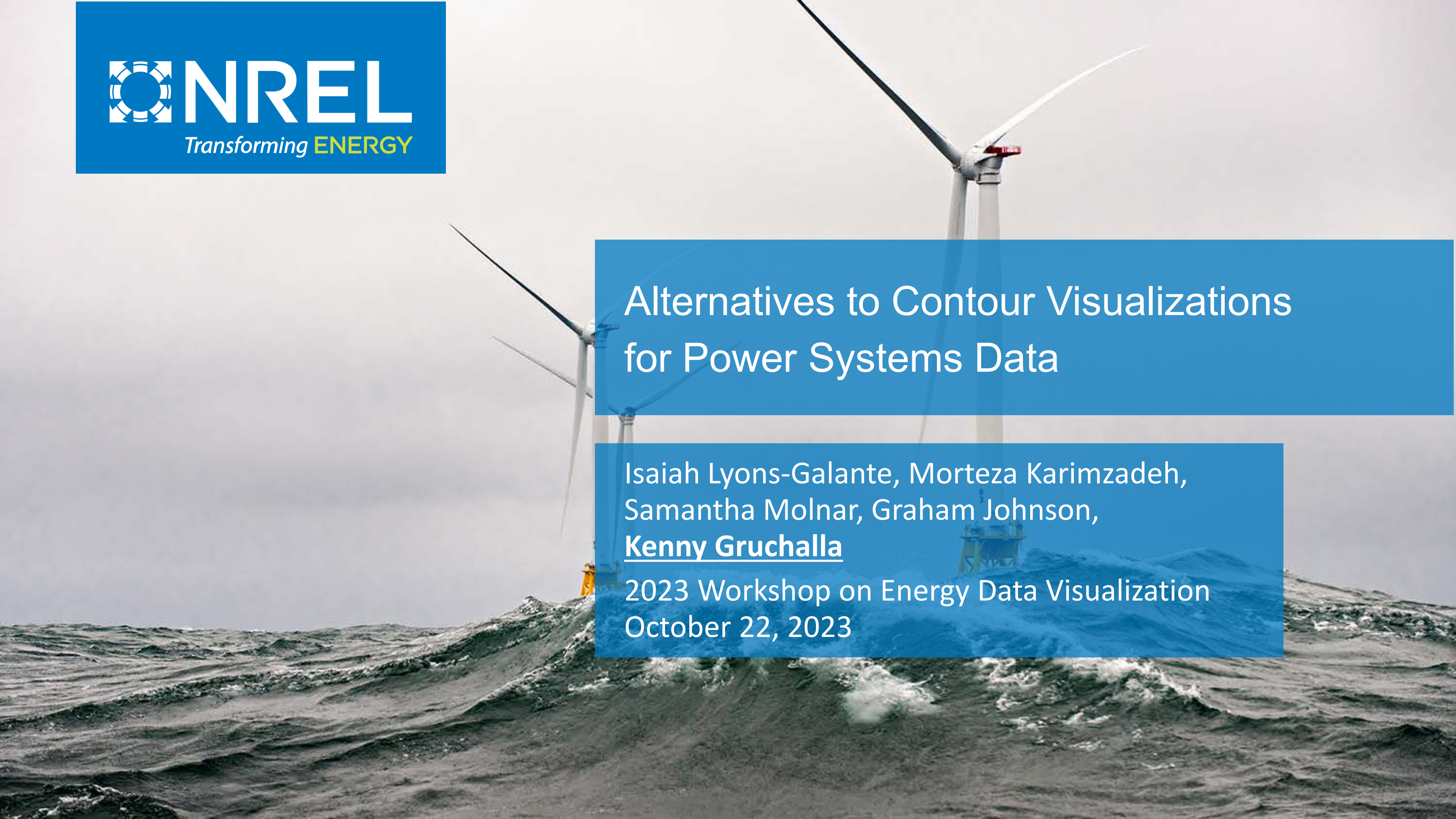
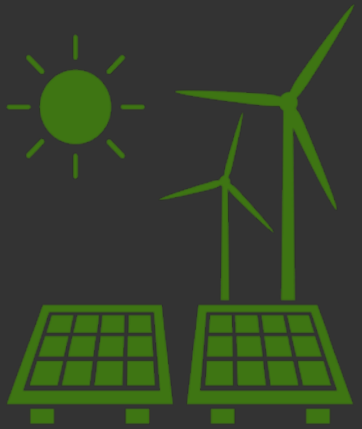


