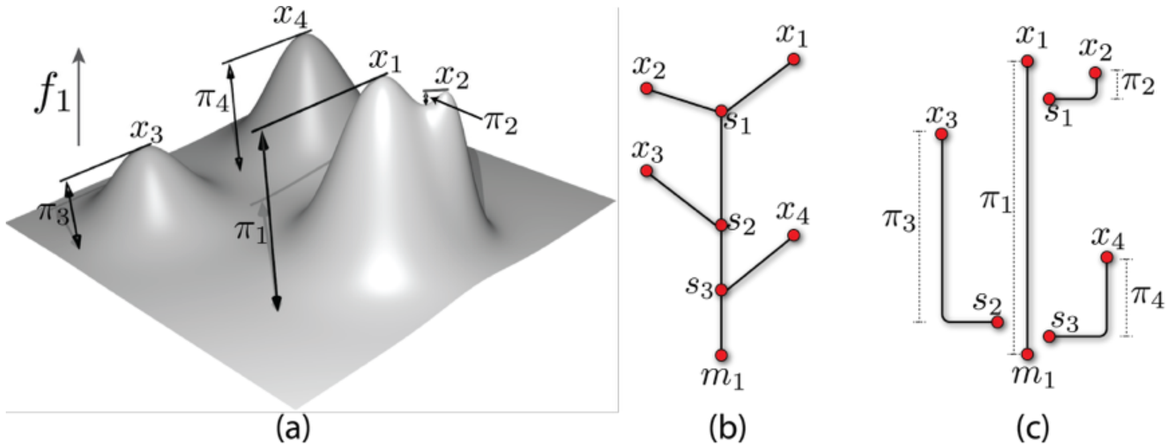
Using Maximum Topology Matching to Explore Differences in Species Distribution Models



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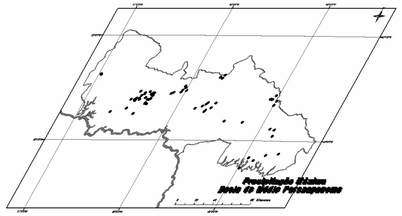
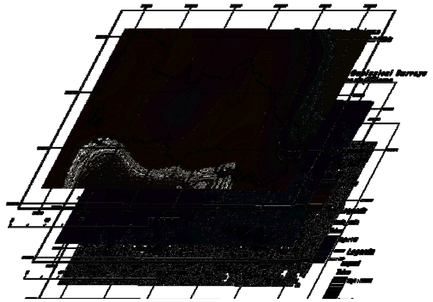
USGS science for a changing world

Species Distribution Models (SDM)

Observations



Environmental layers



Algorithm

Geographic position

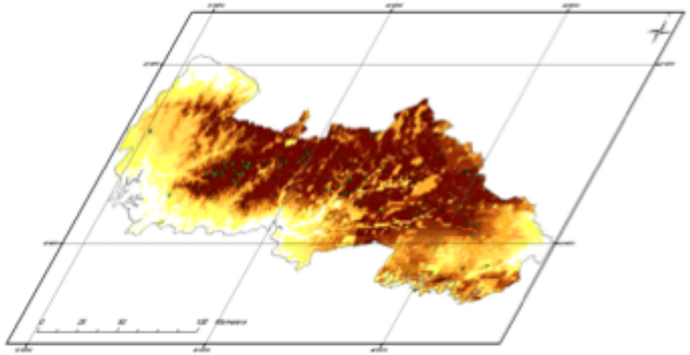
Temperature

Precipitation

Topography

NDVI

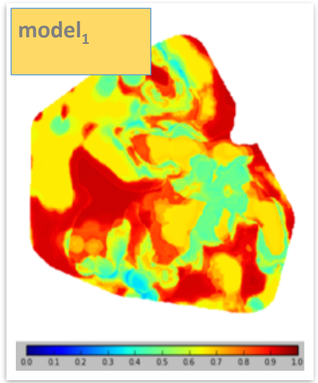
Predictive distribution

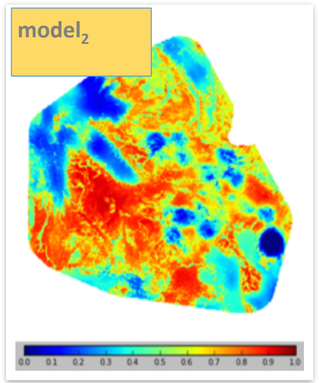


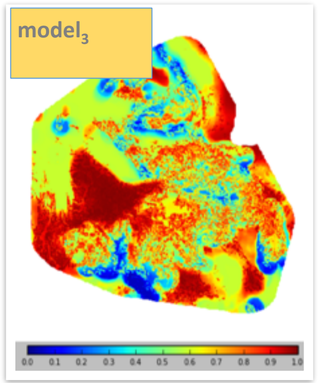
$$f : \mathbb{R}^d \rightarrow [0, 1]$$

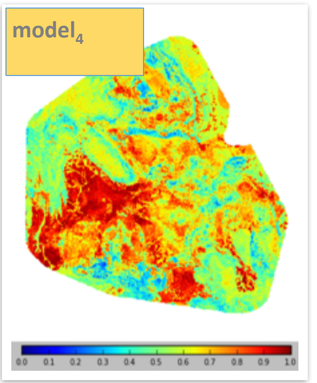
Model Inter-comparison

Predict Distribution









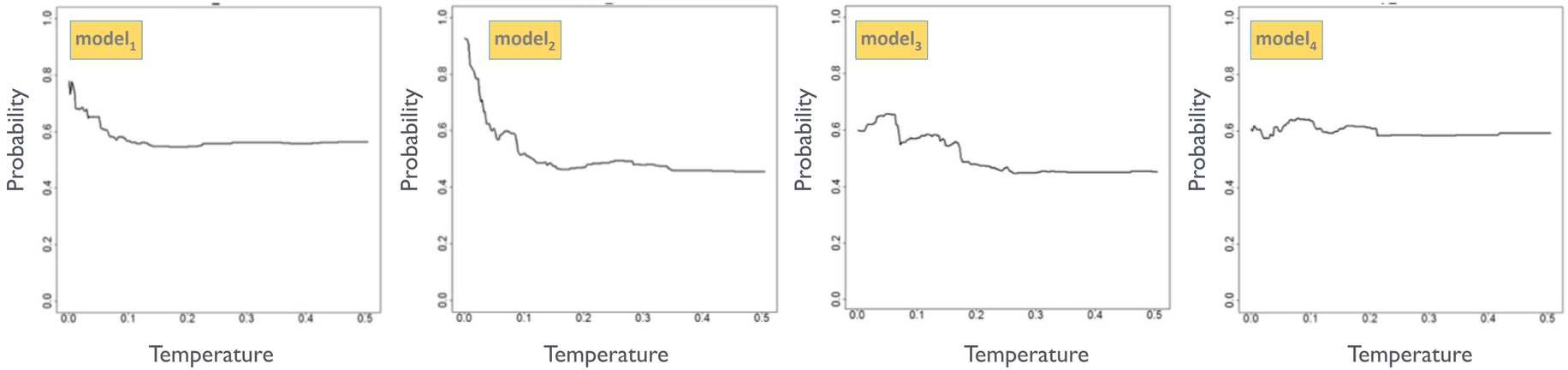
Why are they different?
How do we compare them?

