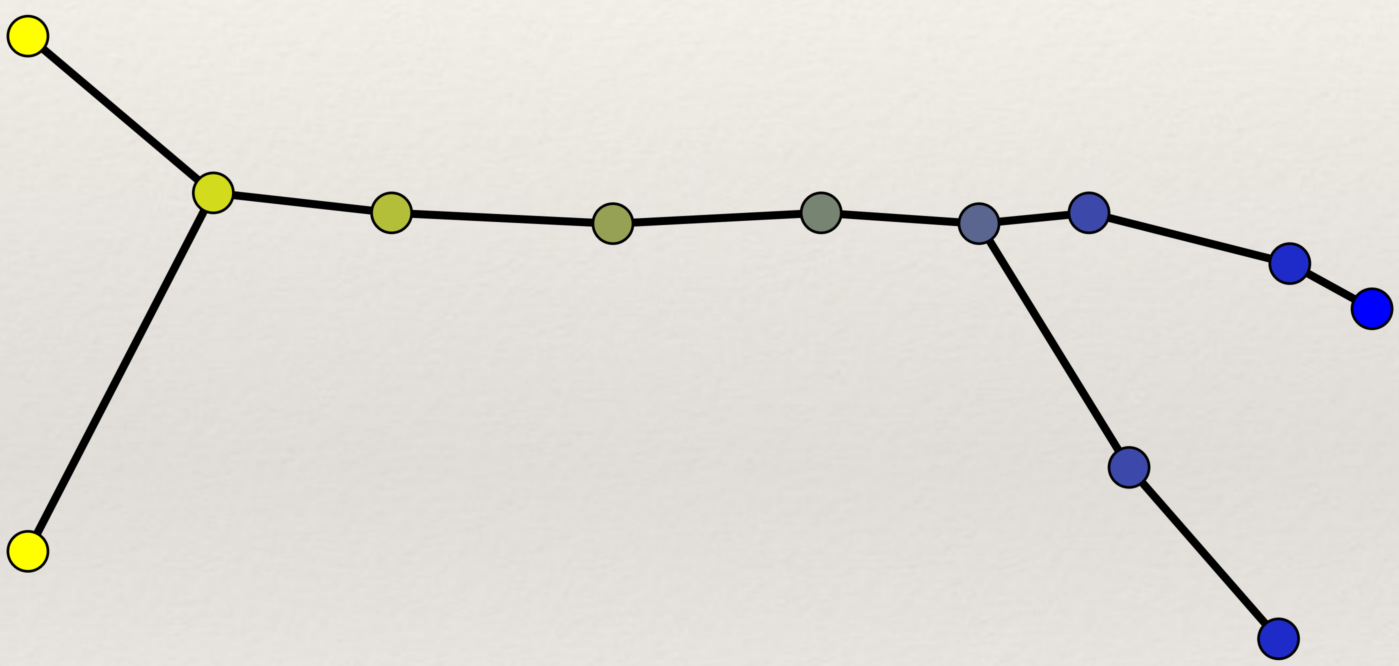


Topological background

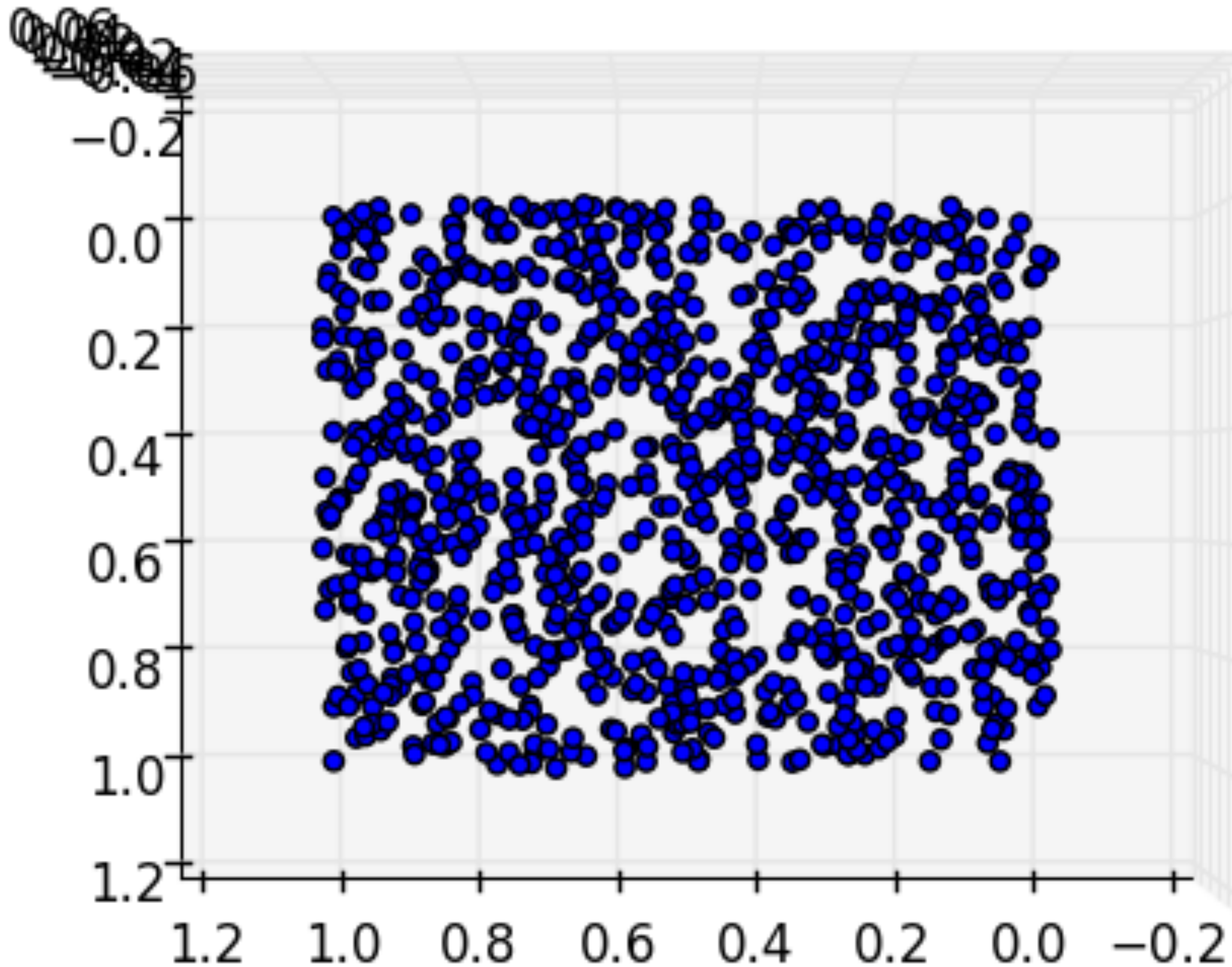


From topology to data: a dictionary

- Topological space
- Continuous map
  $X \to Y$
- Cover
- π_0
- Nerve complex

- Point cloud
- *Filter* function or *lens*
  $X \to \mathbb{R}^d$
- Partition with overlap
- Clustering wrt *metric*.
- Nerve complex

Mapper is parametrized by a choice of **lens**(es), of **metric**, of (parameters for) **partition** and of **clustering** method.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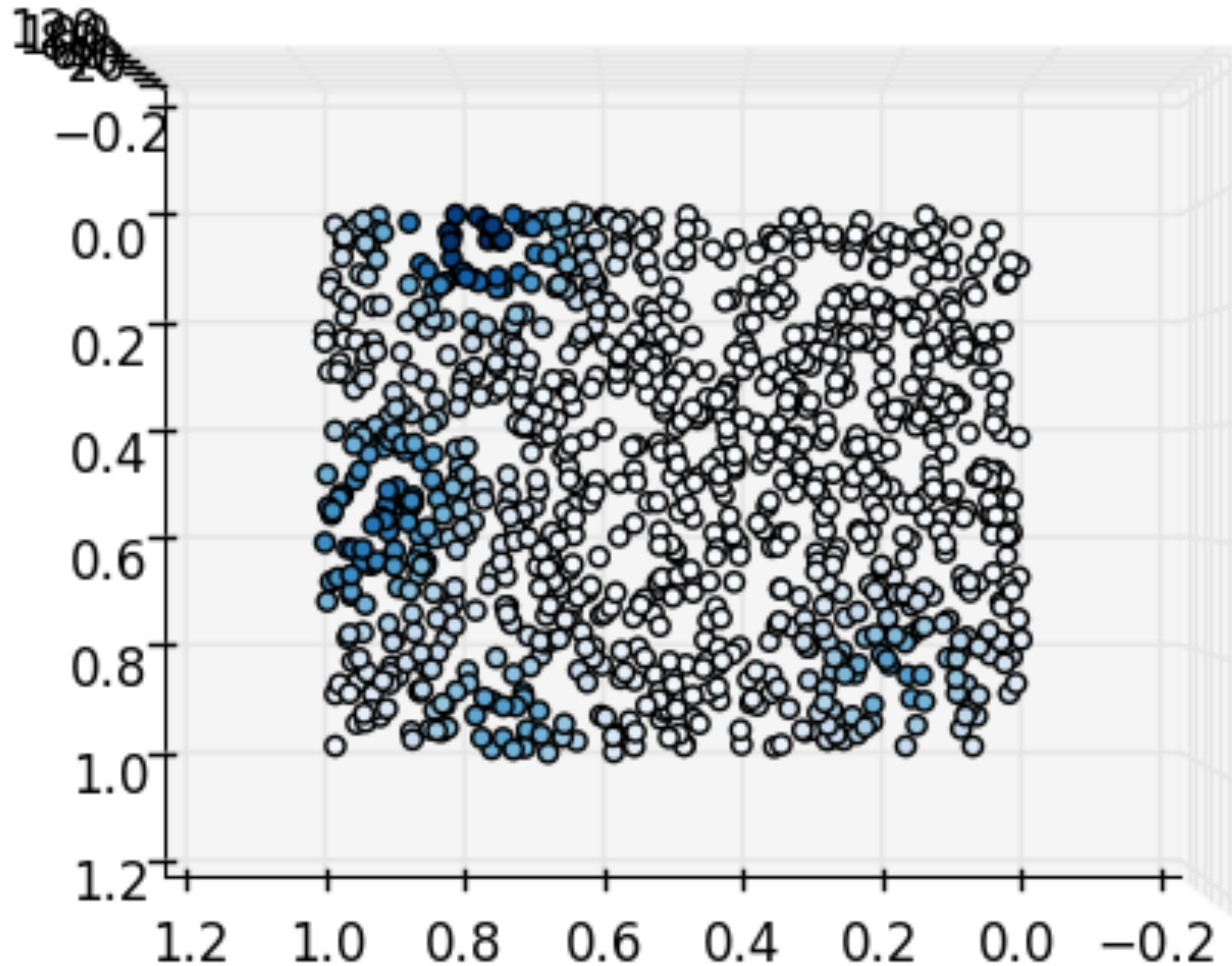