Alternatives to Contour Visualizations for Power Systems Data

Isaiah Lyons-Galante, Morteza Karimzadeh, Samantha Molnar, Graham Johnson, **Kenny Gruchalla**

2023 Workshop on Energy Data Visualization
October 22, 2023

Motivation



Increased renewable generation

is driving the need to visualize networks with more density and complexity

colored contour maps are ill-equipped to represent.

K. Gruchalla, S. Molnar, G. Johnson. **Reevaluating Contour Visualizations for Power Systems Data** *IEEE Transactions on Smart Grid,* March 2023.

Contour algorithms are based on **geographical distances**.

In power and cyber systems, the geographic distance typical isn't important, but **topological distance** is!

p20ulv4164 and p20ulv25353 are **226.6m** apart, but the shortest electrical network path between the two is **4104.4m**.
p20ulv423 and p20ulv3546 are **85.3m** apart, but the shortest electrical network path between the two is **4079.1m**.

Gruchalla, et al. 2023

Contour Visualization

Weber & Overbye 2000

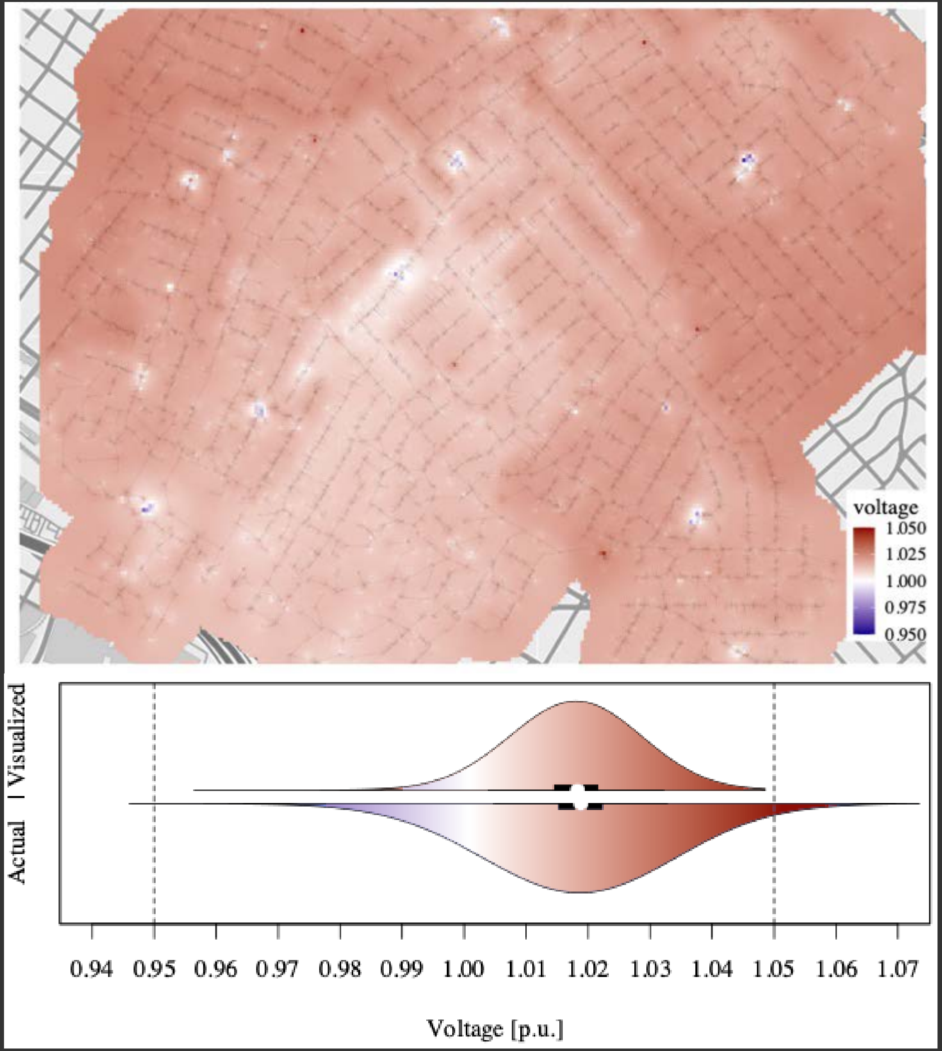
O(nm)