Ecologist's Approach

Visualize one-dimension at a time (default response curve)

Predictors

Temperature	[0, 0.5]
Precipitation	mean
Topography	mean
NDVI	mean
…	…



SHORTCOMINGS:

- Restricts the analysis to one dimension at time
- Interaction between dimensions are lost because of dimensionality reduction

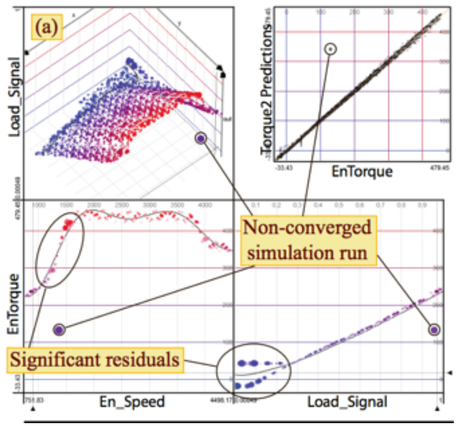
Goals

- **Explore** SDMs in the high dimensional domain
- **Compare** different SDMs

Our approach is to use the **topology of SDMs** for exploring and comparing them

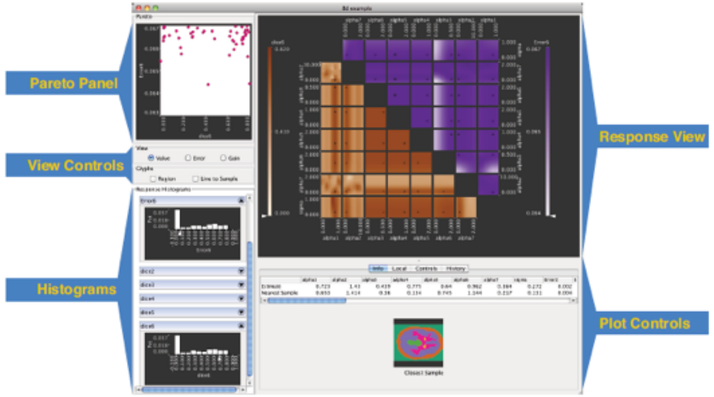
Challenges: Exploring High Dimensional Functions

[HyperMoVal]



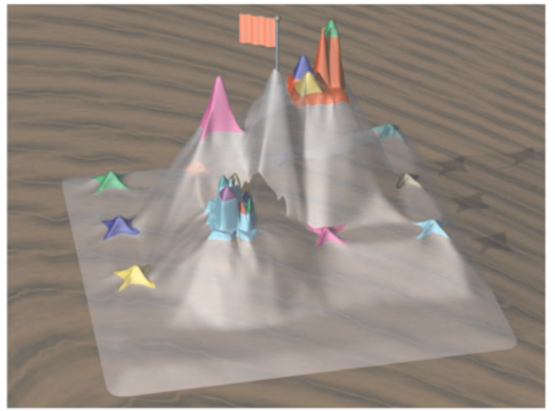
[Piringer et al. 2010]

[Tuner]



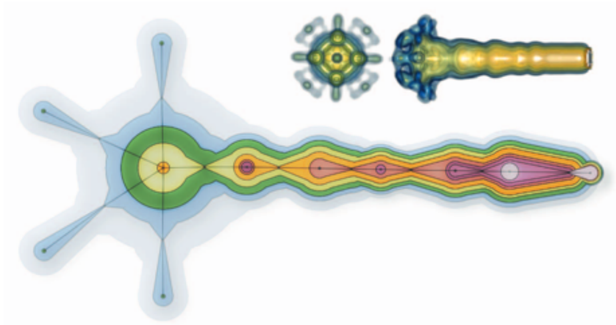
[Torsney-Weir et al. 2011]

[Topological Landscape]



[Weber et al. 2007]

[Topological Spines]

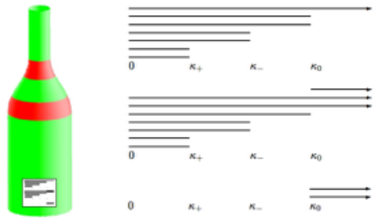


[Correa et al. 2011]

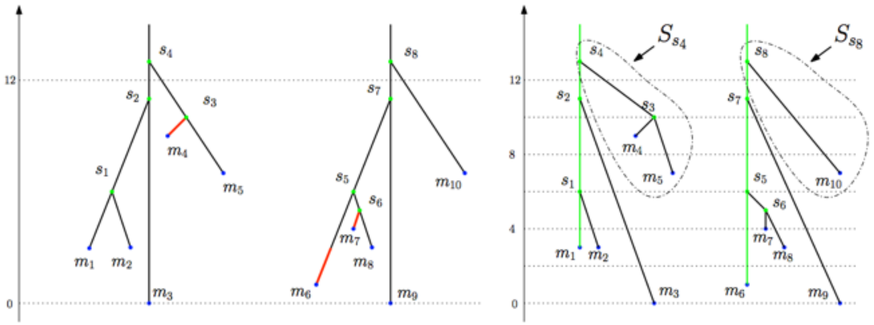
- Shortcoming:
  - Require to manually explore and compare two high dimensional spaces

Challenges: Comparing Scalar Functions

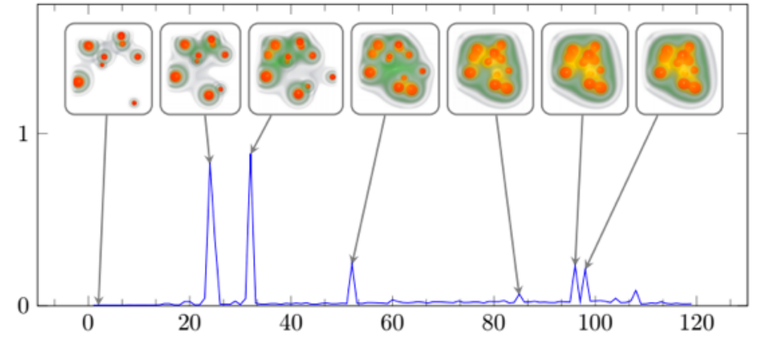
- Existing work:
  - Distance between visual representations of topological persistence
    [Carlsson et al. 2004][Cohen-Steiner et al. 2007]
  - Distance between topological data structures
    - Merge trees / Reeb graphs
      [Morozov et al. 2013][Beketayev et al. 2014][Bauer et al . 2014]
    - Extremum graphs
      [Narayanan et al. 2015]
- Shortcomings:
  - Location of critical points not considered
  - Similar features can be far away



[Carlsson et al. 2004]

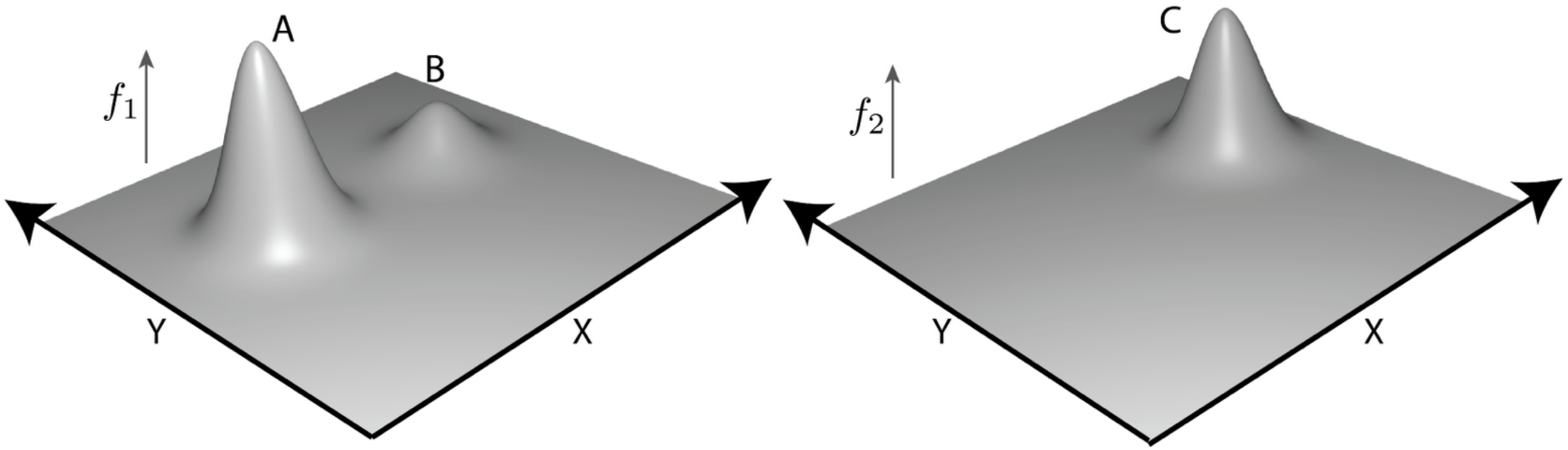


[Beketayev et al. 2014]



