Structural Validation of Synthetic Power Networks Using the Multiscale Flat Norm

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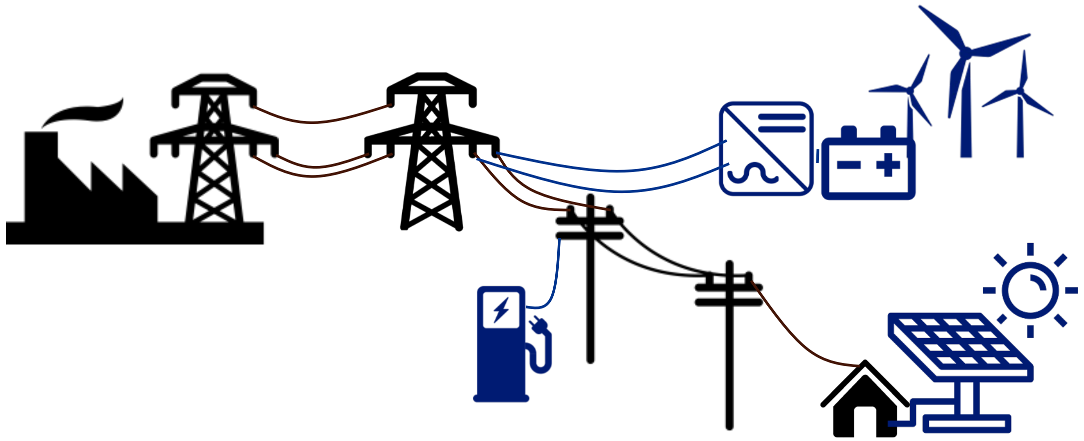
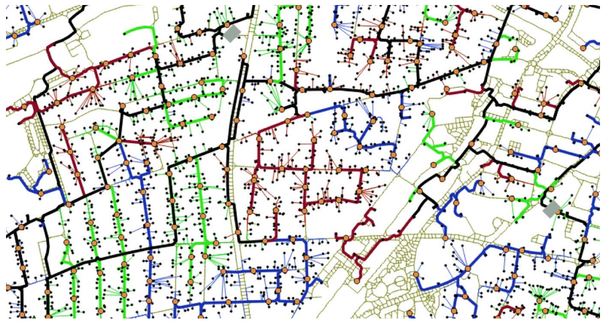
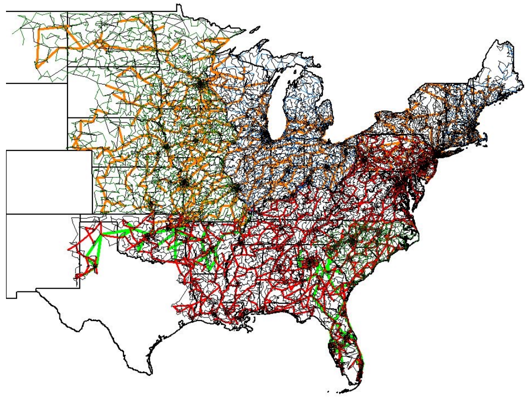
Why Synthetic Power Grid?

- Need for synthetic power grid
  - New technologies in the power grid – electric vehicles, solar photovoltaics, wind farms, electric storage units.
  - System planners and policymakers require actual power grid data.
  - Actual power grid data is proprietary.
- Validation tools to determine accuracy of digital duplicates of power grid.
  - Operational validation
  - Structural validation