Metric	Data	Contour	Error
Median	1.0188	1.0183	0.05%
Kurtosis	16.632	4.296	74.17%
SD	0.0057	0.0048	15.79%
Min	0.9459	0.9564	1.11%
Max	1.0734	1.0486	2.31%

Shepard's method is inverse distance weighting scheme.

$$g_k = \frac{\sum_{i=1}^{N} w(c_k, v_i) x_i}{\sum_{i=1}^{N} w(c_k, v_i)}$$

$$w(c_k, v_i) = \frac{1}{d(c_k, v_i)^p}$$



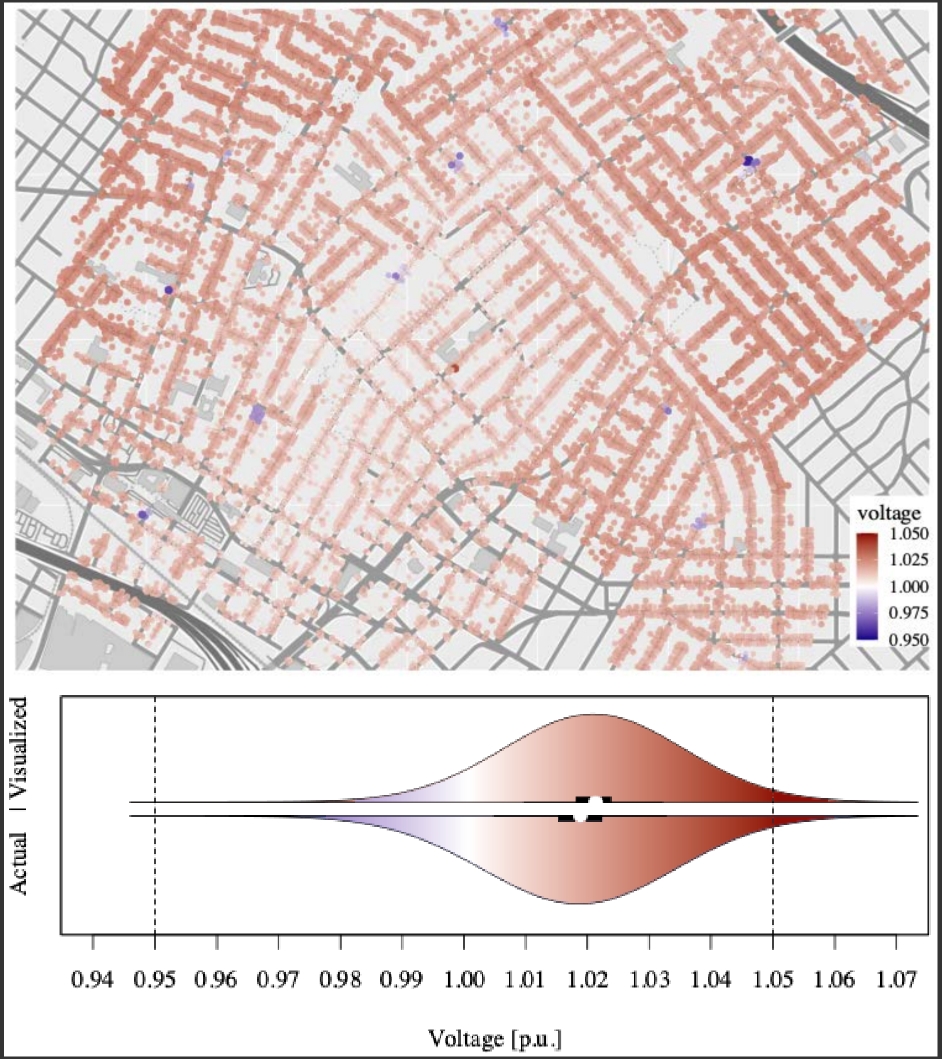
Glyph Visualization

Figueroa-Acevedo, et al. 2020

O(n)

Metric	Data	Contour	Error
Median	1.0188	1.0183	0.05%