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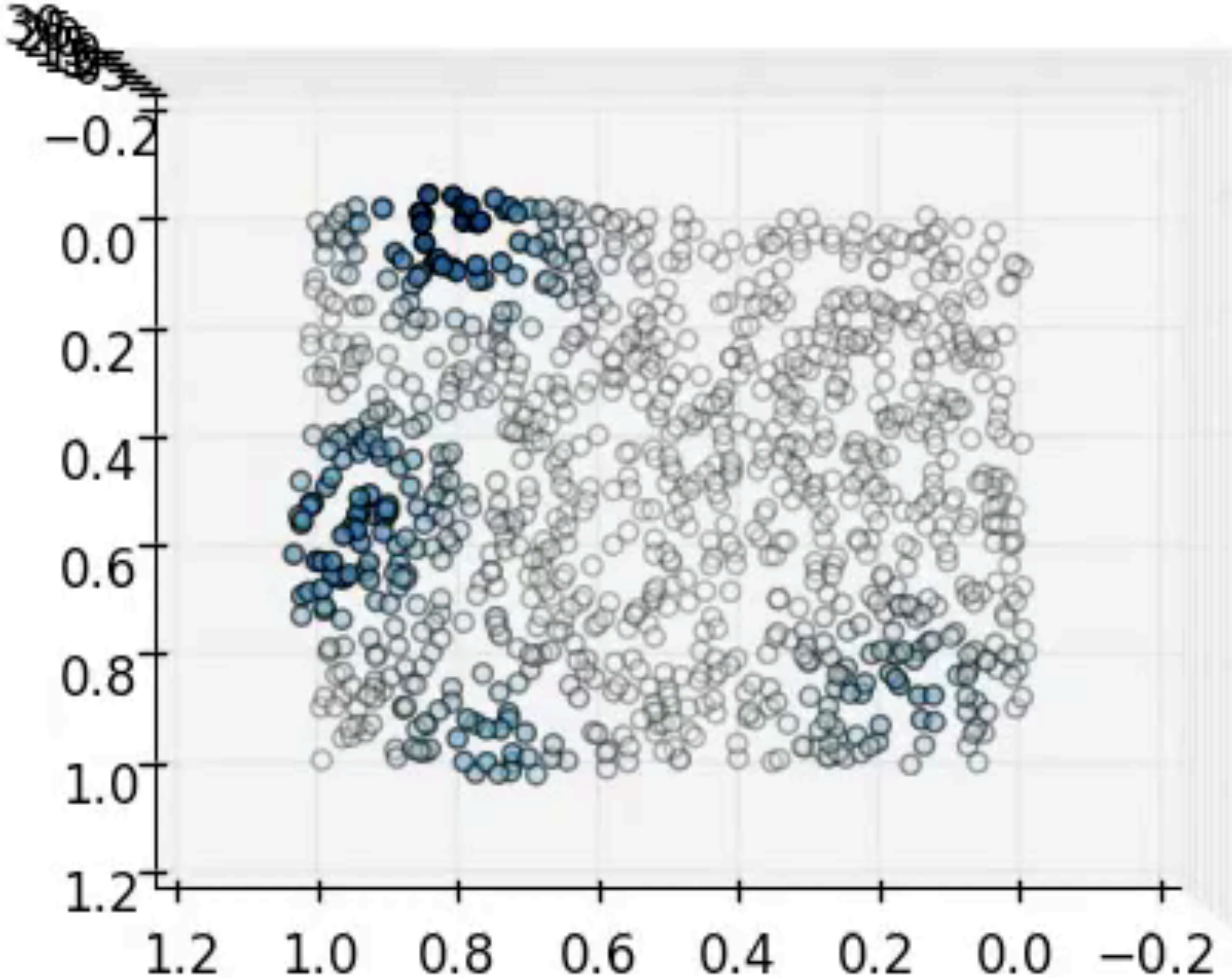

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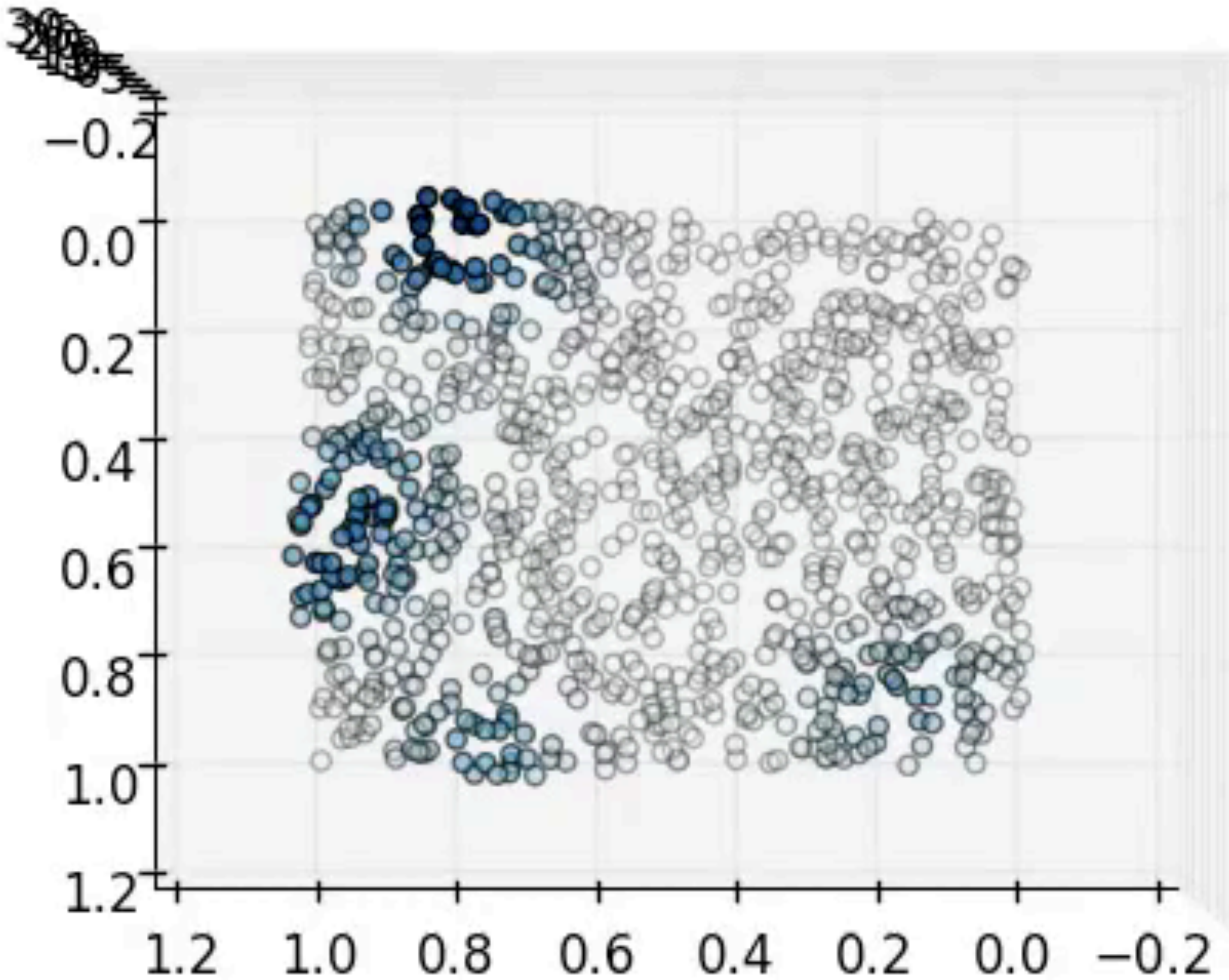

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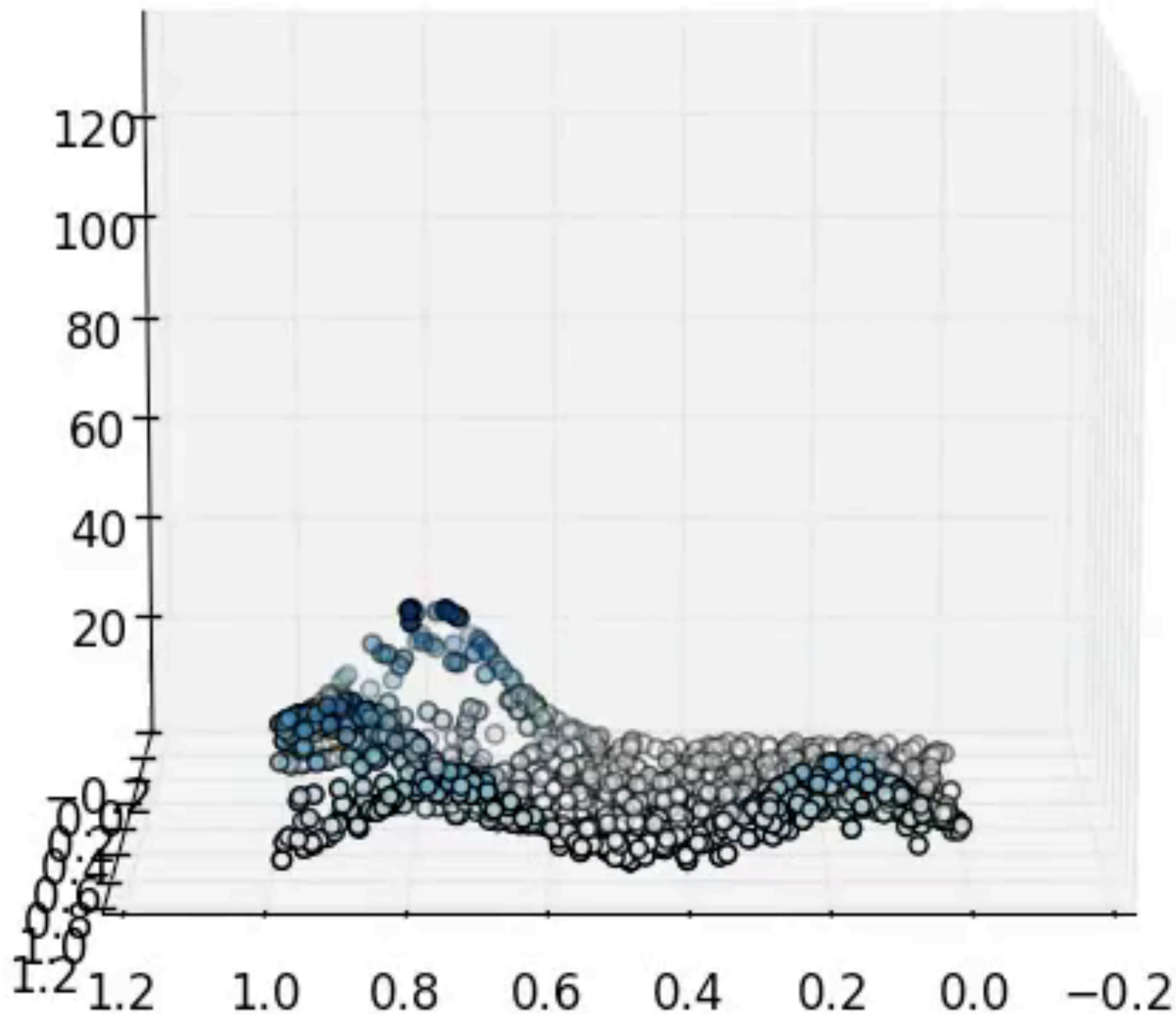