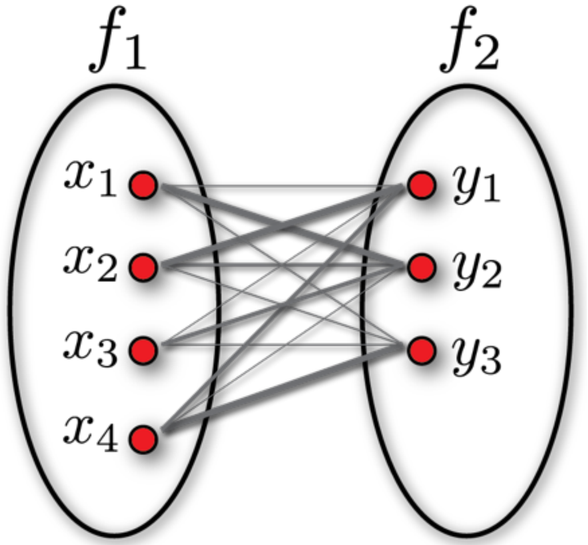
[Narayanan et al. 2015]

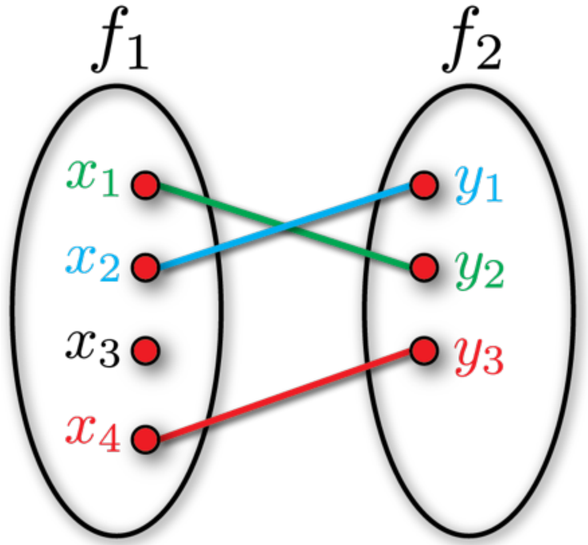
Motivation



Is there a way to compute a locality-aware similarity measure?

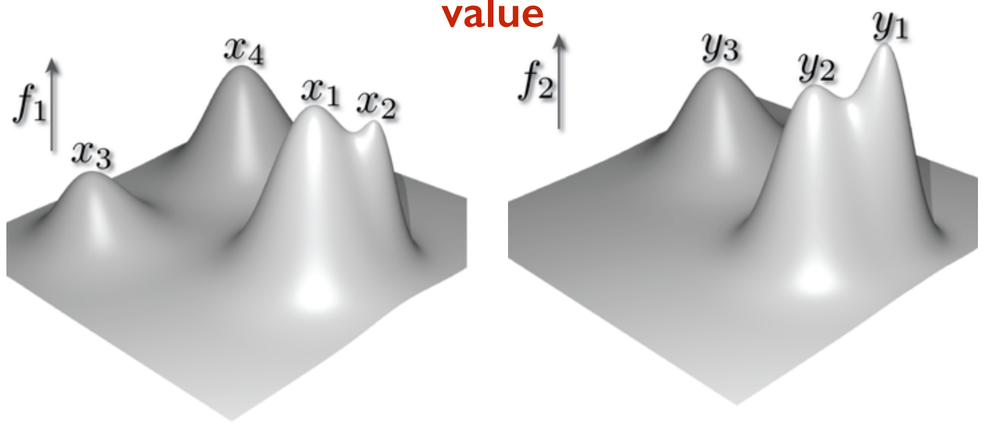
Maximum Topology Matching

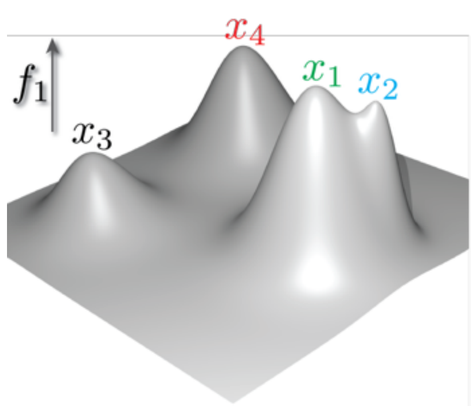


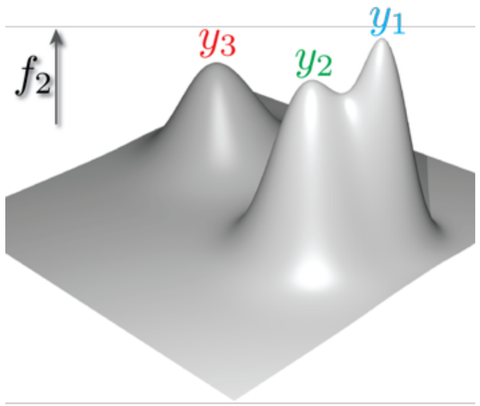


$$w_{a,b} = (1 - \delta_{a,b}) e^{\frac{d_g(a,b)}{r^2}}$$

function value — locality

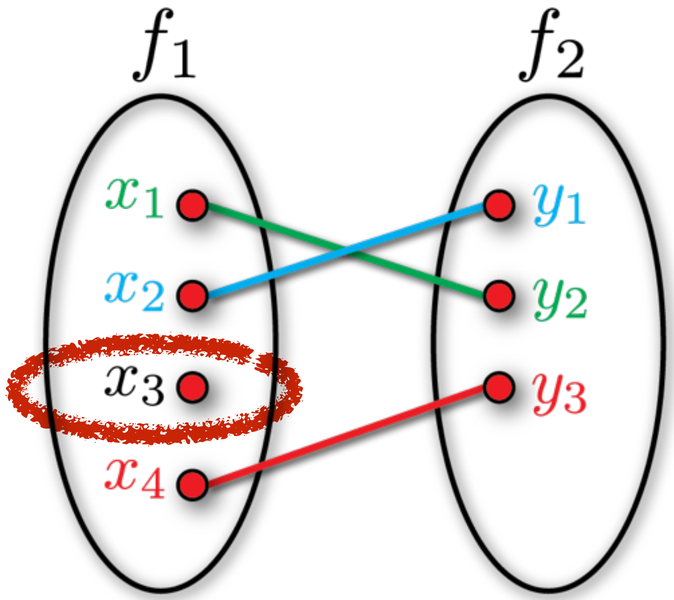


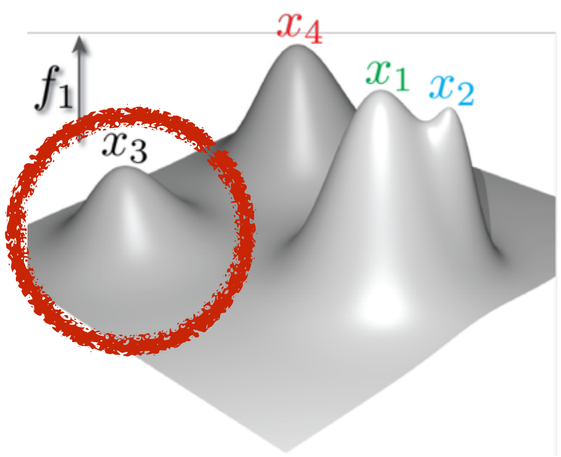


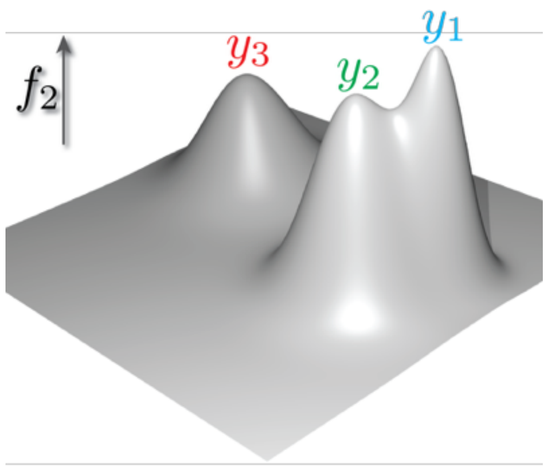


Topological Similarity

Intuition: It is the minimum simplification required to obtain a perfect matching between two functions







