Creating Distribution Boundaries Using Computational Geometry

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In my job I get asked stuff like:

“Can you determine the pole count by vintage year for each school district in Oncor’s service area?”

And I answer: “No problem!”

- We answer that question each year when we render ad valorem taxes (not just to school districts, but to over 1600 tax jurisdictions). And more than simply reporting pole counts, Oncor summarizes the value of its investment in each jurisdiction by vintage year, prime account, property unit and general ledger for over 17-million items of electrical distribution property.

- This Ad Valorem Tax program takes only eleven minutes to run.
But until recently when I was asked:

“Can you report the pole count by vintage year for each of Oncor’s electrical feeders?”

- I had to answer: “Sorry, there’s no practical way to determine that.”

- Two options:
  - For a given feeder I might have directly queried Oncor’s GIS data to identify the poles associated with that feeder — but if I ran this query on all feeders, the query would never finish. — Or —
  
  - I might have extracted connectivity data from Oncor’s GIS and written a program that traces each pole back to its “owning” circuit breaker — but that’s way too much work!
So why does this easy question about school districts become difficult when it’s asked about feeders?

Because school districts have boundaries, but feeders don’t.

- Oncor defines and maintains all political boundaries that lie within its service area.
- But in Oncor’s GIS we have no equivalent “feeder” boundaries.
So, if Oncor defines and maintains boundaries for school districts in its GIS, why not do the same for feeders?

- Because there’s just too much work involved to make it worth the trouble.
- Besides, rather than having a graphic operator hand draw these “feeder” boundaries, there is a better way to create them.
We can create “Feeder Boundaries” computationally!

- We define the boundary of a feeder as: “The outer edge of the transformer Voronoi regions that comprise that feeder”.
- The following slides illustrate what we mean by “Voronoi region” and how it this relates to the problem of creating feeder boundaries.
For a given set of point “sites” in 2-dimensional space ...
… a “Voronoi region” (shown in Gray) is the area closer to one site than to any other site.

Note: The Voronoi “edges” (in red) are equidistant from adjacent sites.
The “Voronoi diagram” is the union of the Voronoi regions for all “sites”.

Intersections of Voronoi “edges” are called “nodes” (the blue points), and ...
... each “node” is equidistant to three “sites” — i.e., it’s the center of a circle formed by three adjacent sites.

No green “site” can be inside any such blue circle.
Properties of the Voronoi diagram:

- Each Voronoi region is a convex area bounded by straight-line segments.
- By definition, all points on a Voronoi edge are equidistant from the defining points whose cells share that edge.
- A Voronoi node (formed by the intersection of three or more Voronoi edges) is the center of the circle through the points whose cells share those edges. Such a circle does not contain any other point in its interior.
- The Voronoi diagram of N points has no more than $2N - 5$ nodes and $3N - 6$ edges.
Map of the Streets South of Bowen Road Substation
Same Area with Transformer Locations Marked
Transformers Only
Voronoi Diagram of These Transformers
Transformer Cells Color-coded by Feeder
Simply defining a feeder as the sum of its Voronoi “cells” would seem to solve the problem of defining a feeder’s area.

- It only **seems** that way.
  - Oncor has over 850,000 distinct transformer locations, but only about 2900 feeders. If we define feeders as lists of Voronoi regions, then we quickly exceed the computer memory of a desktop PC.

- Worse yet, the time required for “point-in-polygon” testing is inherently linked to the total number of vertices comprising the polygons. A feeder boundary defined as the sum of its transformers’ “cells” just has too many Voronoi nodes.

- The number of vertices has to be reduced. **But how?**
The answer becomes obvious when we observe that most Voronoi edges are between sites of the same feeder.

- We can simply discard all the Voronoi edges that are internal to the *feeder boundary*.
- What we mean by *feeder boundary* will be explained later, but you can get a graphically sense of where the feeder boundary must be located by looking at our three example feeders (Bowen Road Substation, feeders 3122, 3171 & 3181) in this next slide.
Voronoi Cells Color-coded by Feeder
This problem of constructing feeder boundaries is analogous to farmers building fences between neighboring farms.

Each farmer wishes to construct a fence between his fields and those of his neighbors, but not between any of his own fields.