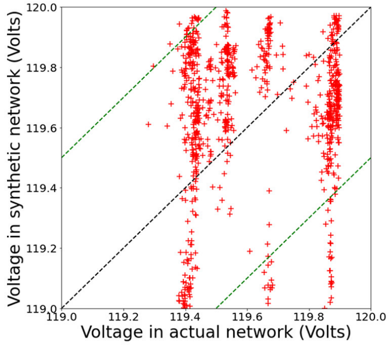


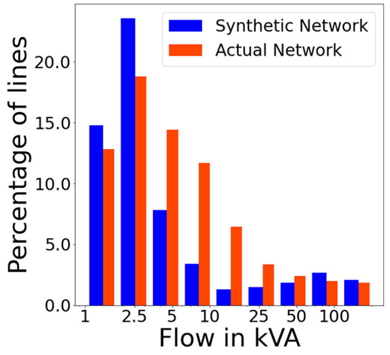


NREL SMART-DS synthetic models



TAMU synthetic electric grids

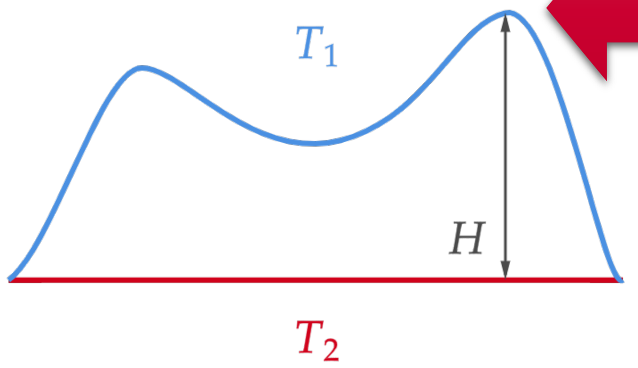




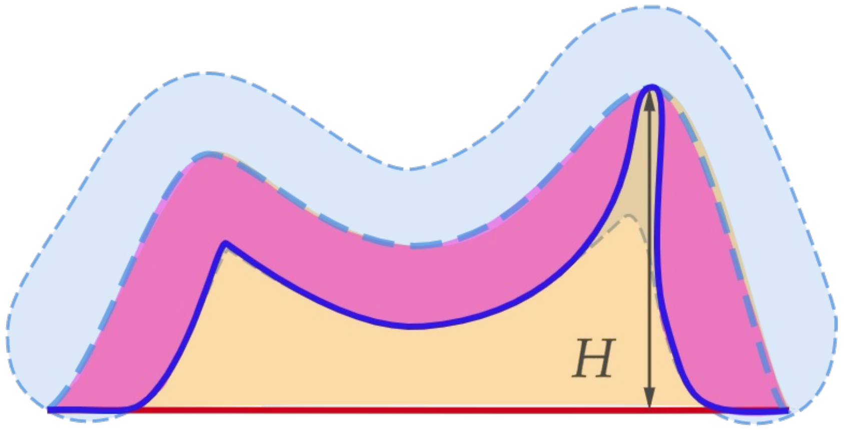
Network Structure Comparison

How can we compare structure of a pair of networks with no node-to-node or edge-to-edge correspondence?