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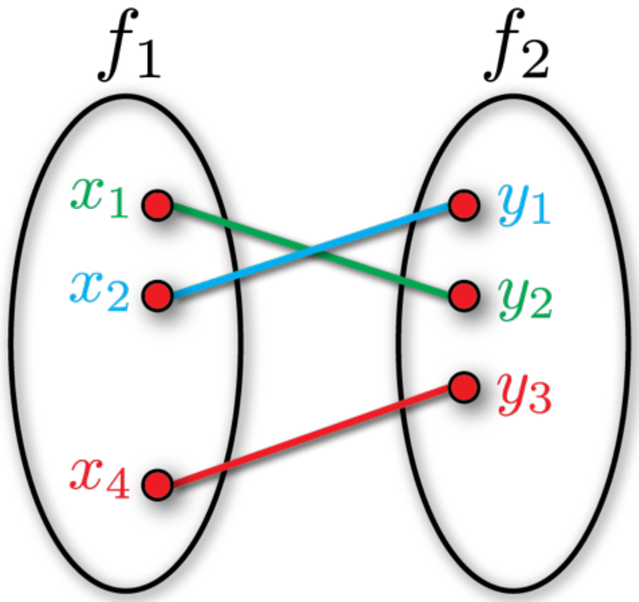
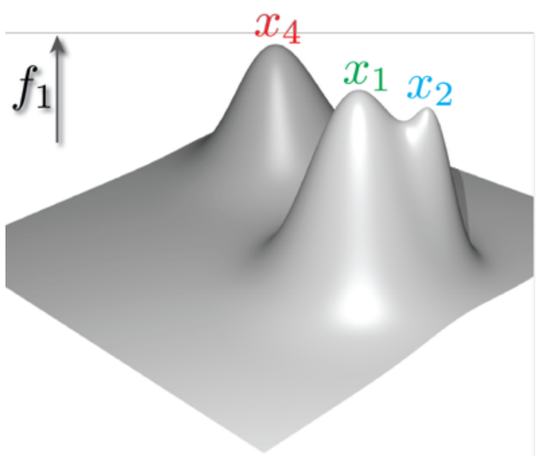
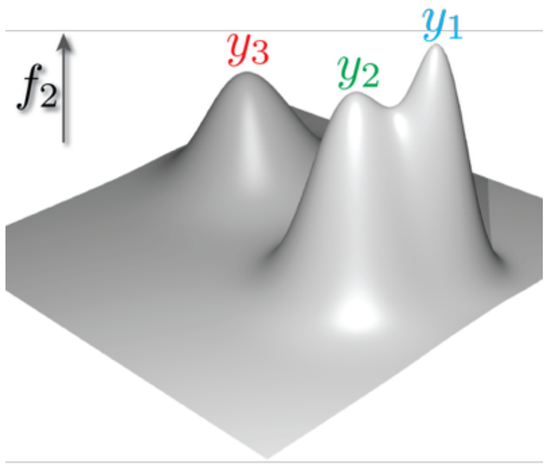
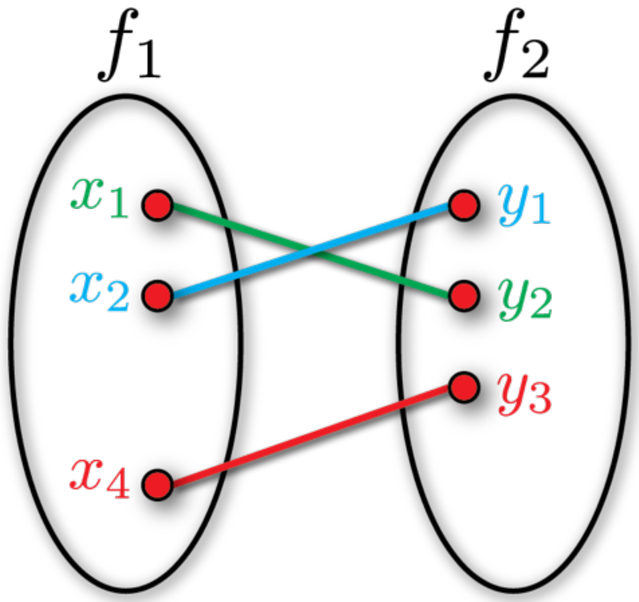