By this analogy, each “farmer” represents a substation feeder breaker.

And each of the “fields” of a farmer is analogous to the Voronoi cell of a transformer on that feeder.
1. Ownership of the Fields is Established.
2. The Surveyor Stakes the Fence Locations.
3. Farmer Brown Begins Building His Fences.
... and His Neighbors’ Fields to His Right.
Thus, He Builds His Fence in a CCW Direction.
Keeping His Own Fields Left, Farmer Brown ...
... Works His Way Back to Where He Started.
Brown’s Entire Farm is Enclosed by One Fence.
As did Brown, Green Starts from the West ...
And Likewise Keeps His Own Fields to His Left ...
Until He Arrives Back Where He Started.
But Green’s Fence Doesn’t Enclose All His Fields
So Green Continues Until All Fields are Enclosed
“Farmer Purple” Builds Three Fences...
Fence #1 ...
Fence #2 ...
... And Fence #3
Just a minute …

Isn’t “Farmer Purple’s” Fence #3 the same thing as “Farmer Green’s” Fence #4?

Well, let’s take a closer look.
As Usual, “Farmer Purple” Starts From the West ...
... And Keeps His Own Property to His Left, but ...
… in so Doing He Travels in a Clockwise Direction.

(CW Orientation Implies a Hole in Purple’s Farm.)
Two questions:

How good are these feeder boundaries?

What good are feeder boundaries?
The First Question, “How good are these feeder boundaries?” asks:

How well does each feeder boundary enclose the features of that feeder?

How well does it exclude the features of other feeders?
Here Are the Facilities of “Bowen/3122”
How Well Does This Represent All Feeders?
2878 Feeders = 6860 Polygons with 504,758 Vertices

GIS Data Extraction: ~1:55:00 hr:min:sec
File I/O: ~4:40 min:sec
CPU Time: ~0:52 min:sec

TOTAL: ~2 hours
So we can represent feeders by boundaries — what good is that?

Please remember what prompted our quest for “feeder boundaries”.

- We were looking for a way to extract feeder statistics. We are wanting to answer “hard” questions such as: “How much ______ is there per feeder.”
- We can fill that blank with a variety of useful statistics:
  - How much degraded inventory …,
  - How much capital value …,
  - How much revenue …,
  - How much return on investment …,
  - etc.
We can also use feeder boundaries to better display feeder statistics.

We can create “by-feeder” statistical maps:

- Vintage Map — average age of electrical facilities
- Facility Map — miles of primary conductor per customer
- Load Map — average per-customer kWh
- Outage Map — reliability, as measured by SAIDI value
- ROI Map — return on investment (revenue/investment)
- Demand Map — average per-customer peak kW
- Trouble Map — trouble reports that are currently open
- OPEX Map — operating expense per kWh delivered
- CAPEX Map — annual capital expense per added kWh
“Hatch Map” of 2003 SAIDI (System Average Interruption Duration Index) Values
“Prism Map” of the 2003 SAIDI (System Average Interruption Duration Index) Values
Anything else?

Are “feeder” boundaries the only boundaries that can be created by tracing the perimeter of associated Voronoi regions?

- No — we can group Voronoi regions by:
  - Protective device,
  - Feeder section,
  - Feeder,
  - Substation,
  - Service center, or
  - By whatever groupings of whatever features (not just transformers) that are meaningful.
Example Feeder Boundaries (in pale blue)
Protective Device Boundaries (in white)
Substation Boundaries (in purple)
Conclusion

These “feeder boundaries” are a useful adjunct to Oncor’s geographic information system.

- “Feeder boundaries” can be used to extract feeder-level statistics that would be otherwise unavailable.
- They can also be used to display these statistics within their geographic context.
- “Feeder boundaries” are not the only operational boundaries that can be generated by this computational method. Transformers can be grouped to produce boundaries at any chosen level of detail — feeder, substation, service center, etc.
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- Professor Held wrote “VRONI”, a commercially available program that generates the initial Voronoi diagram upon which this boundary-tracing program is built.
  - Visit his home page at — http://www.cosy.sbg.ac.at/~held/
  - Contact him by email sent to — held@cosy.sbg.ac.at