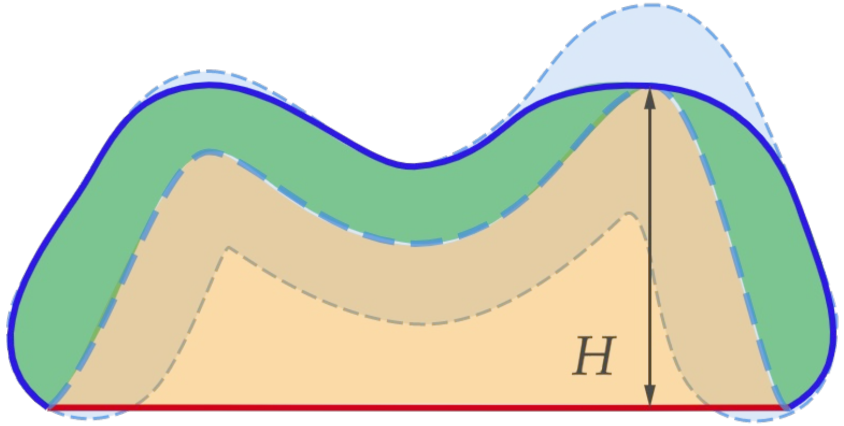
Hausdorff distance



Hausdorff distance metric is sensitive to this point

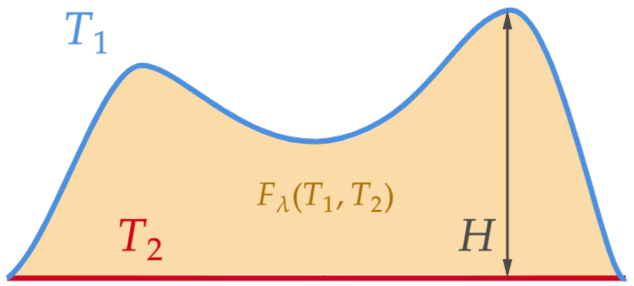


Decrease in area between geometries denoted by magenta shaded region



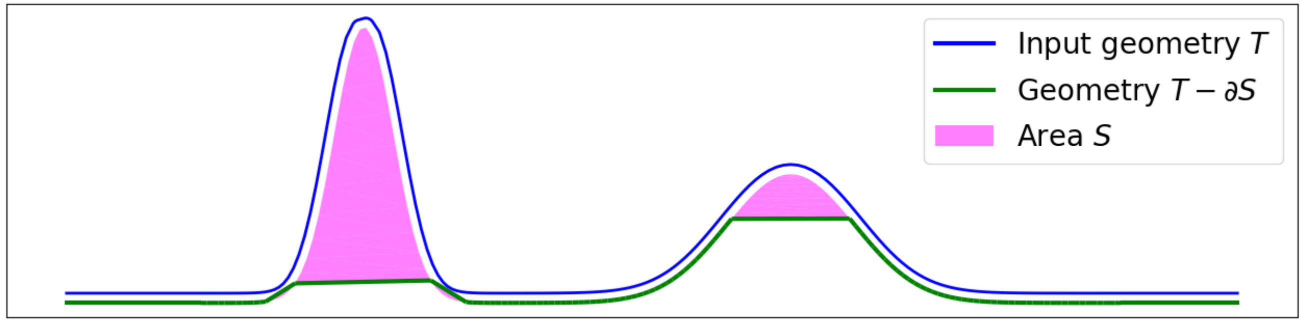
Increase in area between geometries denoted by green shaded region

What can be a suitable alternative for Hausdorff distance?



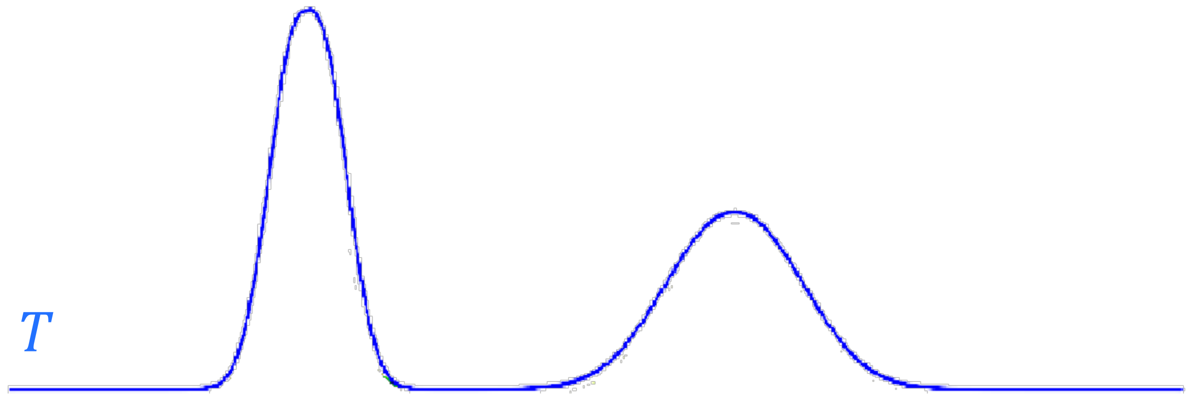
Area between the geometries can be a suitable distance metric

The Multiscale Flat Norm



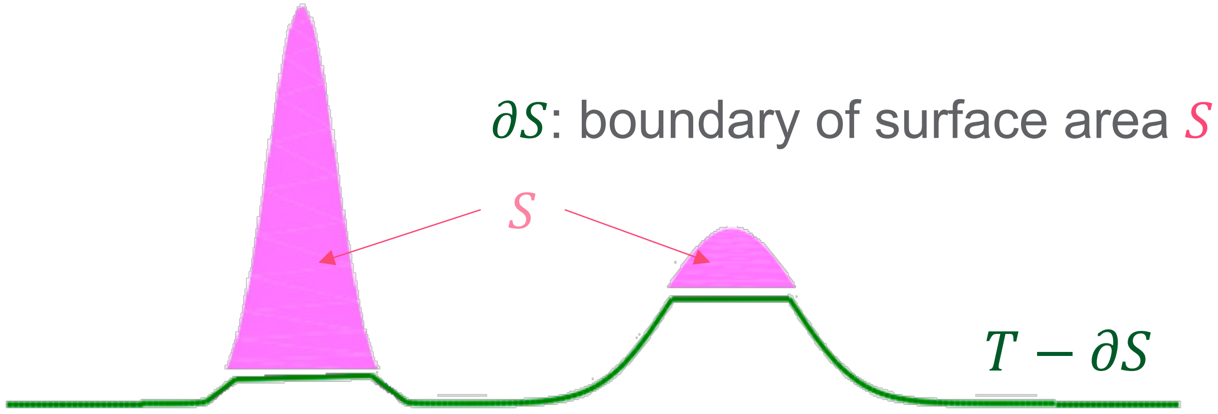
$$\mathbb{F}_\lambda(T) = \min_S \mathbf{Length}(T - \partial S) + \lambda \cdot \mathbf{Area}\ (S)$$