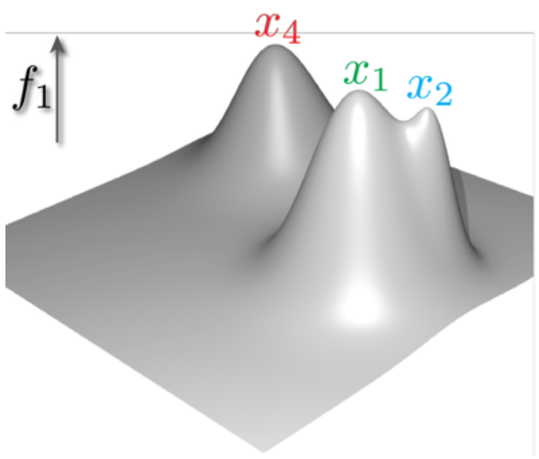


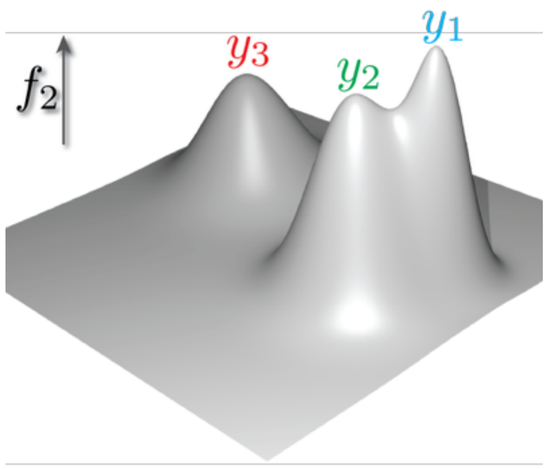


Functional Similarity

Intuition: Measures the amount of change required to get **identical functions**

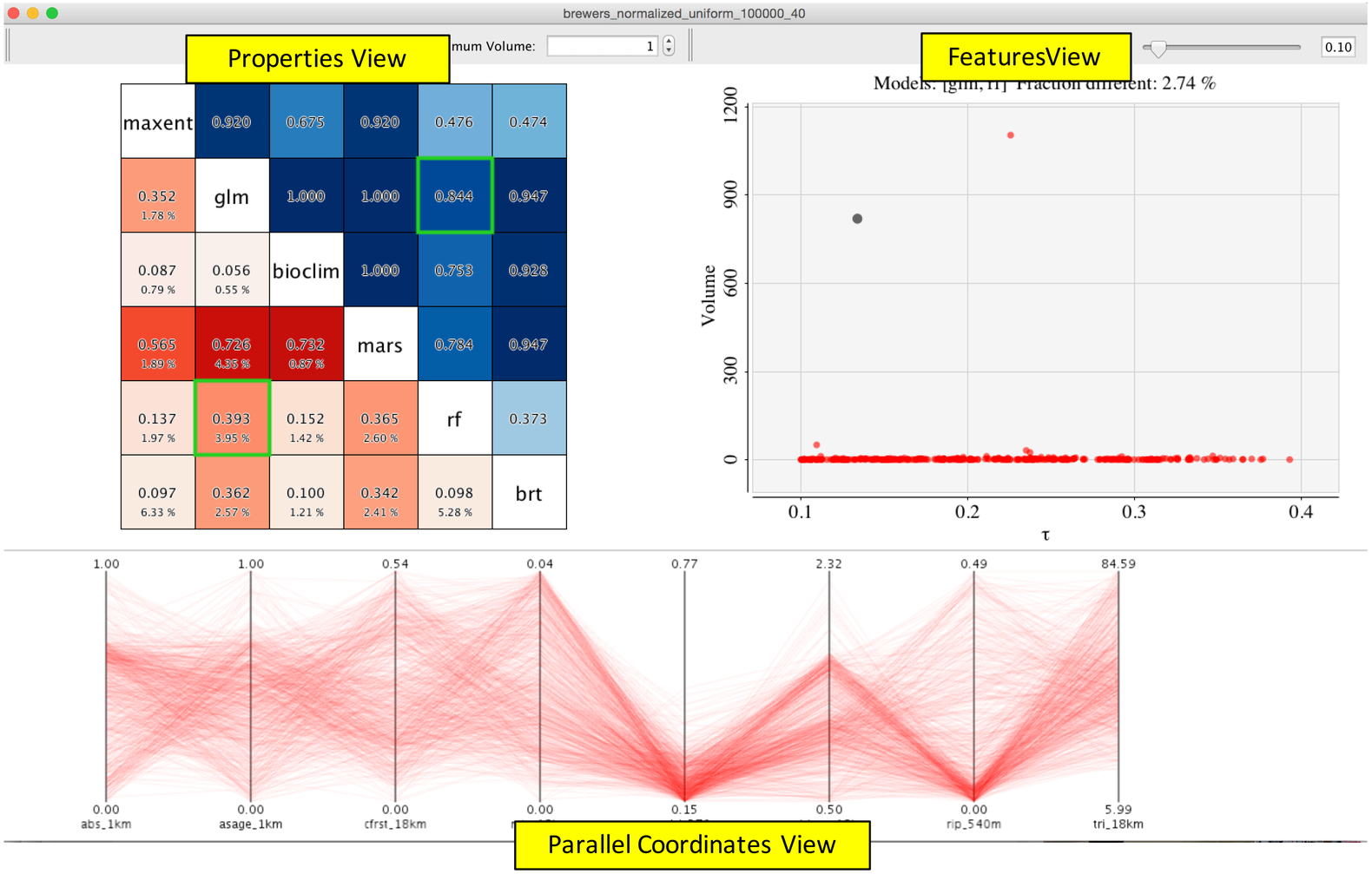




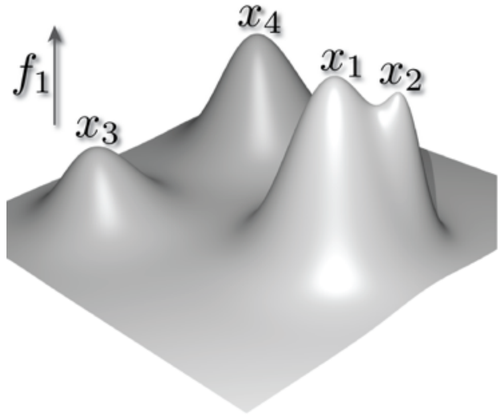


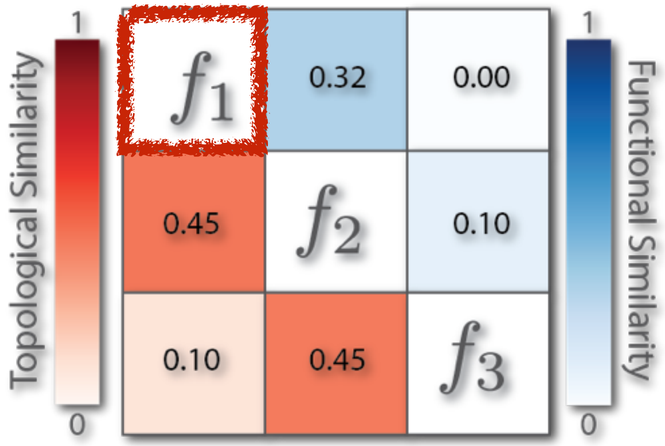
Exploration Framework

Exploration Framework

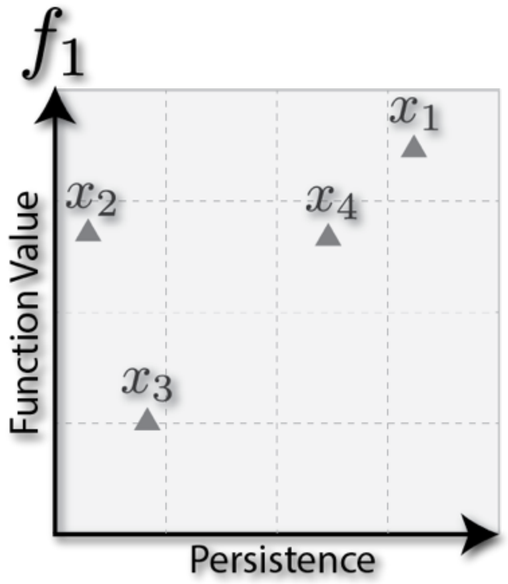


Exploring a SDM

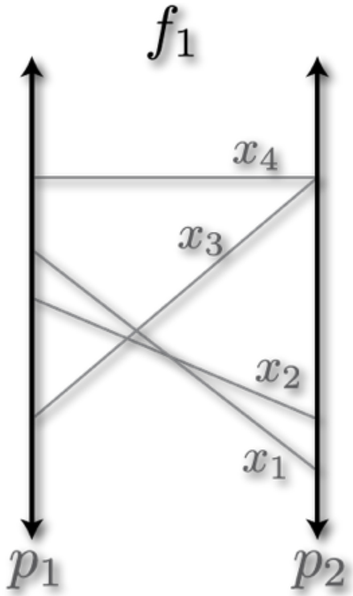




Properties View

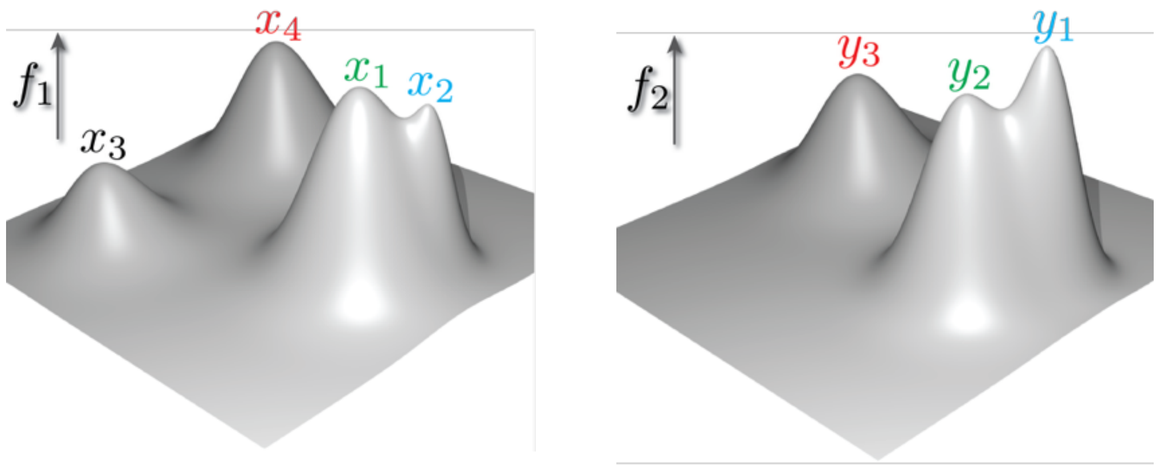


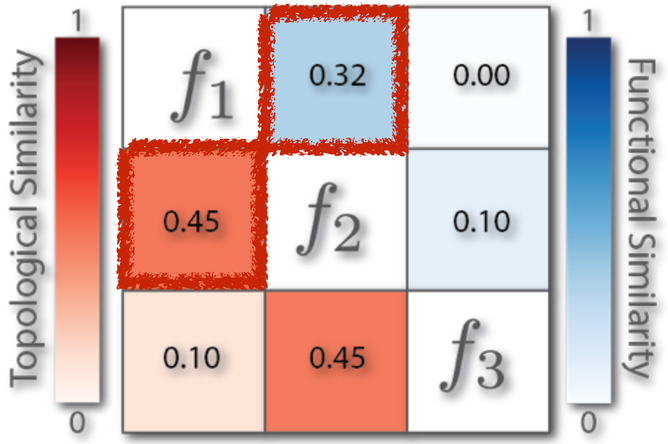
Features View



Parallel Coordinates View

Similarities Between Models