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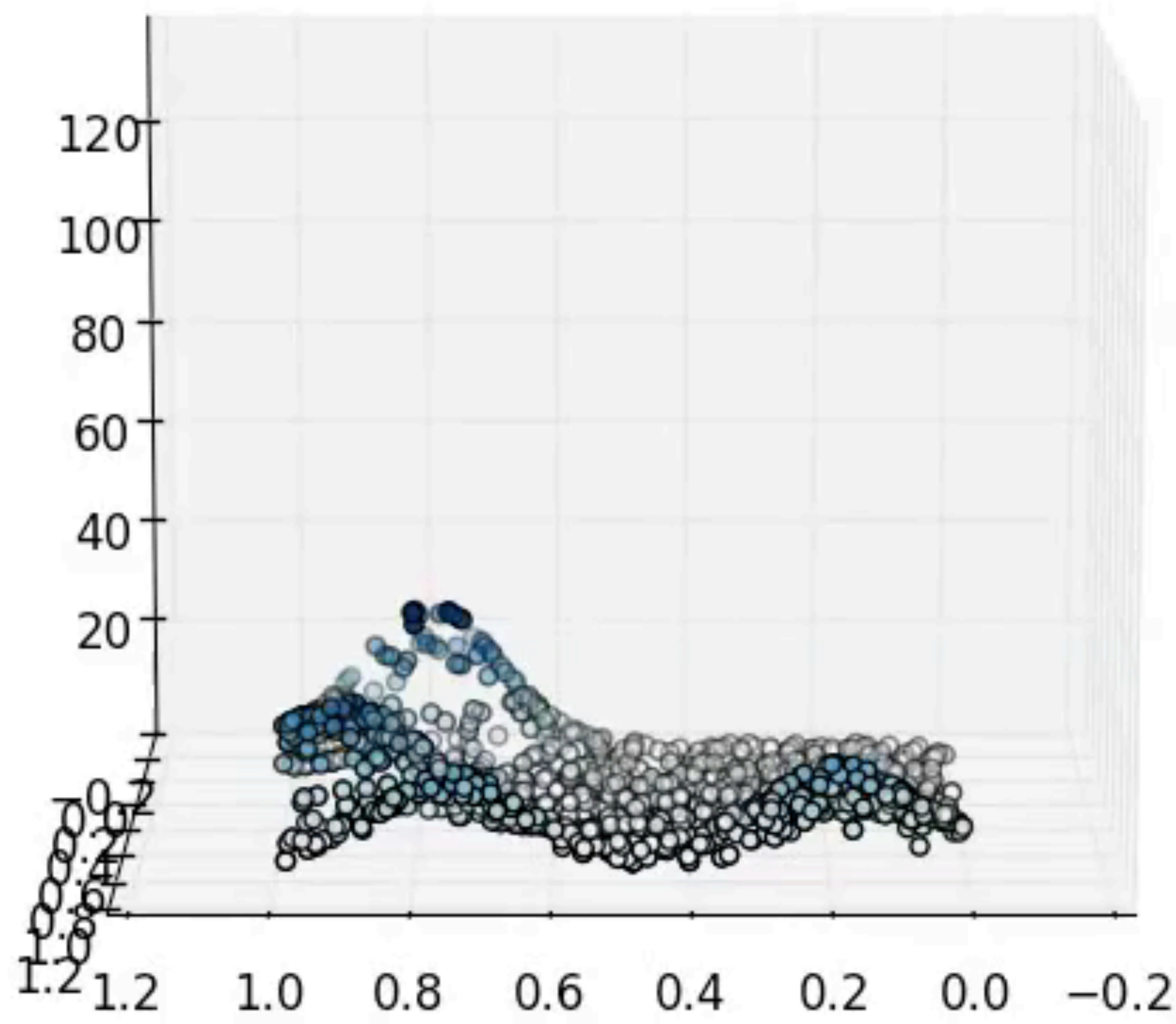

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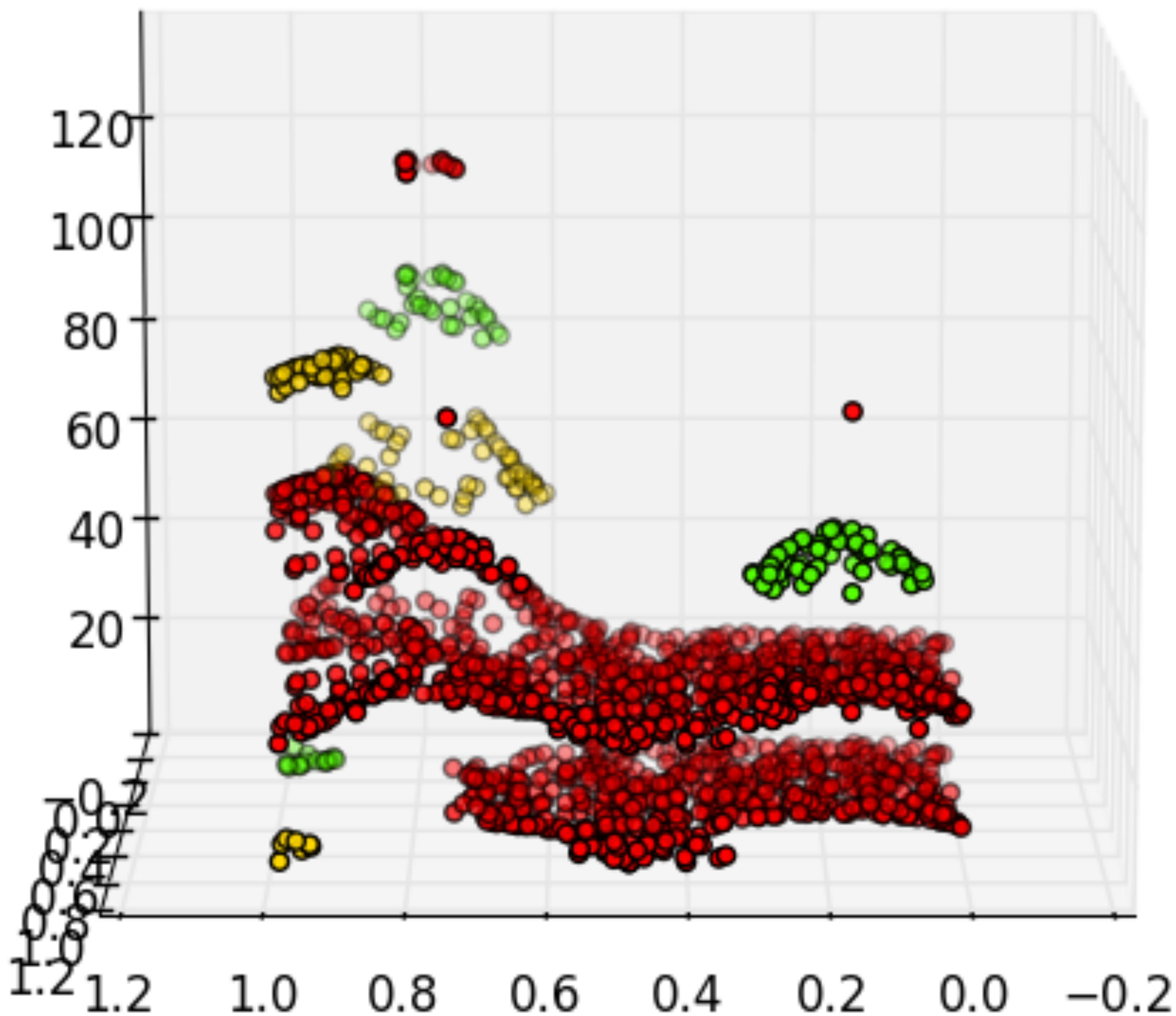

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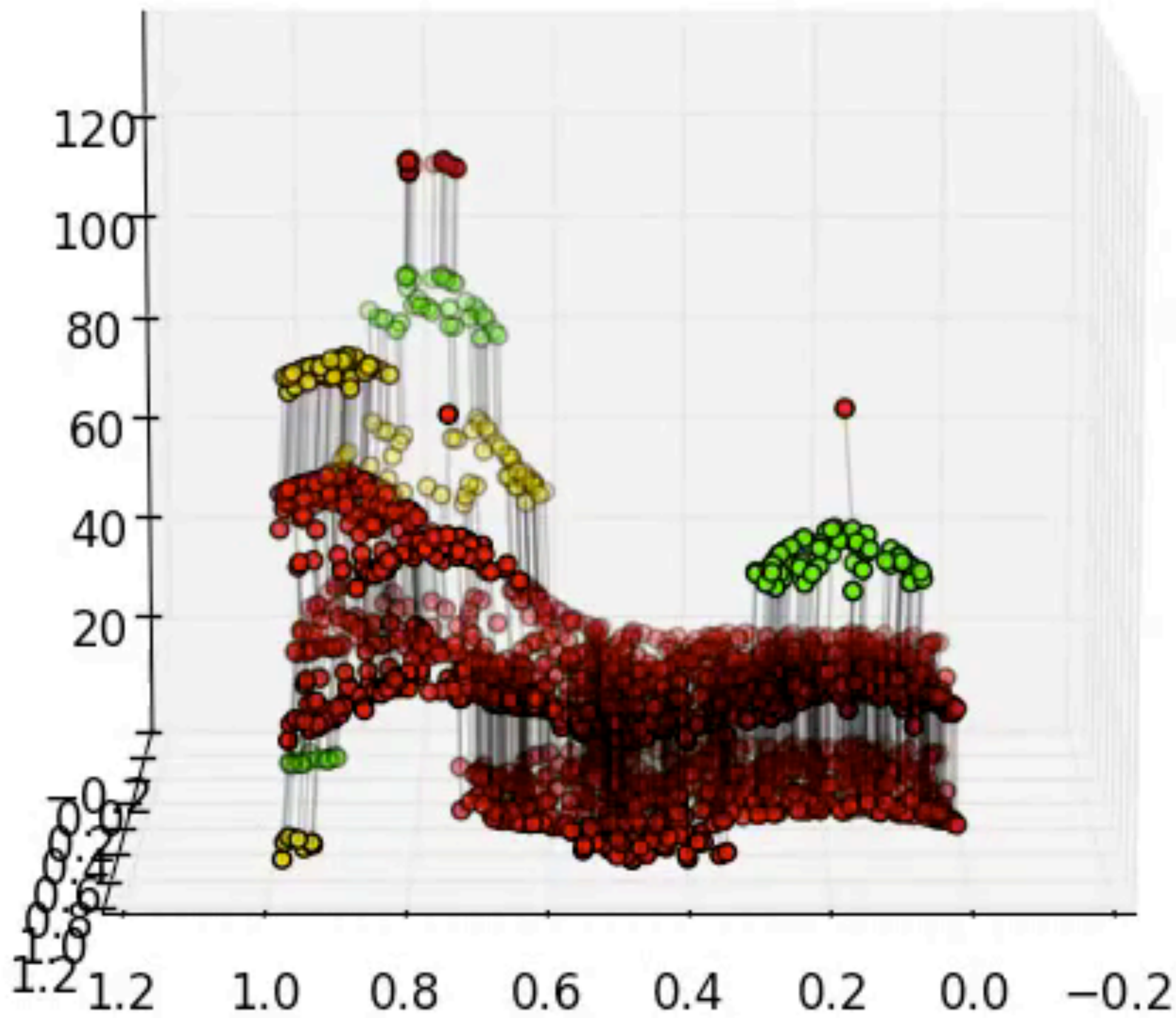
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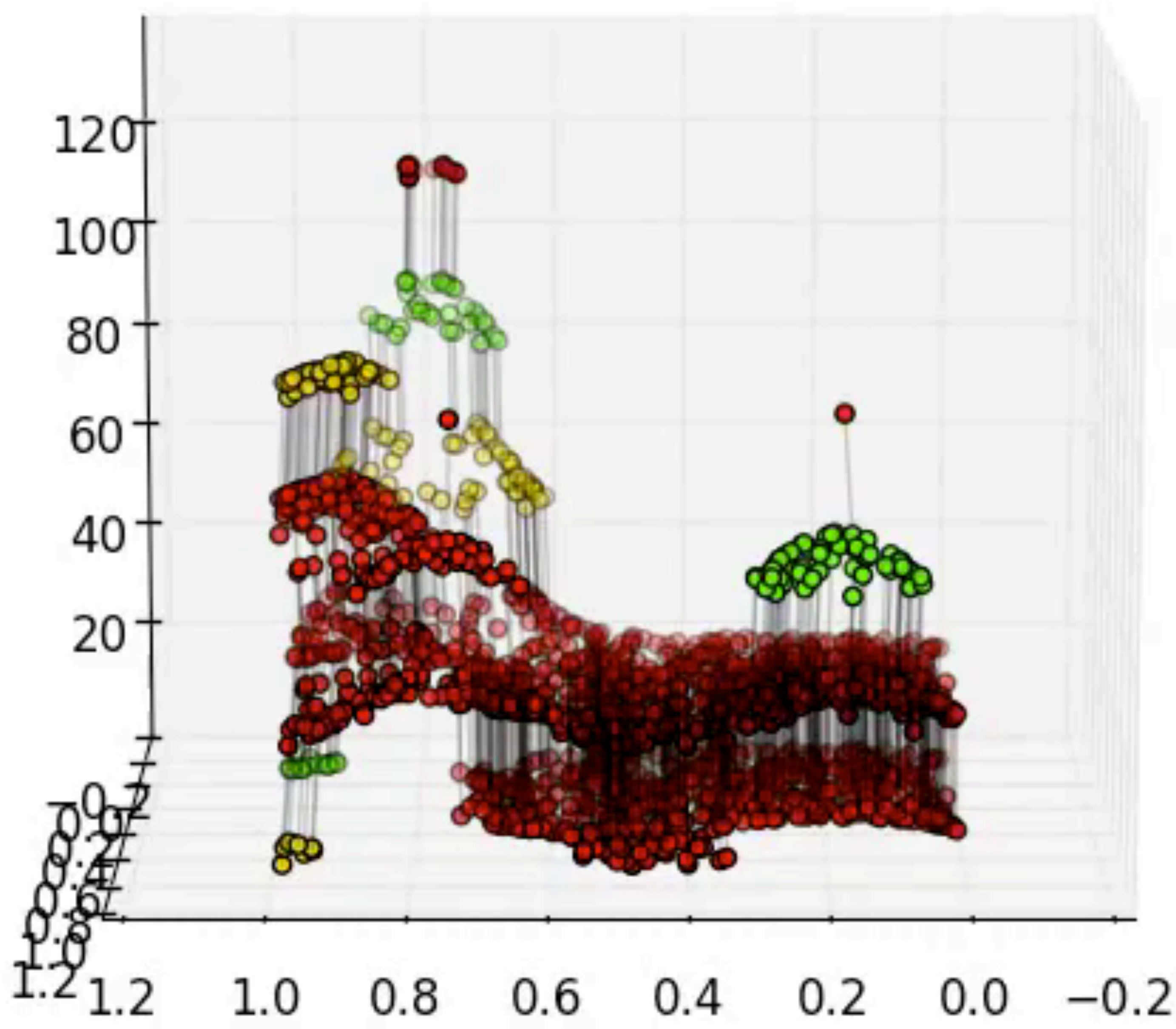