Flat norm distance between two geometries
$$\mathbb{F}_\lambda(T_1, T_2) = \mathbb{F}_\lambda(T_1 - T_2)$$

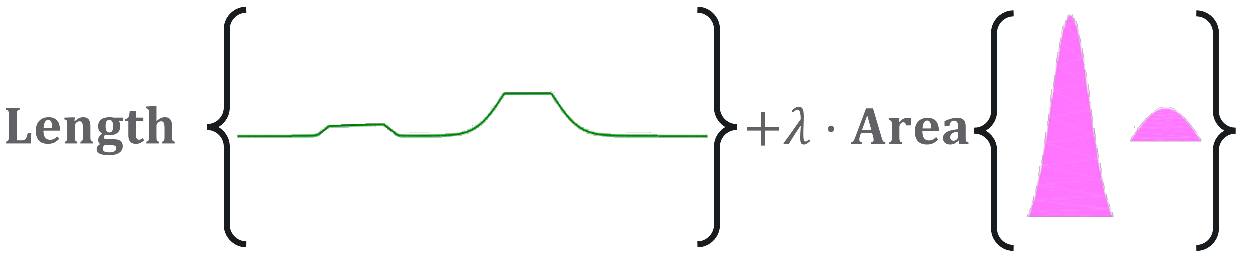


Cover the input geometry T using one of the two operations

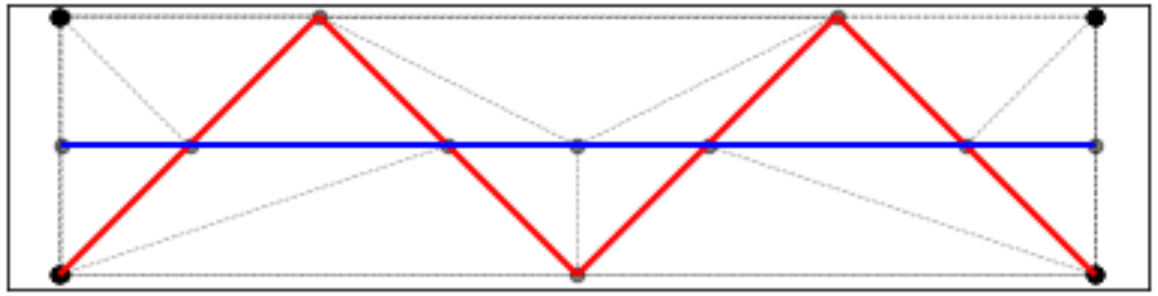
- drawing geometry $T - \partial S$, or
- boundary ∂S of area patches S for untraced portions.