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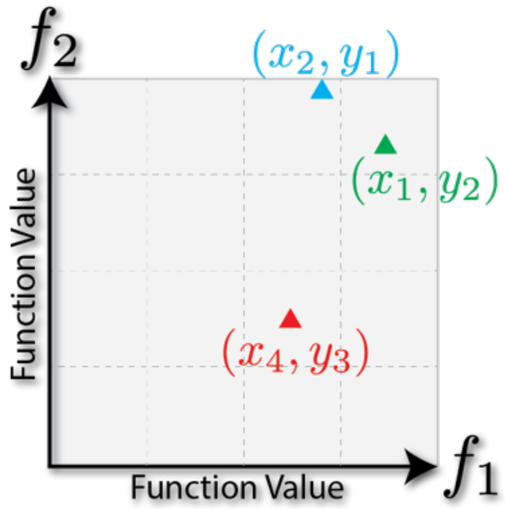
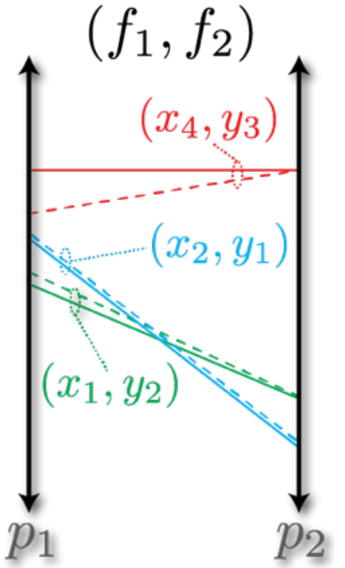
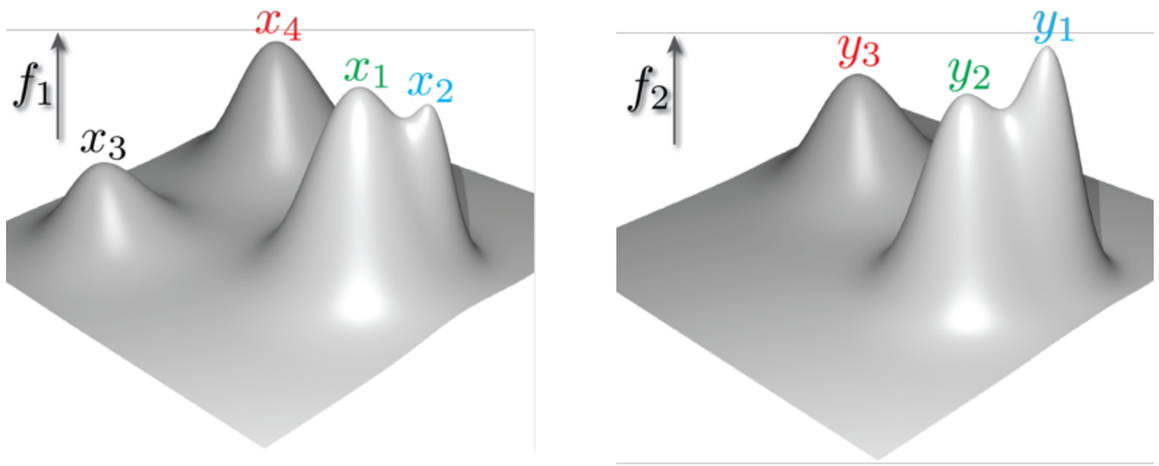


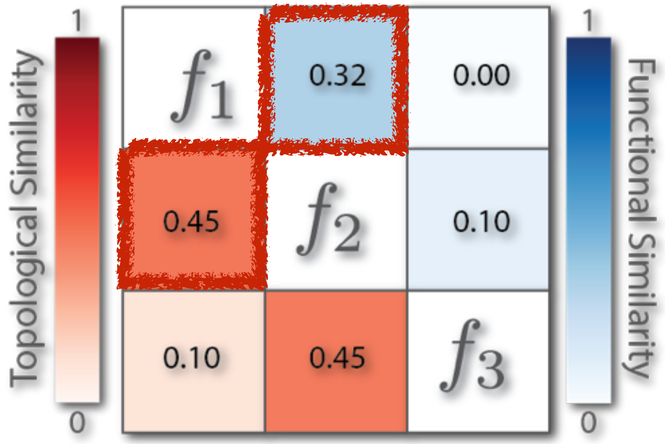
Features View



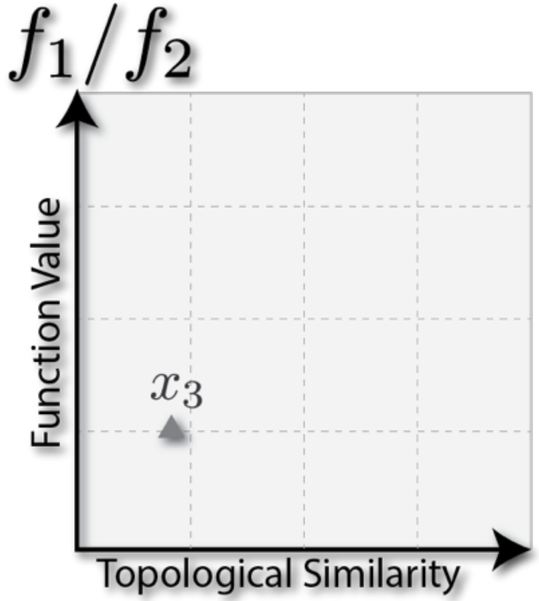
Parallel Coordinates View

Differences Between Models

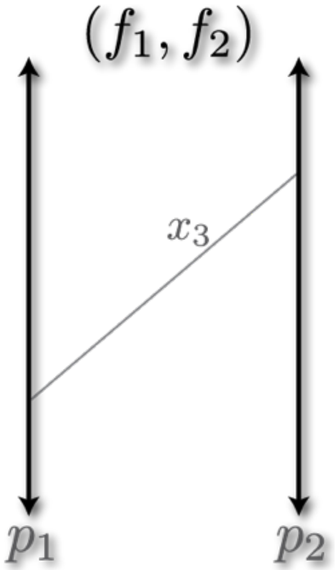




Properties View



Features View



Parallel Coordinates View

Case Studies

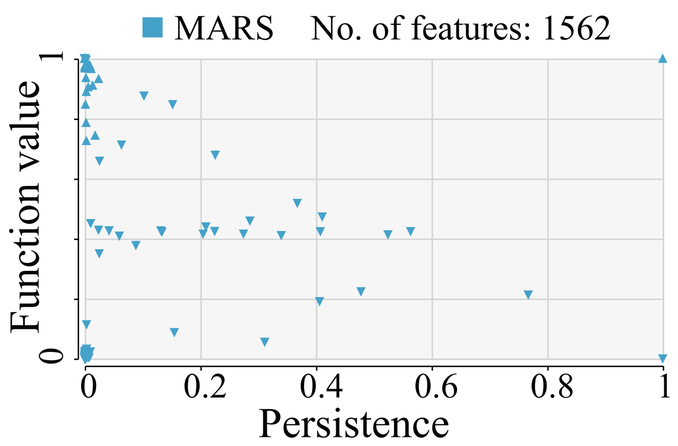
Data Sets

- Brewer's Sparrow
  - 8 predictors
  - 5 models
- Sagebrush
  - 8 predictors
  - 5 models
- Spruce Fir
  - 9 predictors
  - 5 models