Kurtosis	16.632	53.810	223.53%
SD	0.0057	0.0062	8.77%
Min	0.9459	0.9459	0.00%
Max	1.0734	1.0734	0.00%

Each each bus is directly represented by a mark (glyph) sized and colored by voltage, Z-ordered by distance from nominal voltage.

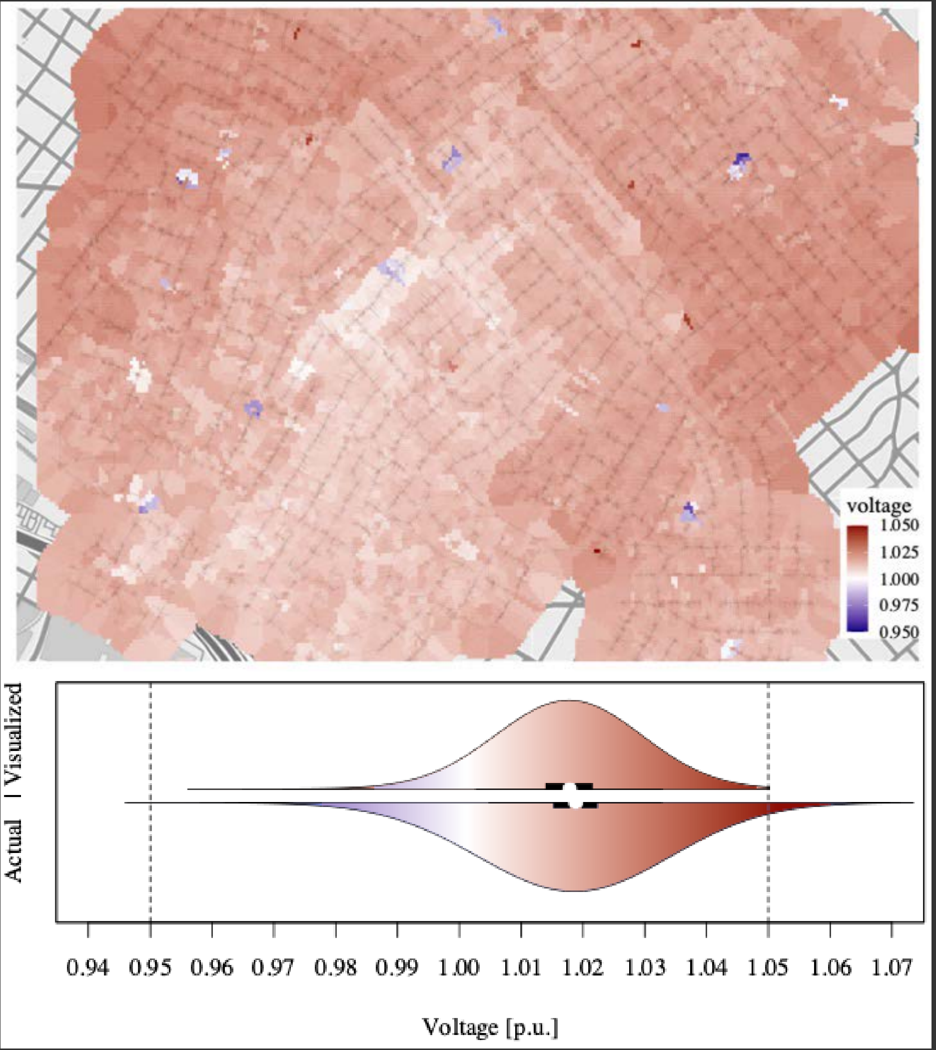


Networked Contour Visualization

$O(n\ m) + O(n \log n)$

Metric	Data	Contour	Error
Median	1.0188	1.0179	0.09%
Kurtosis	16.632	9.203	44.67%
SD	0.0057	0.0054	5.26%
Min	0.9459	0.9561	1.08%
Max	1.0734	1.0502	2.16%