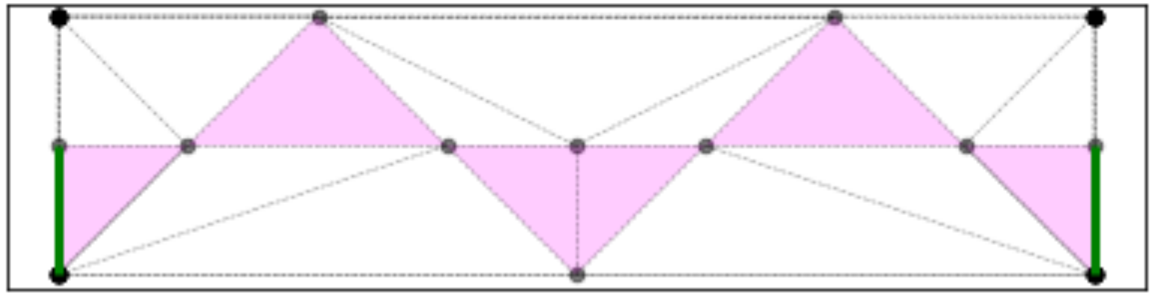


At the same time, ensure that we minimize



Computing the multiscale flat norm

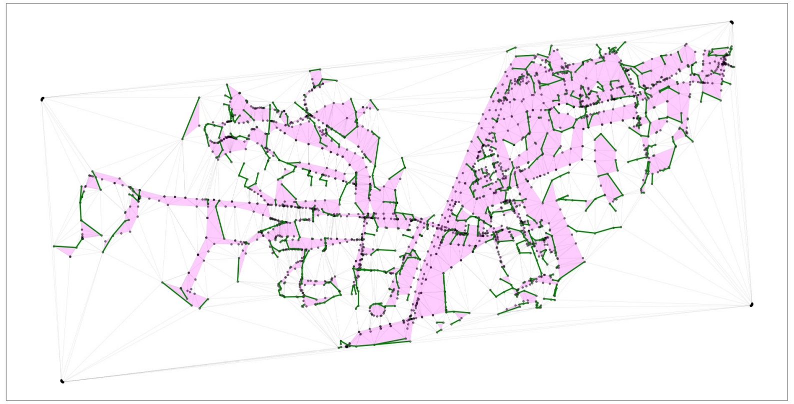




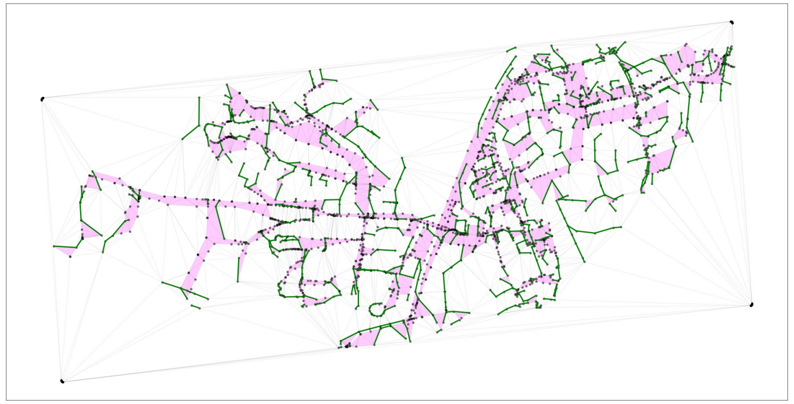
$$\mathbb{F}_\lambda(T_1 - T_2) = \min_{\mathbf{x},\,\mathbf{s}} \mathbf{w}^T\mathbf{x} + \lambda(\mathbf{v}^T\mathbf{s})$$
$$s.t. \quad \mathbf{x} = \mathbf{t} - [\partial]\mathbf{s},$$

Effect of Scale Parameter λ

Scale, λ = 1000 : Flat norm, $\mathbb{F}_\lambda$ = 29.966 km



Scale, λ = 50000 : Flat norm, $\mathbb{F}_\lambda$ = 39.758 km



Scale, λ = 100000 : Flat norm, $\mathbb{F}_\lambda$ = 45.752 km

$$\mathbb{F}_\lambda(T) = \min_S \mathbf{Length}(T - \partial S) + \lambda \cdot \mathbf{Area}(S)$$