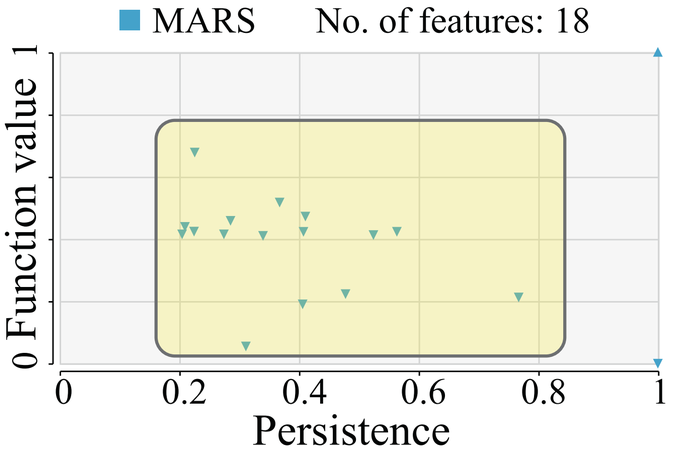
Implementation

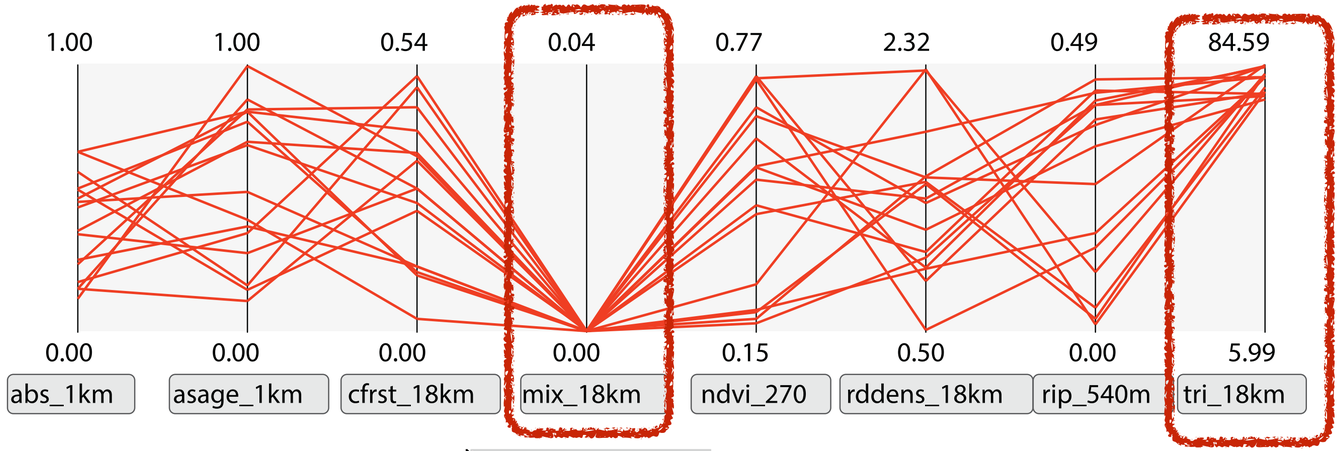
- Domain of SDM
  - Discretize as a graph
  - Sample n=10^5 points in the high-dimensional space
    - Latin Hypercube Sampling
  - Compute the k-nearest-neighbor graph (k=40) for each SDM
- Scalar function
  - Function values are computed using the SDM on the vertices of the Graph
  - Linearly interpolated within each edge
- Cut-off radius for computing edge weights r = 0.1

Exploring a SDM

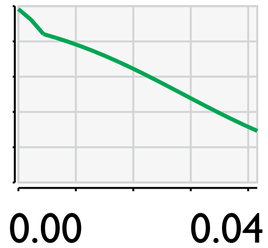


Simplification

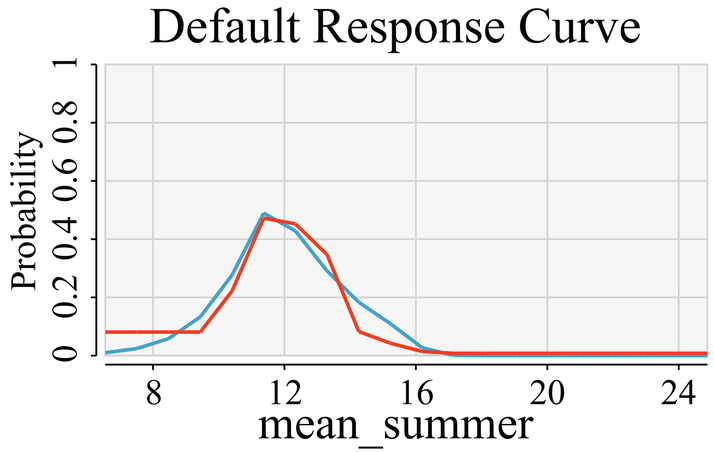


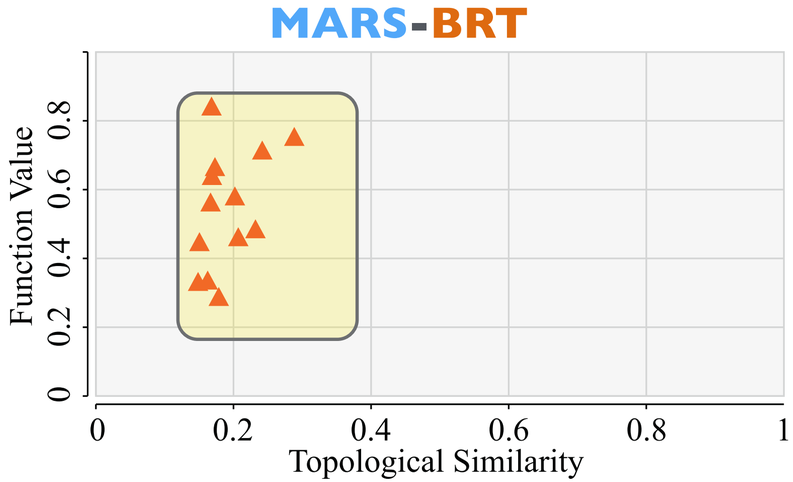


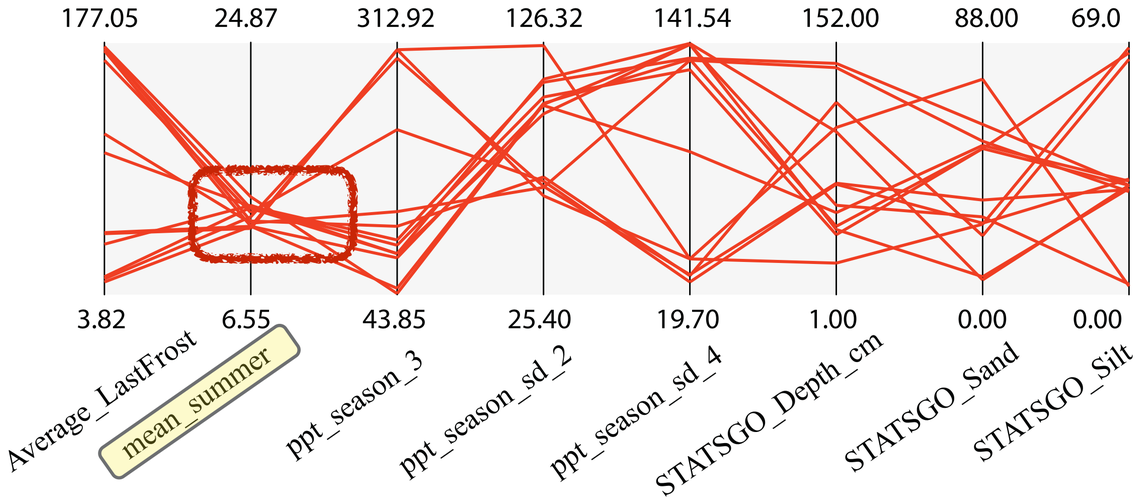
default response curve

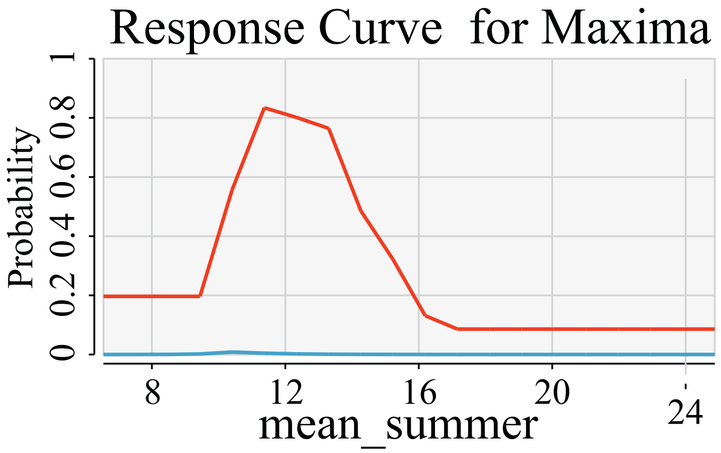


Exploring Differences: MARS vs BRT









Conclusions

- Positive feedback from Ecologists
  - Surprised by results
  - Integrating into SAHM package for VisTrails
- Other Contributions
  - Robustness to noise
    - perturb function values
    - perturb extrema locations
  - Experimentally evaluate effect of parameters to the similarity measures
    - sample size
    - # neighbors
    - neighborhood radius r