Each pixel is network-weighted contour map



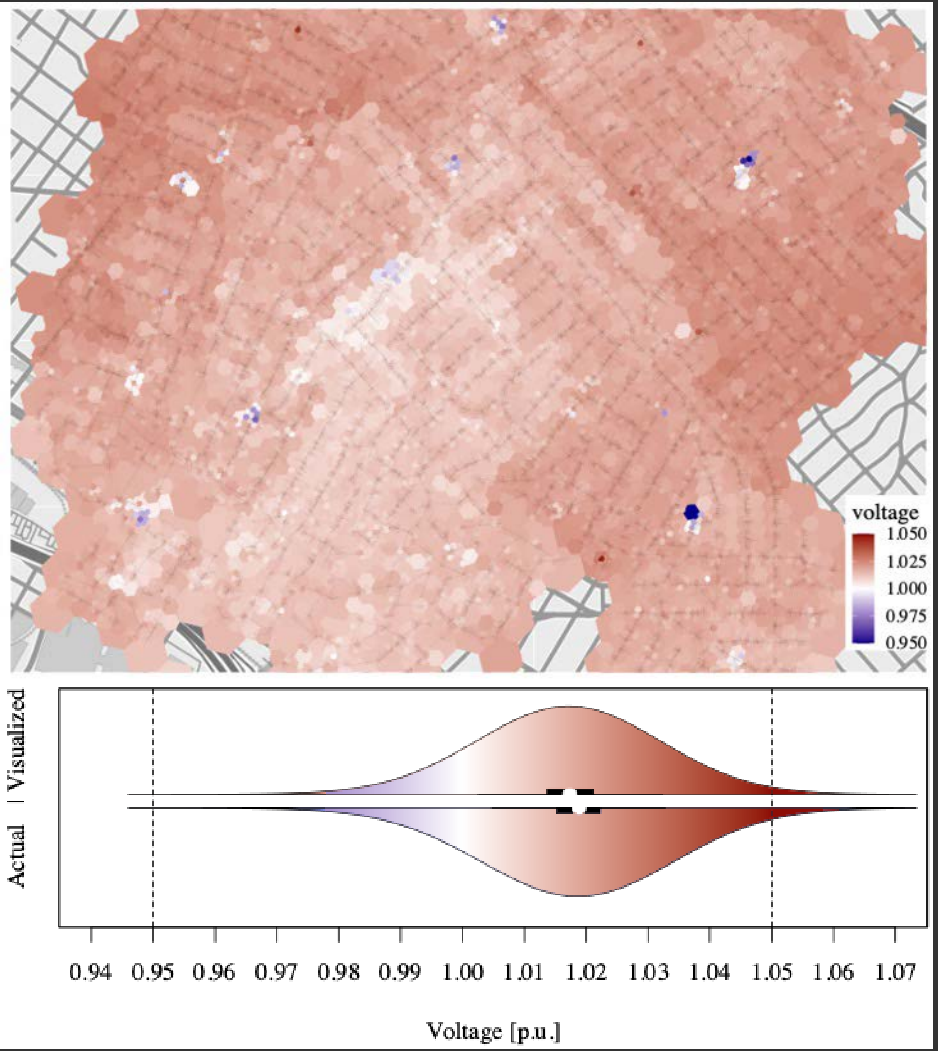
Multi-res H3 (Hex) Visualization

Uber Technologies, Inc

O(nm)

Metric	Data	Contour	Error
Median	1.0188	1.0183	0.05%
Kurtosis	16.632	12.655	23.91%
SD	0.0057	0.0049	14.04%
Min	0.9459	0.9460	0.01%
Max	1.0734	1.0469	2.47%

Aggregate bus values based on a multi-resolution H3 hexagon tessellation.