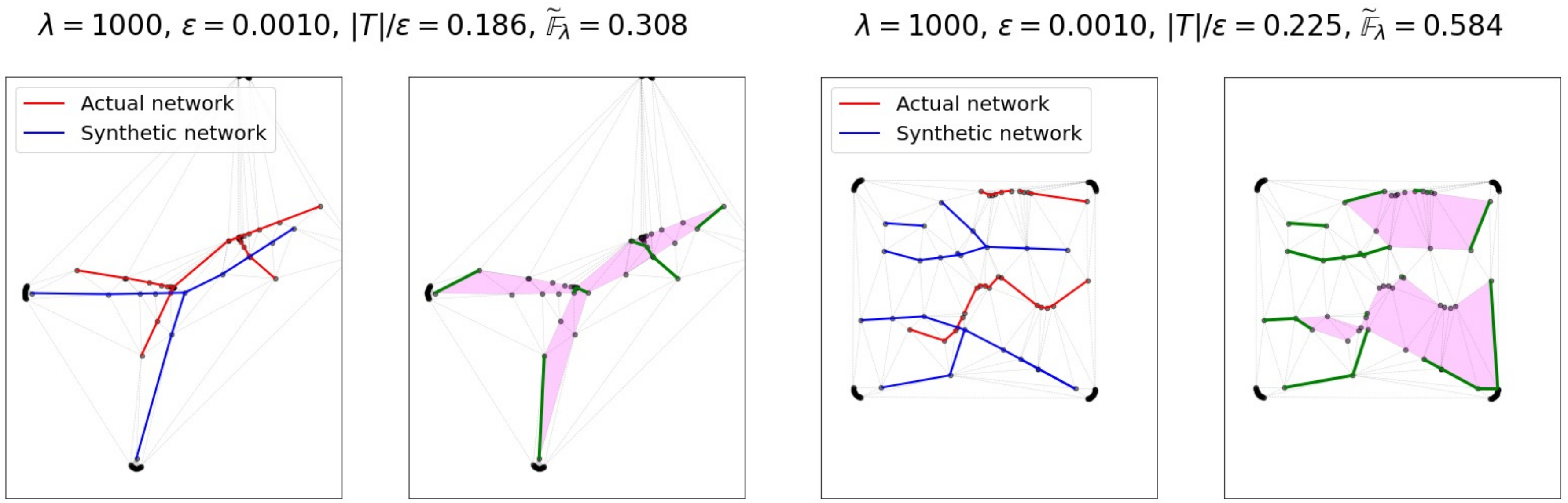
Small λ makes area component cheaper and considers more area in flat norm computation.

Illustrative Examples for Local Comparison

How to remove dependence on length of geometry?

Normalize the flat norm by the total length of input network.

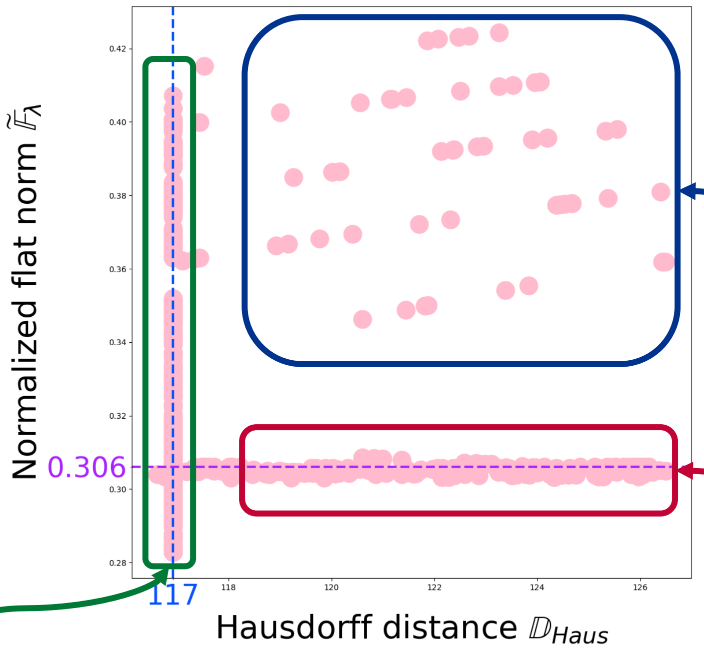
$$\widetilde{\mathbb{F}_\lambda}(T_1 - T_2) = \frac{\mathbb{F}_\lambda(T_1 - T_2)}{|T_1| + |T_2|}$$