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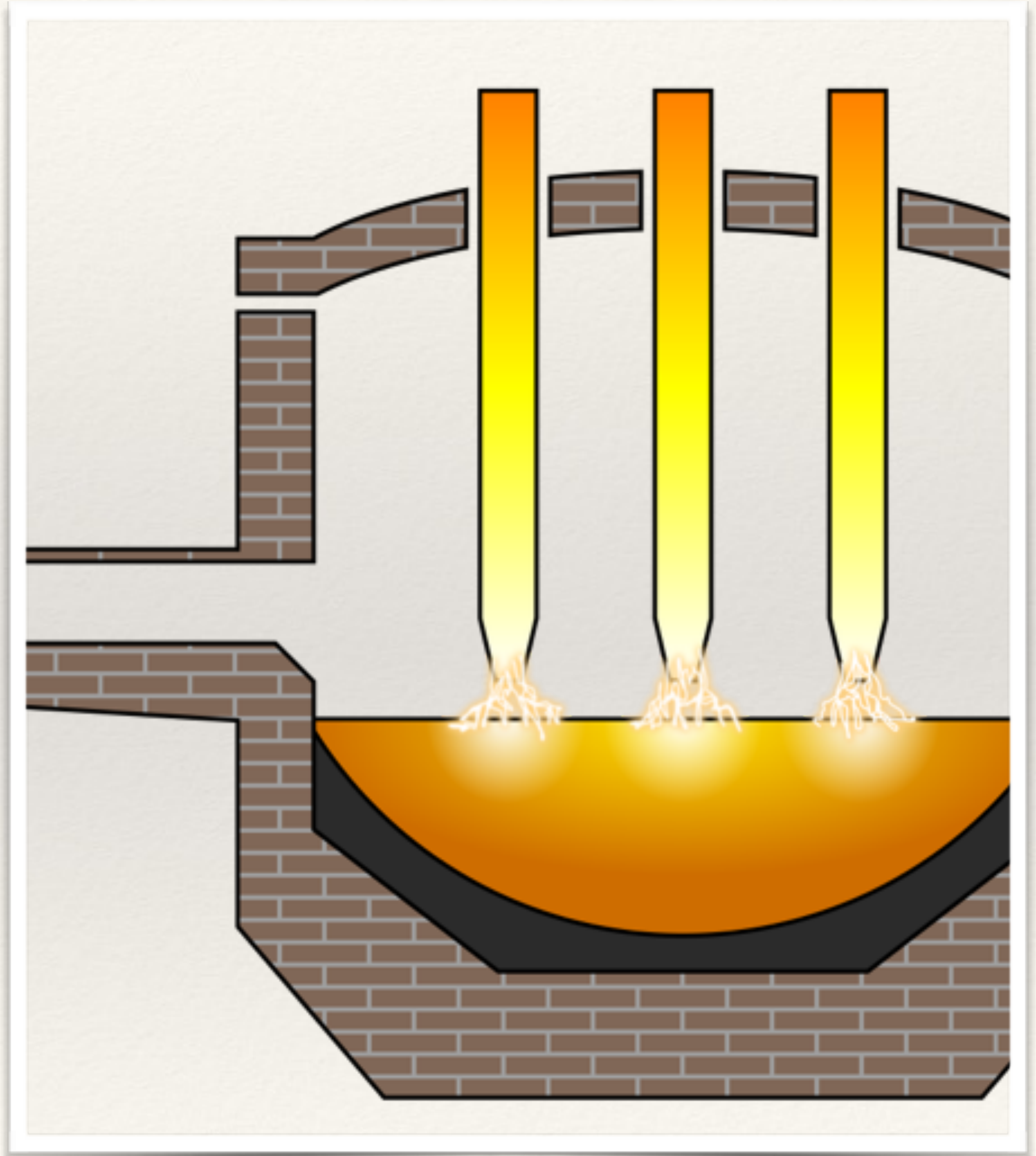
Implementations

- mapper.m
- Ayasdi Core
- PyMapper
- TDAMapper (R)
- mirkoklukas/tda-mapper-py
- MLWave/kepler-mapper

Electric Arc Furnaces

Electric Arc Furnace

- Works by producing electric arcs from electrodes to scrap metal, producing heat that melts the metal.
- Standard 3-phase 220V 50Hz electricity.
- Consumes ~0.4 kWh/kg; theoretical minimum is ~300kWh.



Electric Arc Furnace

- Furnace in Avesta run by Outukumpu Stainless.
- Stainless: expensive scrap, high price output.
- Single charge produces 100 tonnes stainless steel.
- Approximately 5000 charges per year — 15-20 per day.

Furnace picture with permission © Victor Mácha www.facebook.com/VIKTORMACHA.INDUSTRIAL www.viktormacha.com

Temperature constraints

- Optimal temperature ~1600º
- Too low: not fully smelted
- Too high: entire batch spoiled

- Reference measurement possible: single use probe expensive and leaks heat.
- Metallurgical models available. Error spans ±400º. IQR -120º — +18º

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Model parameters

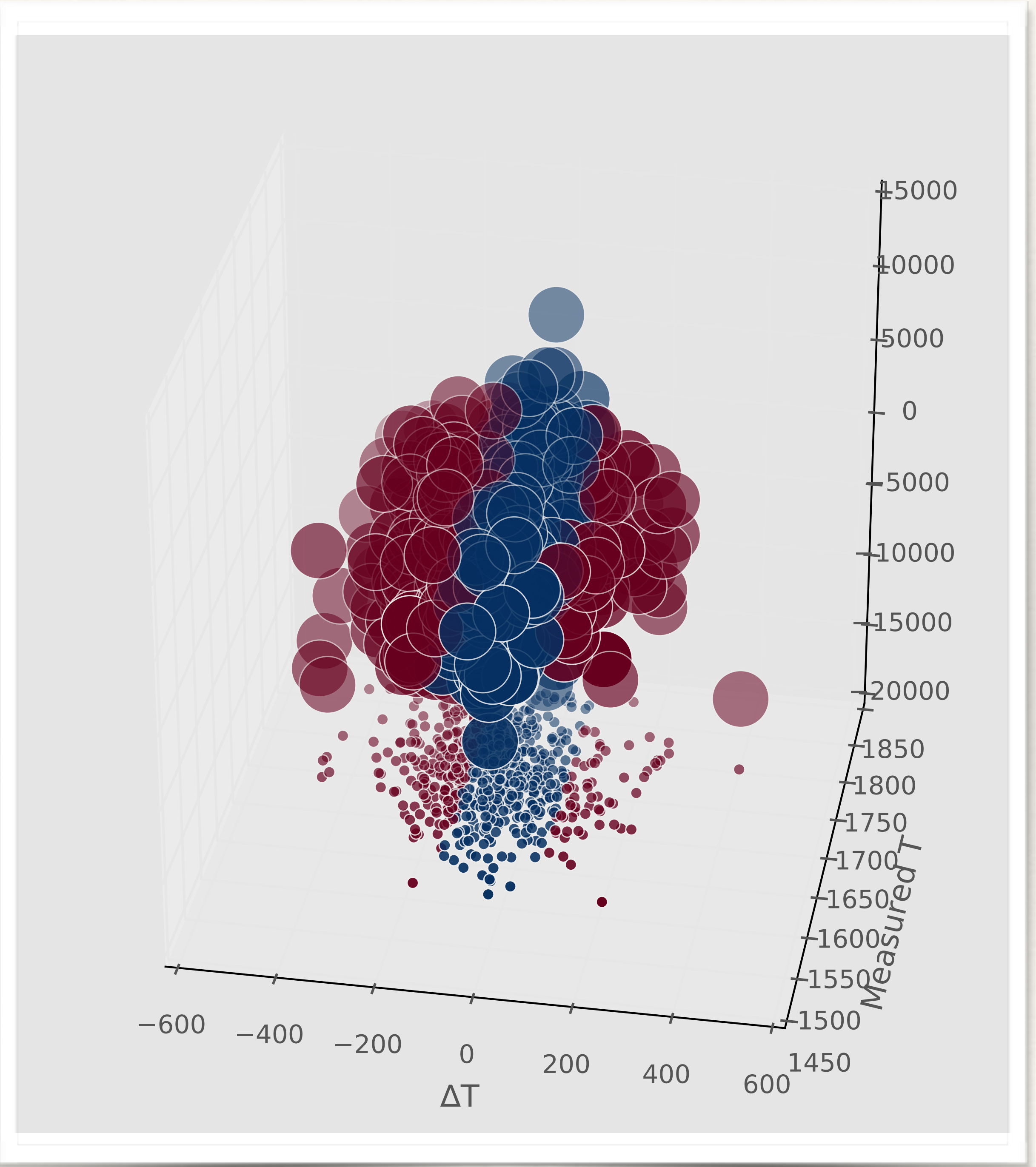
- Known factors at any time point in production:

  Element composition of the scrap
  Energy used
  Temperature of added scrap
  Injected additives: amount & temperature
  Metallurgical model prediction

- **Question:** Can we classify model failure modes, and dynamically recognize them?
  Can we dynamically compensate?