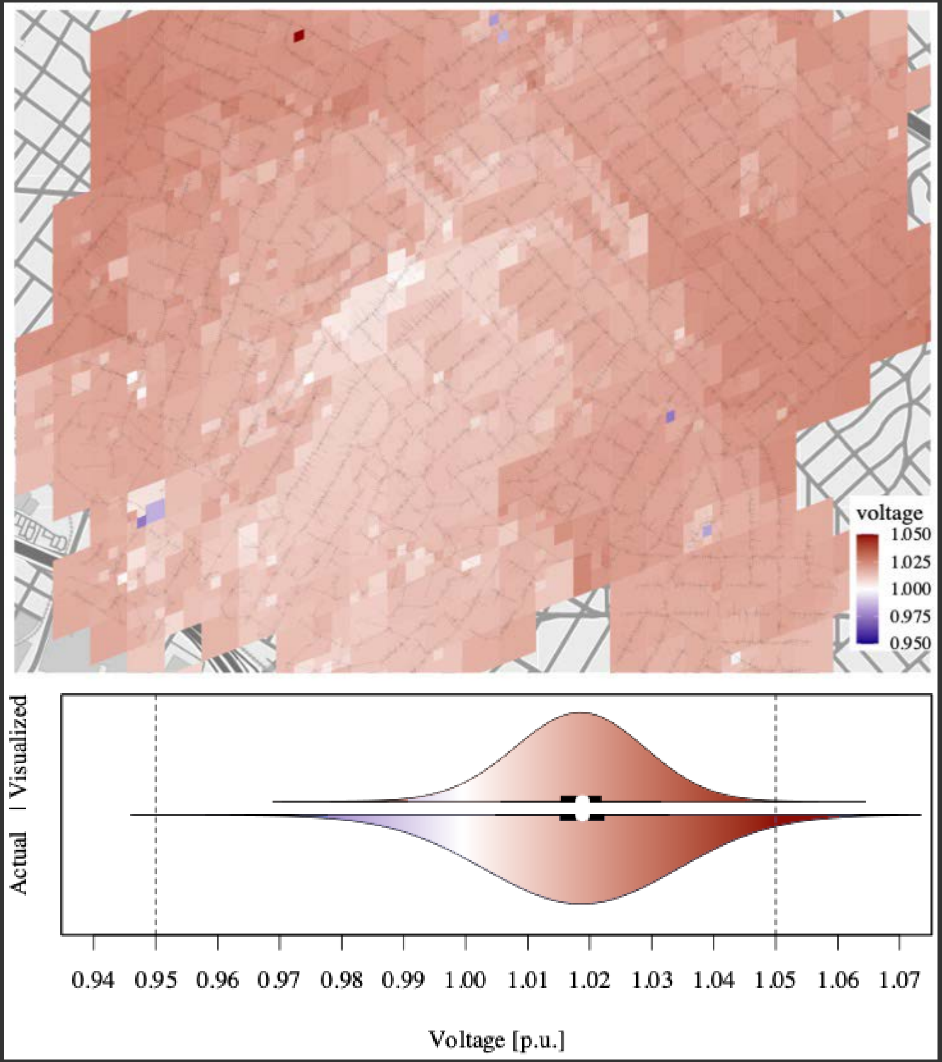
Multi-res S2 (Quad) Visualization

Google

O(nm)

Metric	Data	Contour	Error
Median	1.0188	1.0189	0.01%
Kurtosis	16.632	10.585	36.36%
SD	0.0057	0.0049	14.04%
Min	0.9459	0.9689	2.43%
Max	1.0734	1.0645	0.83%

Aggregate bus values based on a multi-resolution S2 quadrillateral tessellation.