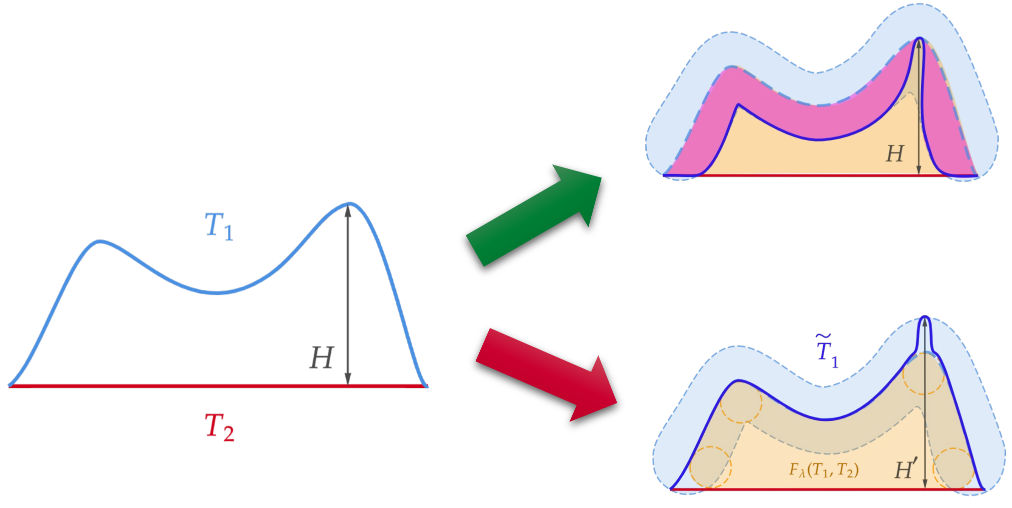


Structurally similar geometries with small normalized flat norm distance

Structurally dissimilar geometries with large normalized flat norm distance

Effect of Perturbation





- perturbation of a point responsible for the original Hausdorff distance, also causing significant change in flat norm

- perturbation of a point not responsible for the original Hausdorff distance
- perturbation of a point responsible for the original Hausdorff distance

Flat norm distance avoids the drawback of Hausdorff distance

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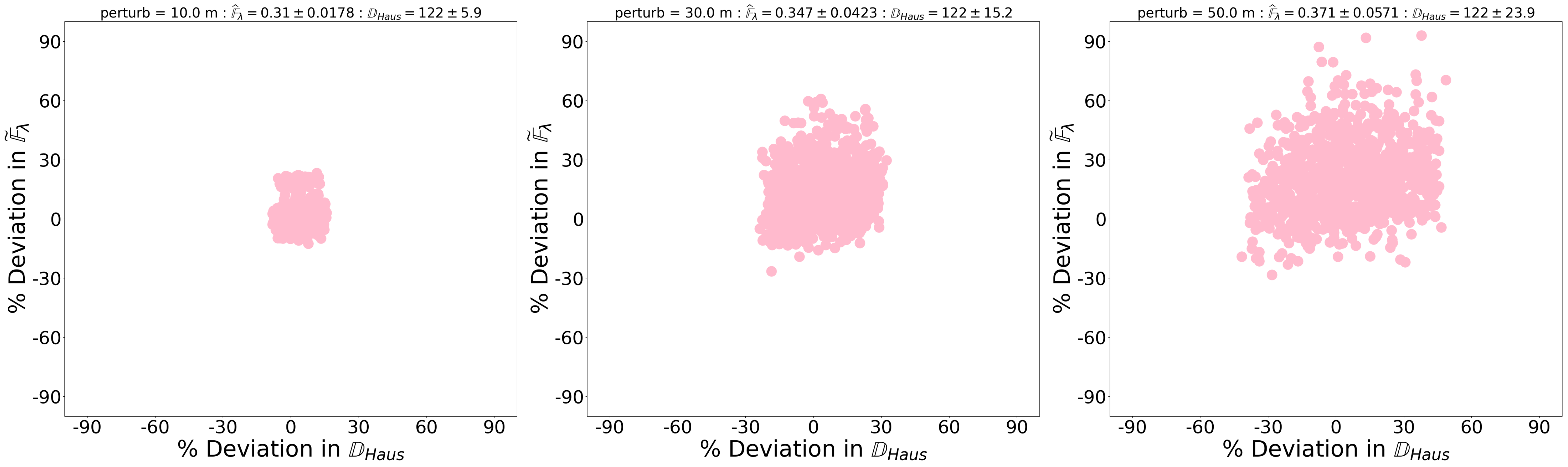
Stability of Multiscale Flat Norm

Increase in the perturbation radius



Hausdorff distance and normalized flat norm distance behave similarly for uniform perturbation of one of the geometries

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Conclusions

- We have proposed a new metric for structural comparison of a pair of geometries
  - It compares the deviation in length as well as the lateral displacement using the area between the geometries.
  - It avoids the usual drawbacks of Hausdorff distance being able to capture changes in the maximum deviation.
- We can use this metric for
  - Comparing any pair of geometries.
  - Comparing networks with no node-to-node or edge-to-edge correspondence, where we cannot use traditional methods like graph edit distance.

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Thank you