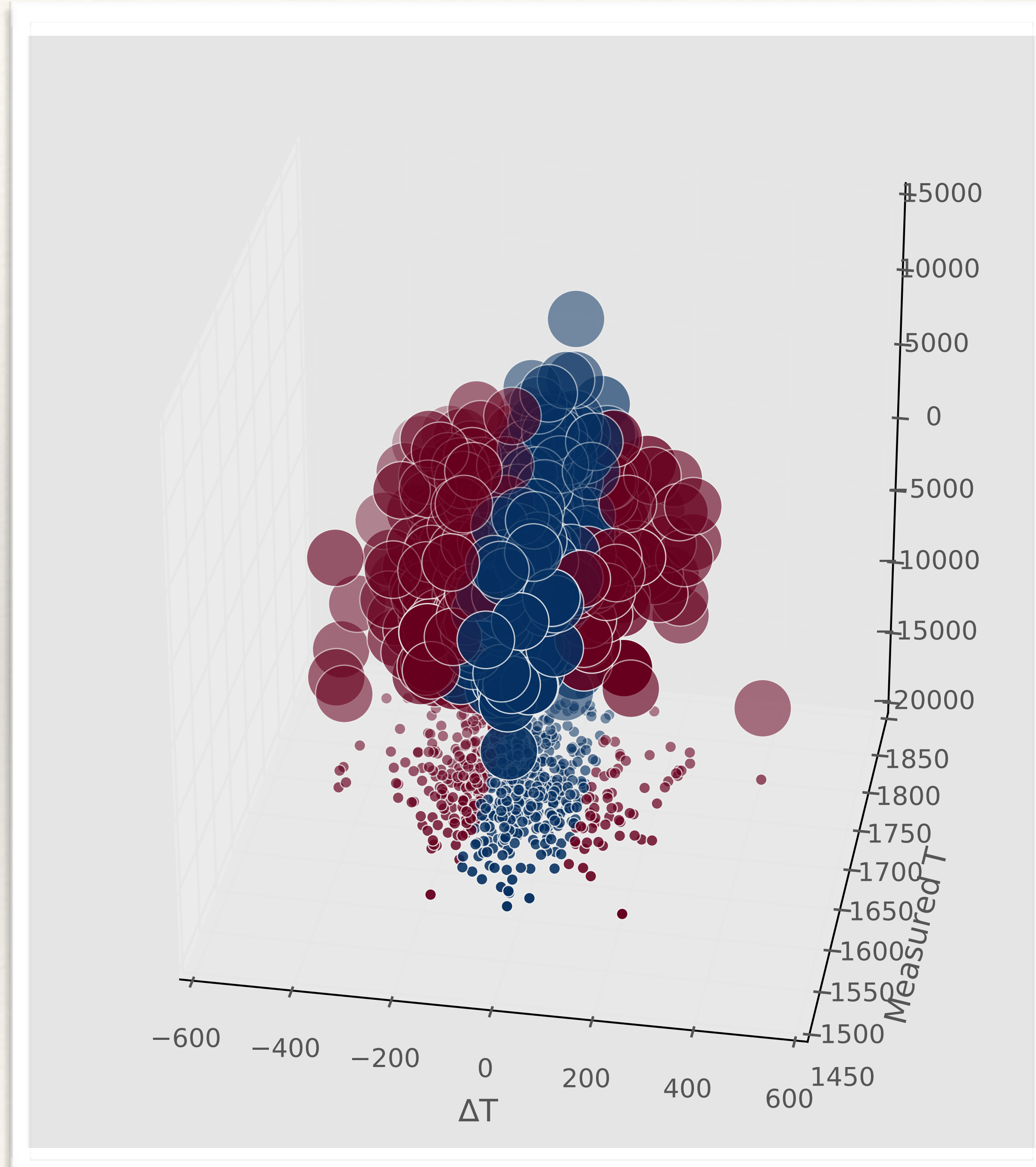
Process diagnostics

Basic idea: Mapper on fibres



Basic idea: Mapper on fibres

- Process model is a function [input data] → [model output]
- Given input data, we can find both measurement [T], prediction [T+ΔT] and prediction error [ΔT].
- Idea: study fibres of the map [input data] → ΔT x T



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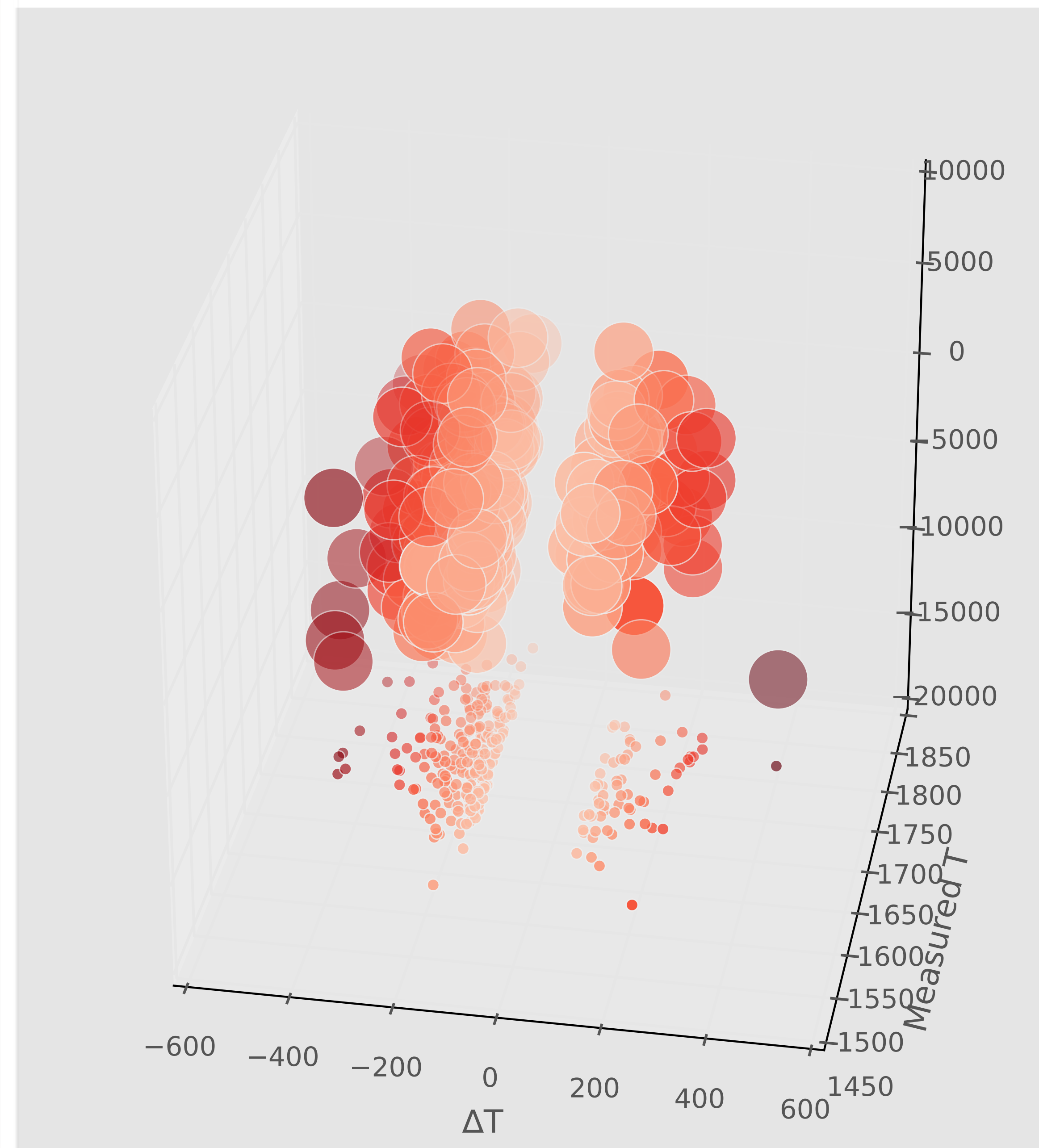
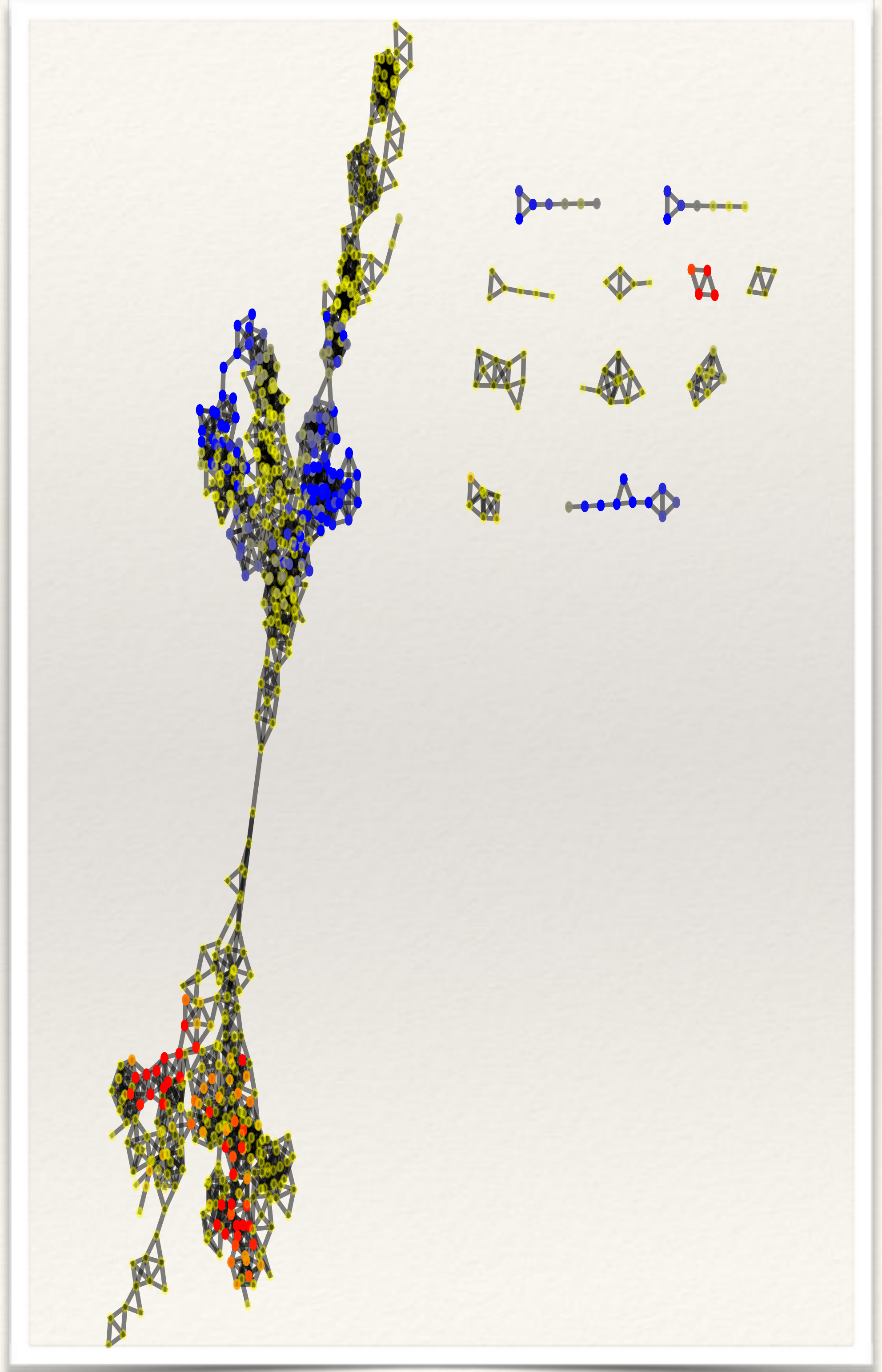
- Esp.: large values of |ΔT|.