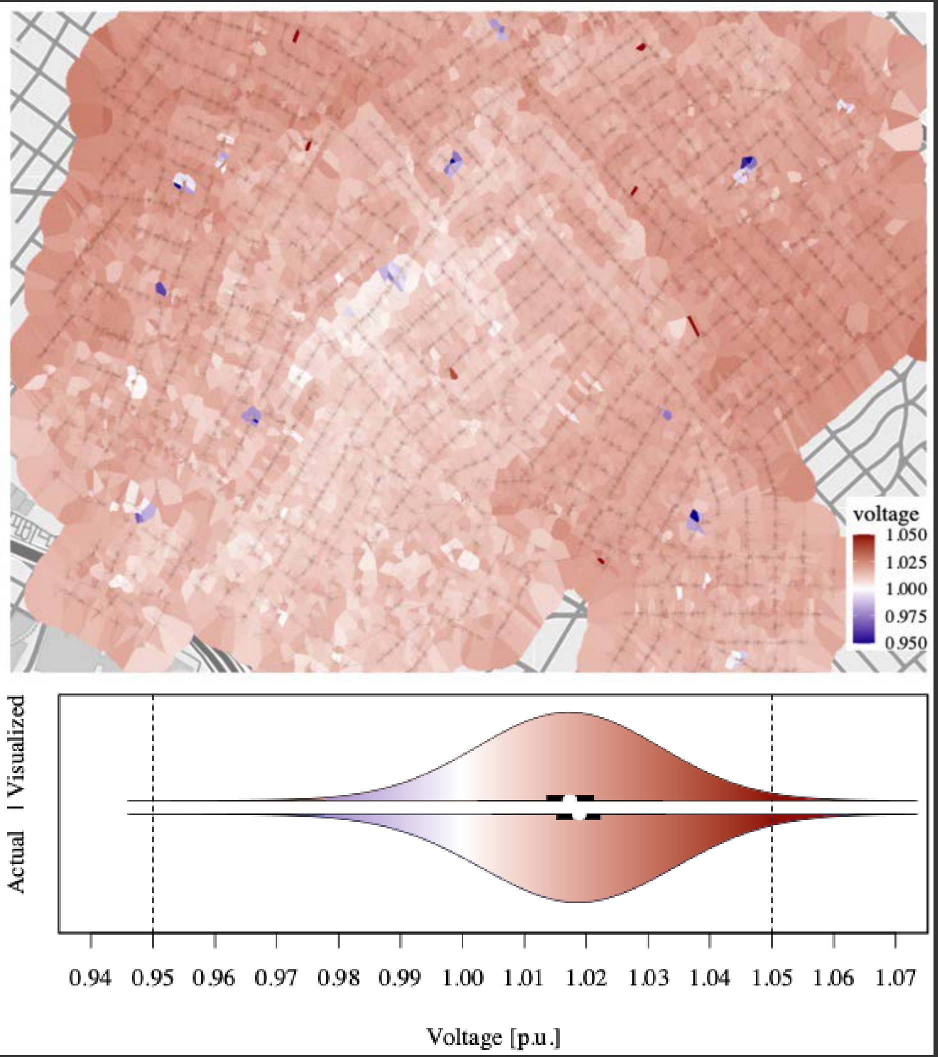


Voronoi Visualization

O(n log n)

Metric	Data	Contour	Error
Median	1.0188	1.0173	0.15%
Kurtosis	16.632	13.520	18.71%
SD	0.0057	0.0059	3.51%
Min	0.9459	0.9459	0.00%
Max	1.0734	1.0734	0.00%

A polygon is created around each bus such that all points within the polygon share that point as their nearest bus.