Future Work

- Each dimension normalized between 0 and 1
  - Can they be standardized instead?
- Neighborhood radius fixed to 0.1 based on discussions with our collaborators
  - Can a different weighting scheme be used irrespective of the domain?
- Use other metaphors to visualize SDMs
  - Eg. topological spines

Acknowledgements

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Thank You!

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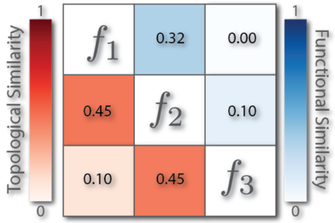

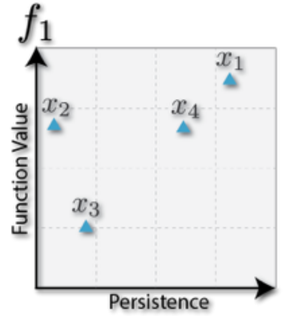

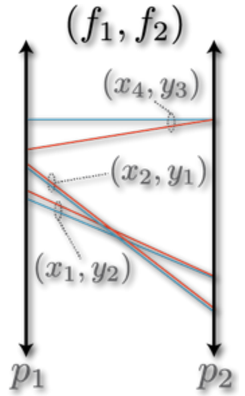

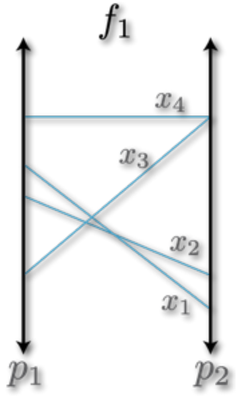

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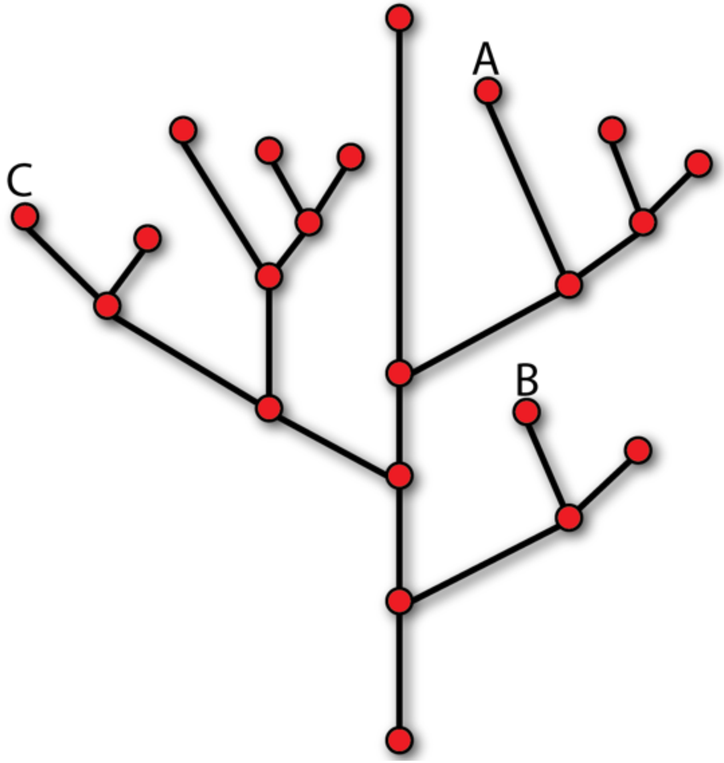
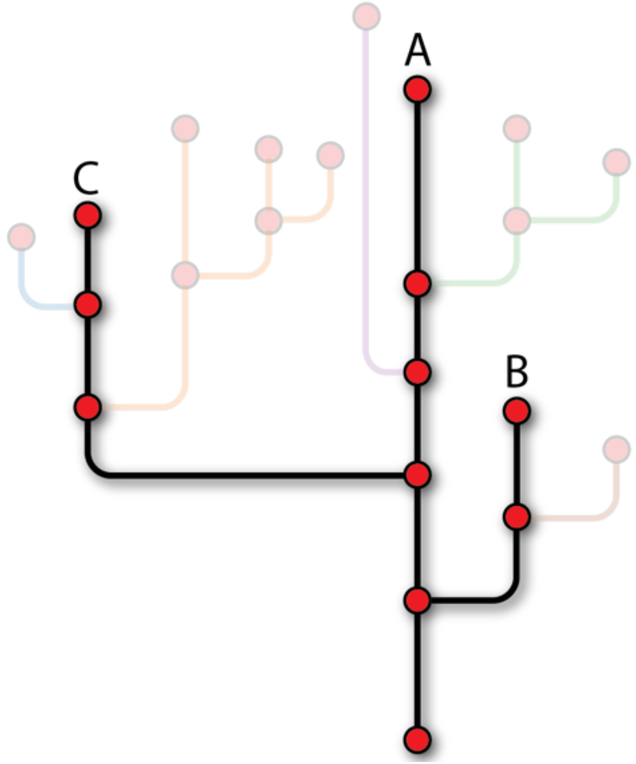
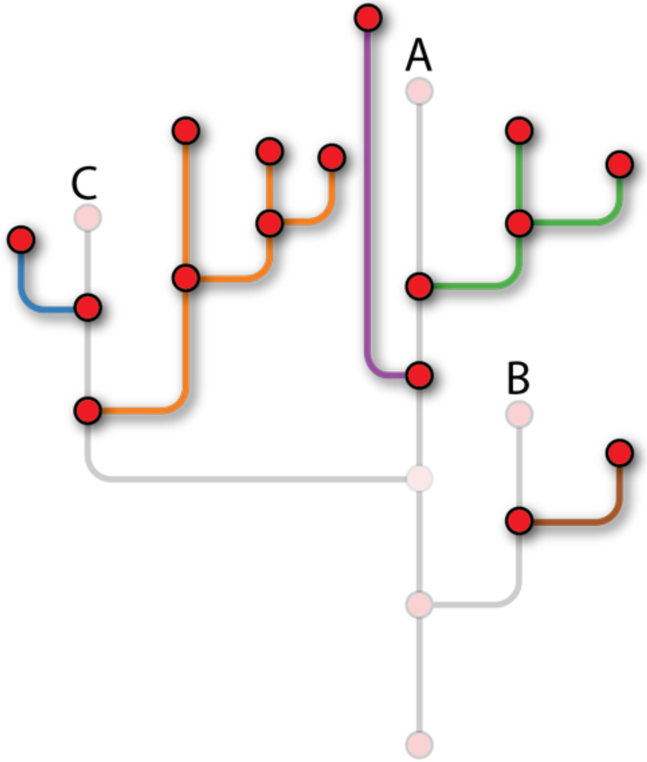
USGS science for a changing world

Similarity Measures: Topological Similarity







$$\tau = \max(\tau_1, \tau_2)$$

- Intuition: It is the minimum simplification required to obtain a perfect matching between two functions

Effect to Noise