Master plan

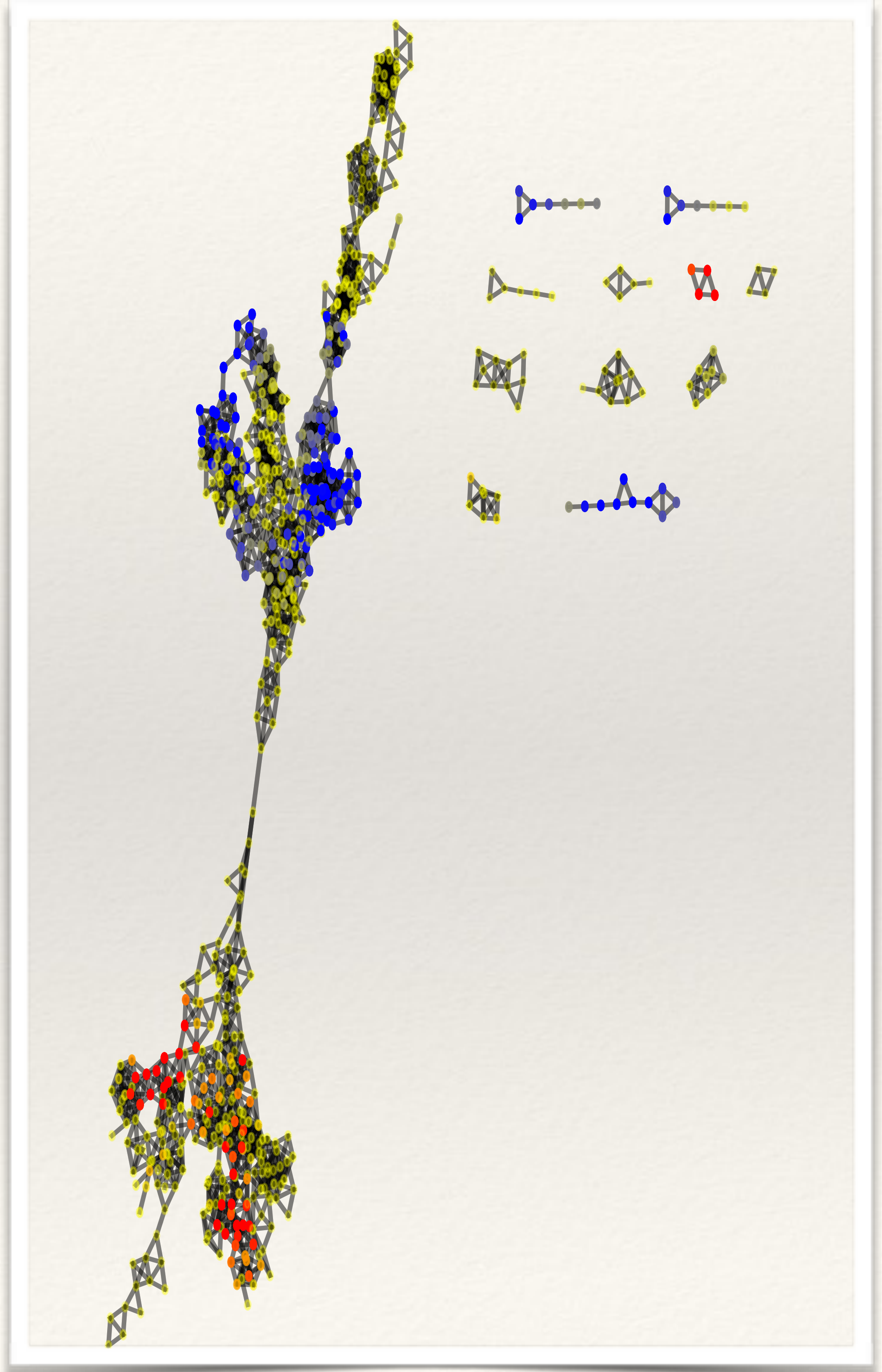
- Flares and features in Mapper
  → classification of fibre shape
- Look for shape of input data over extreme values
- Find failure modes that can be recognized in production
- Test on future data!

The shape of steel



The shape of steel

- Mapper shape from
  Ayasdi Core
  Metric: Variance Normalized
  Euclidean
  Lenses:
  PCA1, PCA2, ΔT, T



The shape of steel

- Mapper shape from
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  Metric: Variance Normalized
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  Lenses:
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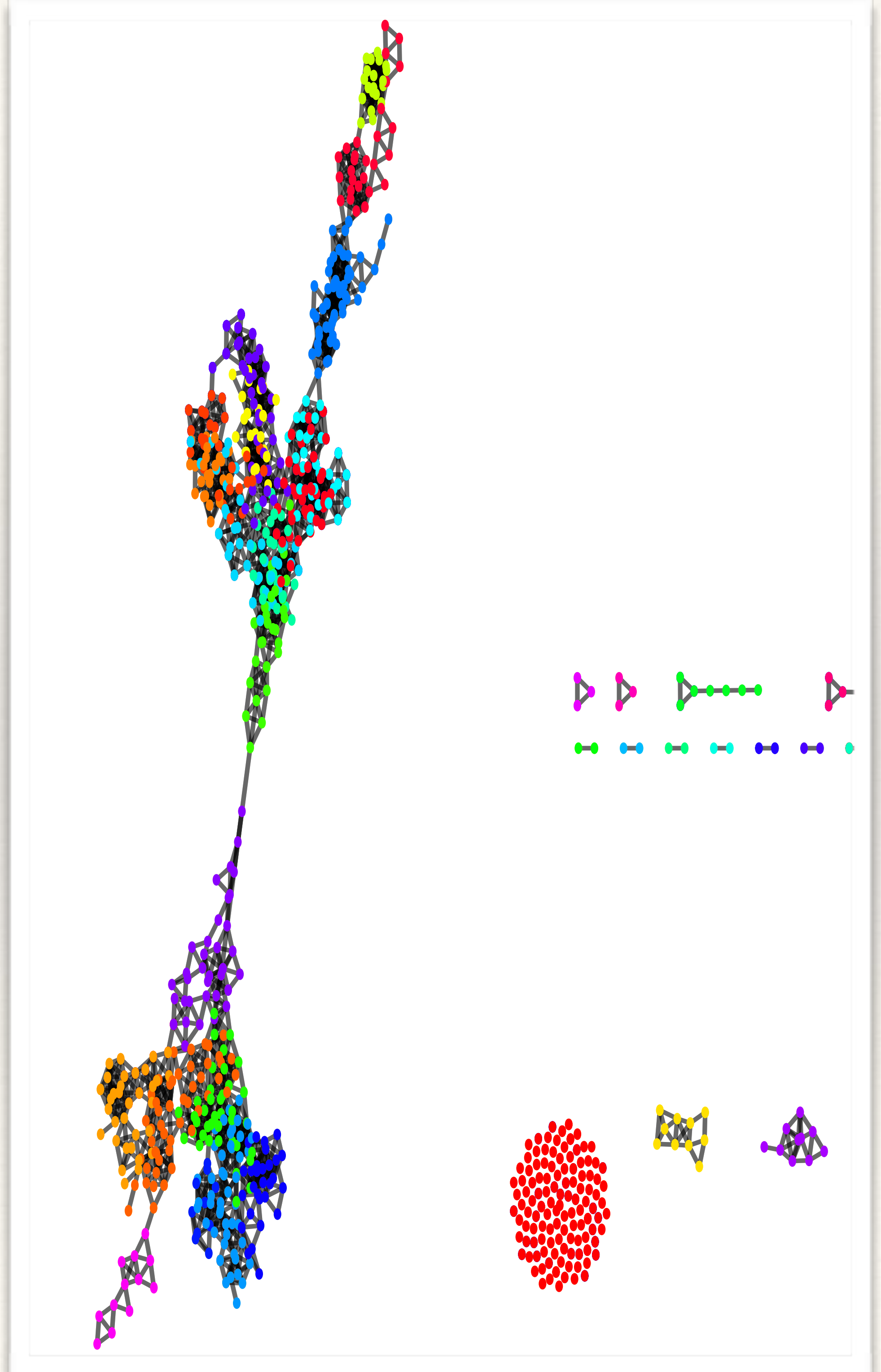
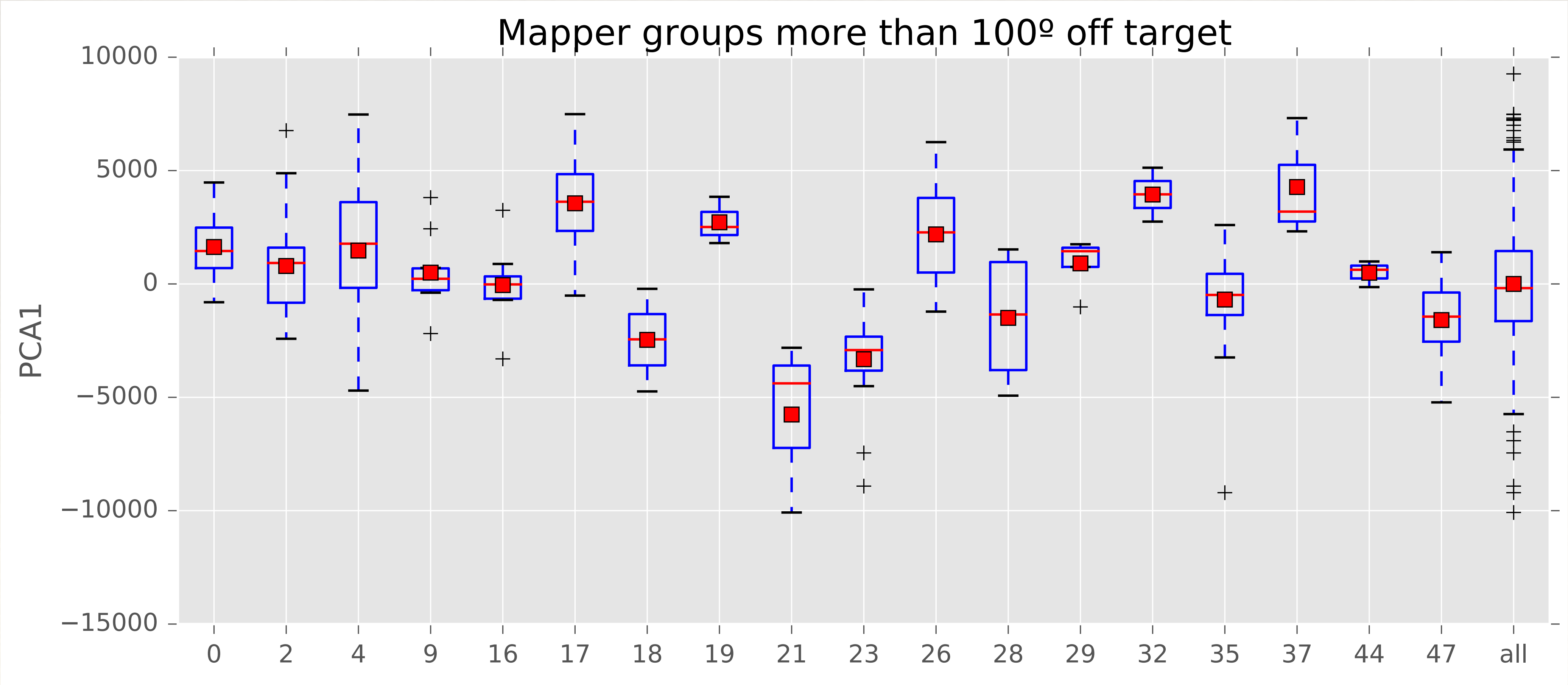
- Core-generated auto-groups.