Analysis

	Contours	Network-weighted Contours	Glyphs	Multi-res H3	Multi-res S2	Voronoi
Accurate Distribution	√	√	X	√	√	√
Preserves areas of high variance	X	X	√	X	X	√
Preserves tails/outliers	X	X	√	X	X	√
Computationally efficient	X	X	√	X	X	√

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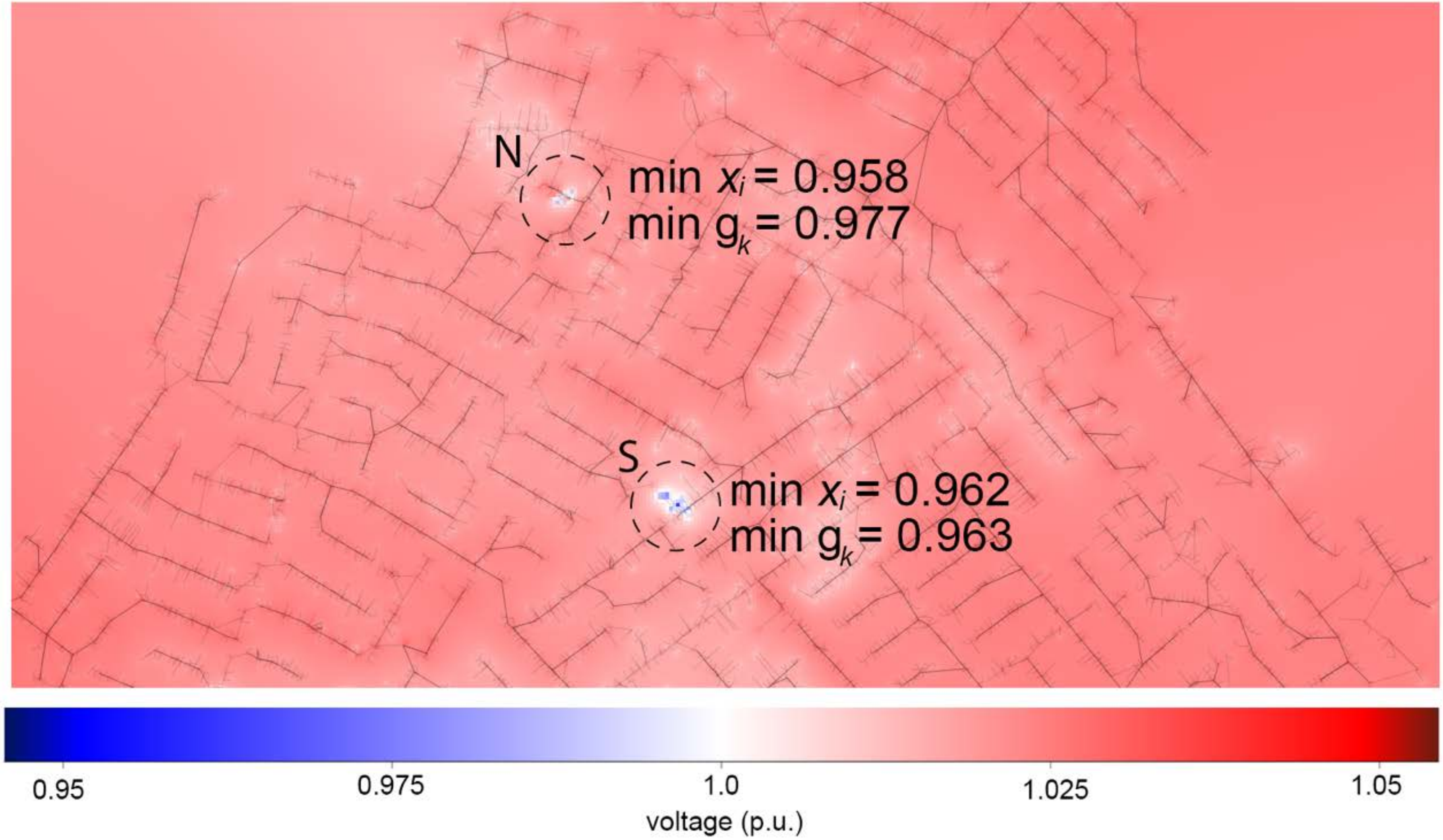
N
min x_i = 0.958
min g_k = 0.977
S
min x_i = 0.962
min g_k = 0.963
0.95
0.975
1.0
1.025
1.05
voltage (p.u.)