Find recognizable extremes

- Drop singleton auto groups
- Drop auto groups with any error less than 100º
- Compute global PCA, eyeball distribution of PCA1 among remaining auto groups



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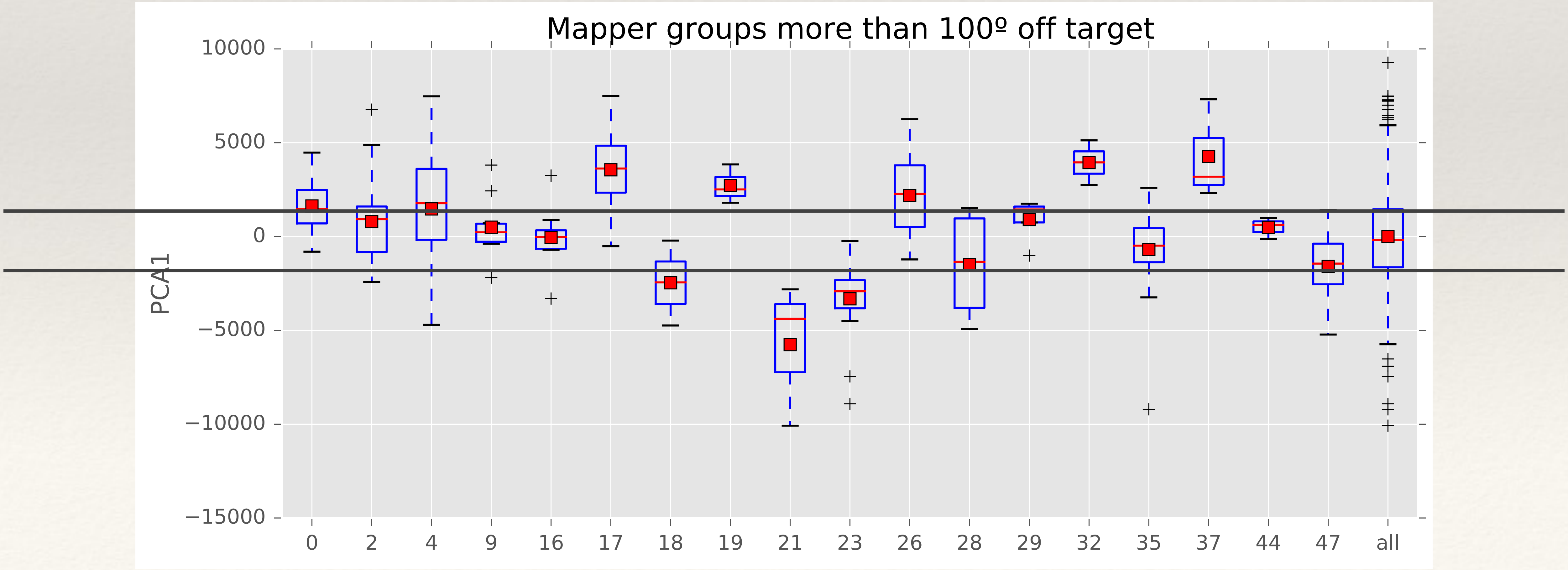

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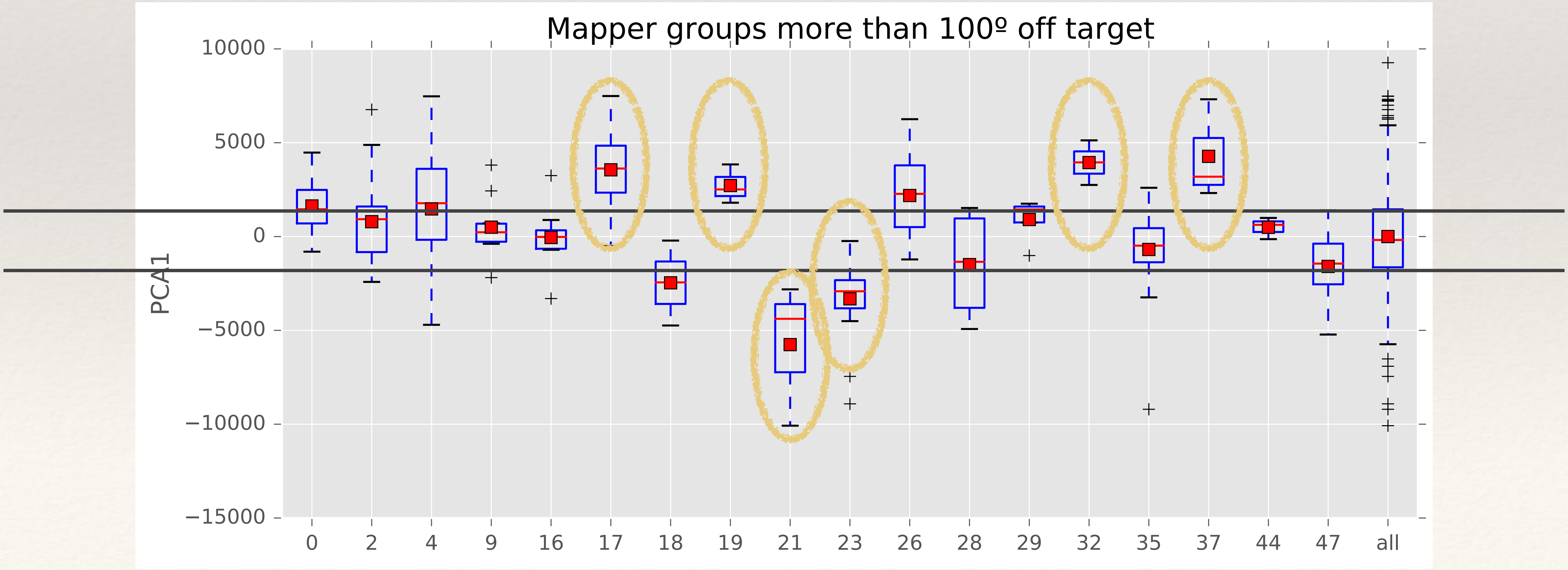
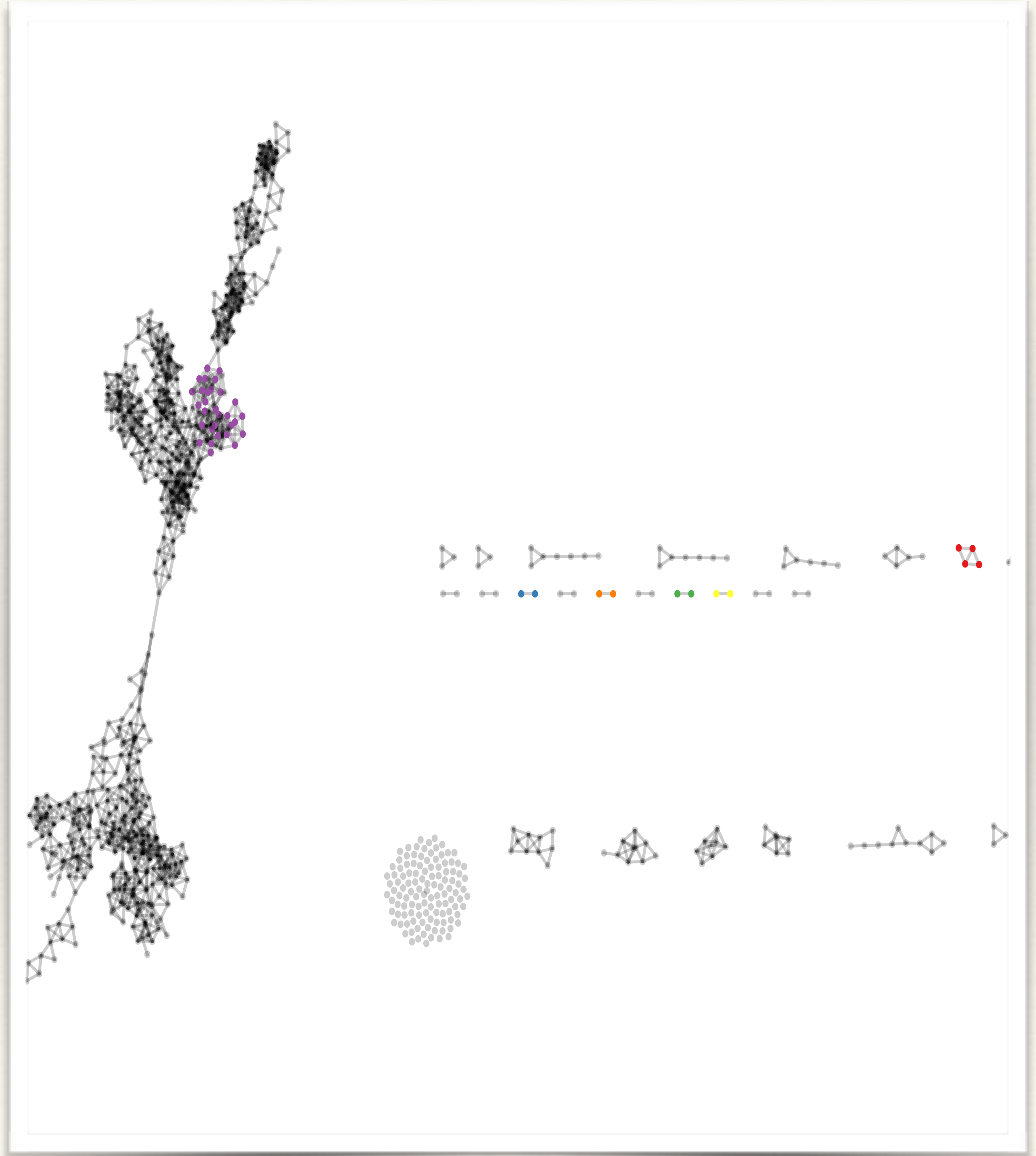


Candidate failure modes

- Auto-generated groups 17, 19, 21, 23, 32, 37.
- Most are very small. Group 23 bigger.
- **Question:** Can we detect membership in Group 23?



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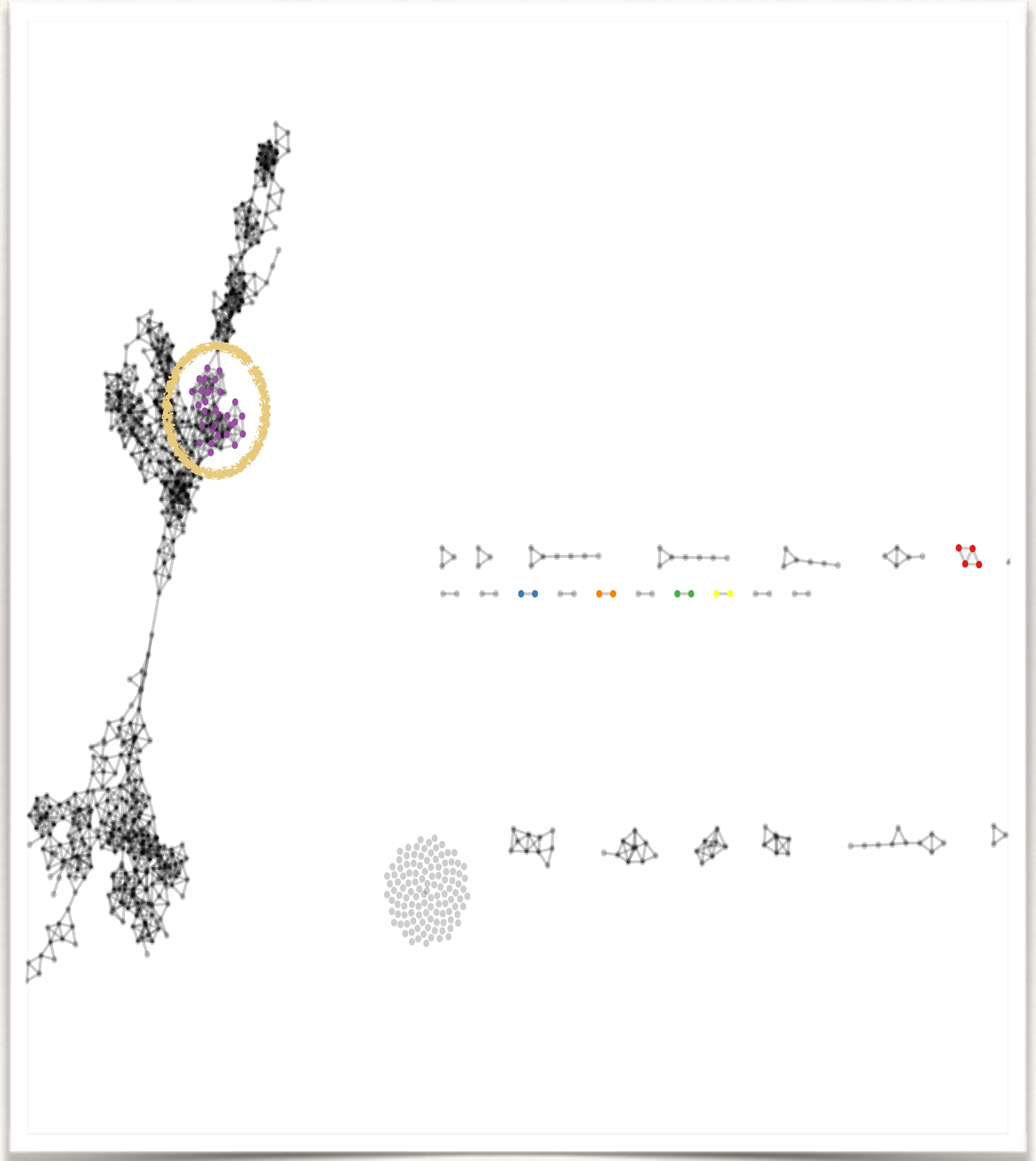
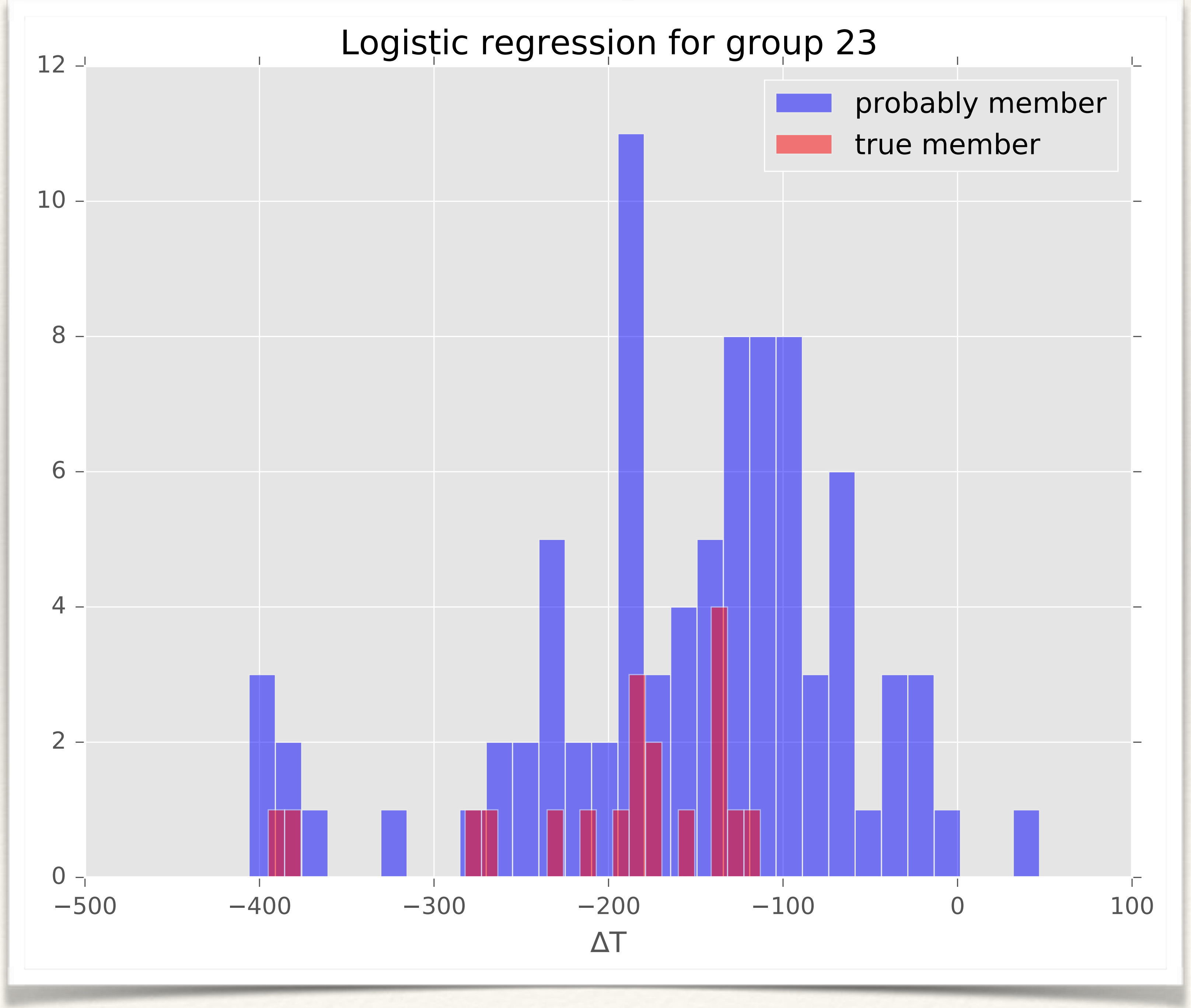
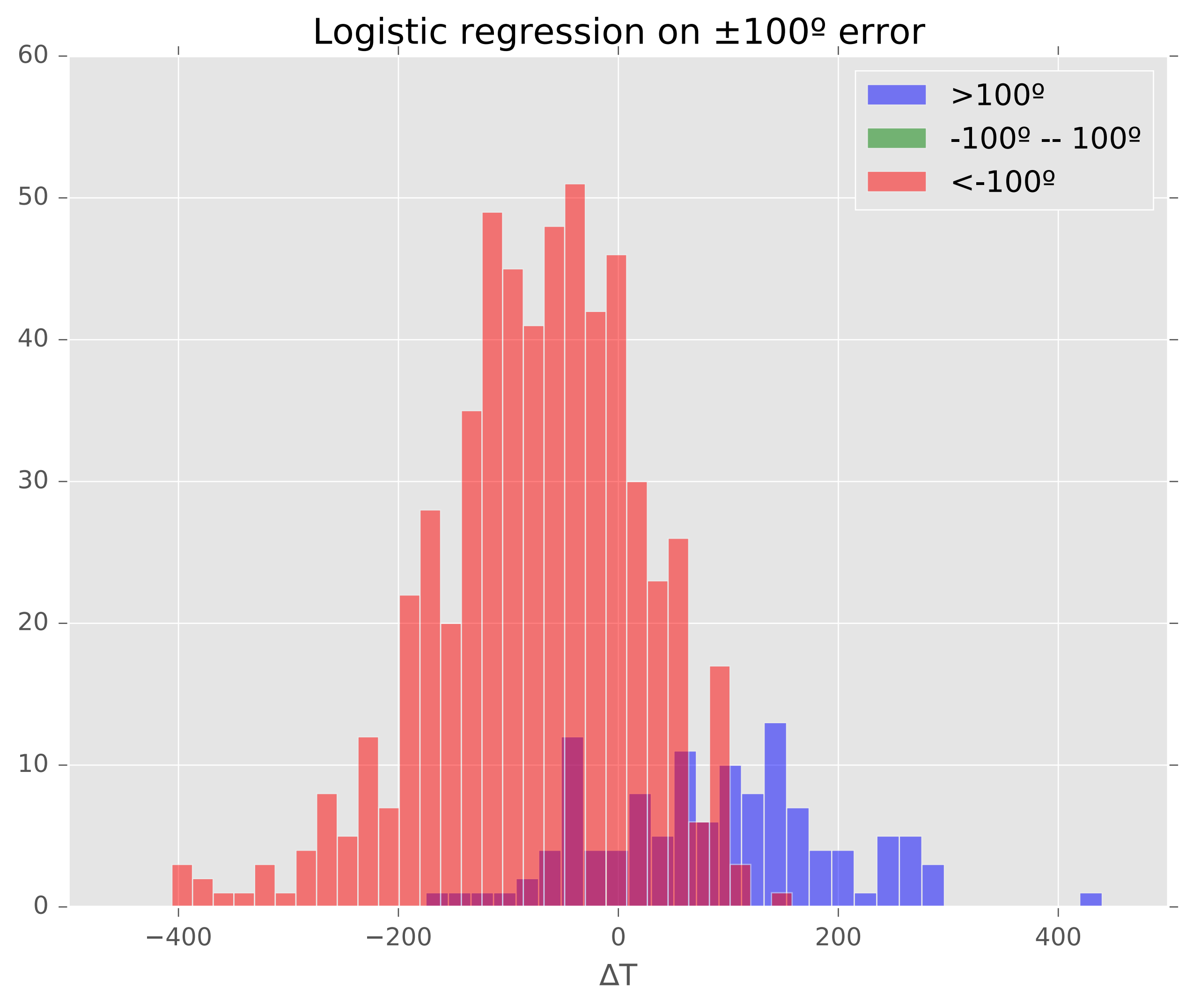


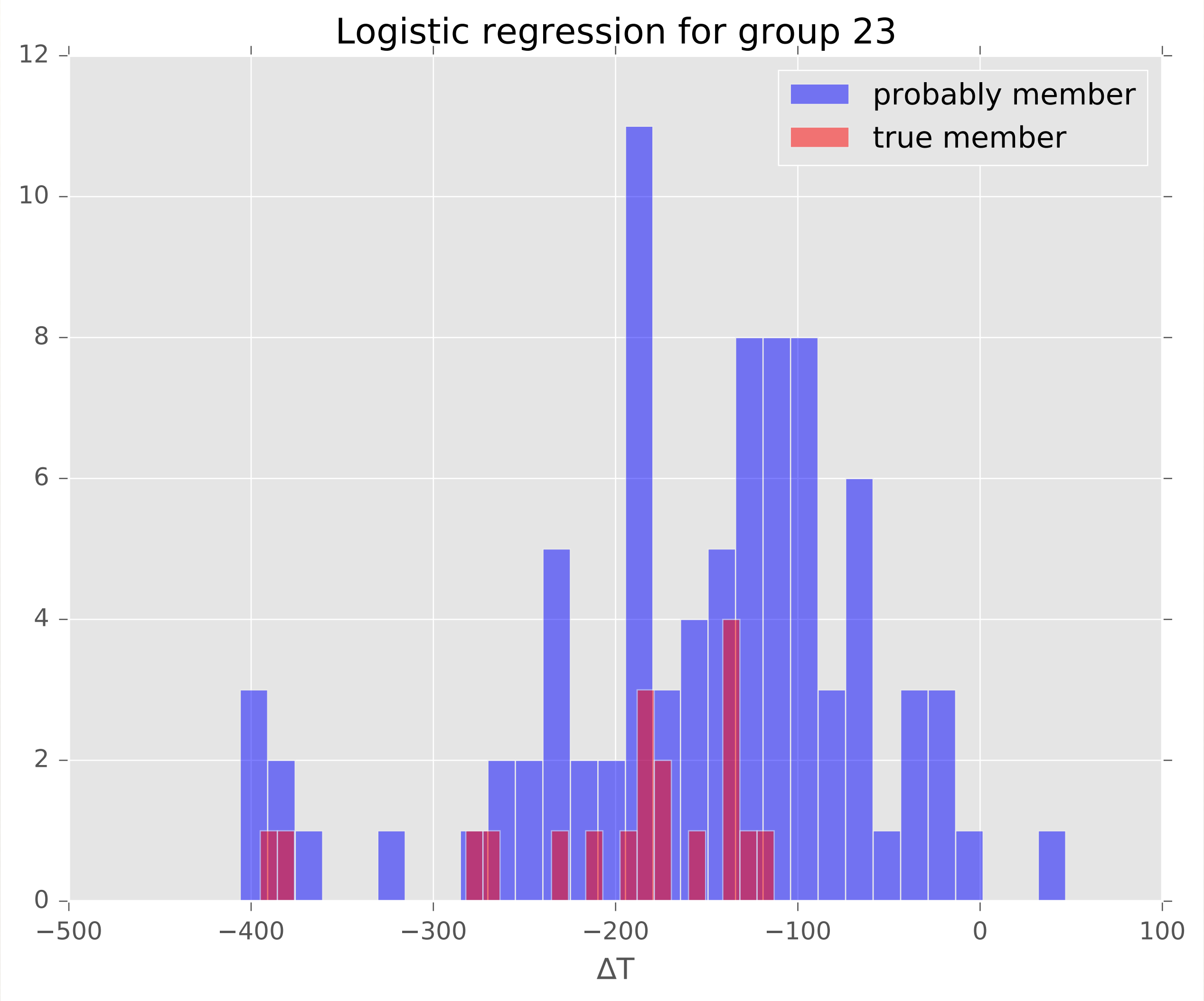
Membership detection, 23

- Logistic regression, class-balanced sampling
- A **lot** of false positives.
- Probably improves with better classifiers.
- Certainly improves with more data.
- Already somewhat useful results.



Why not just do naive regression?





- Far fewer false positives

Where do we go from here?

- Collect more data
- Validate these classifiers
- Test other possibly better classifiers

- Analyze the sound of the furnace:
  frequency spectra correspond to smelting stages
  use Mapper to find recognizable smelting modes?


Thank you for listening