# Teaching the Divide-and Conquer Closest Pair Algorithm Using a Map-Based Visualization

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Nifty Assignment Presentation

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Coastal Carolina University

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Yet another Powerpoint-free presentation!

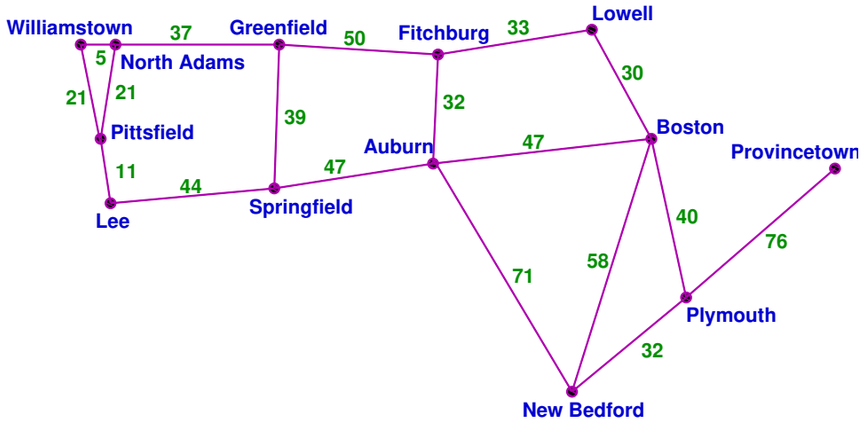
# Agenda

- A quick overview of METAL
  - Motivations
  - Travel Mapping
  - Bringing my “roadgeek” side to work: using Travel
  - Graph data derived from Travel Mapping project
  - Highway Data Examiner
  - METAL’s interactive algorithm visualizations
- METAL’s closest pairs learning module
- Wrapup/acknowledgements

These slides are at `https://courses.teresco.org/metal/talk.pdf`
and the big QR code above will take you there.

# Early Motivation

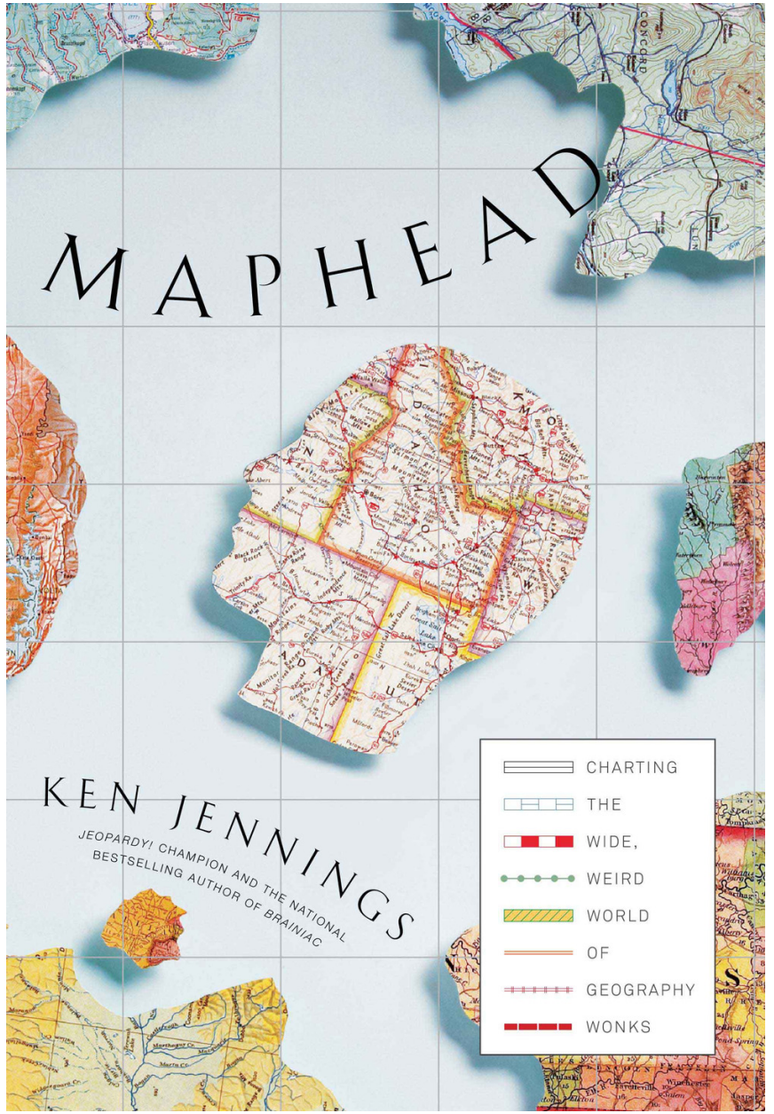
To find a good collection of data sets
for teaching graph (and other) algorithms.




I want an example that's better than this!

- Variety of data sizes
  - small sets to be manageable for testing during development
  - larger sets to be interesting and for performance analysis
- Data source
  - freely and conveniently available data sets
  - a motivating real-world connection
- Meaningful visualizations of results

# Before I was a CS Geek - I was a Map Geek



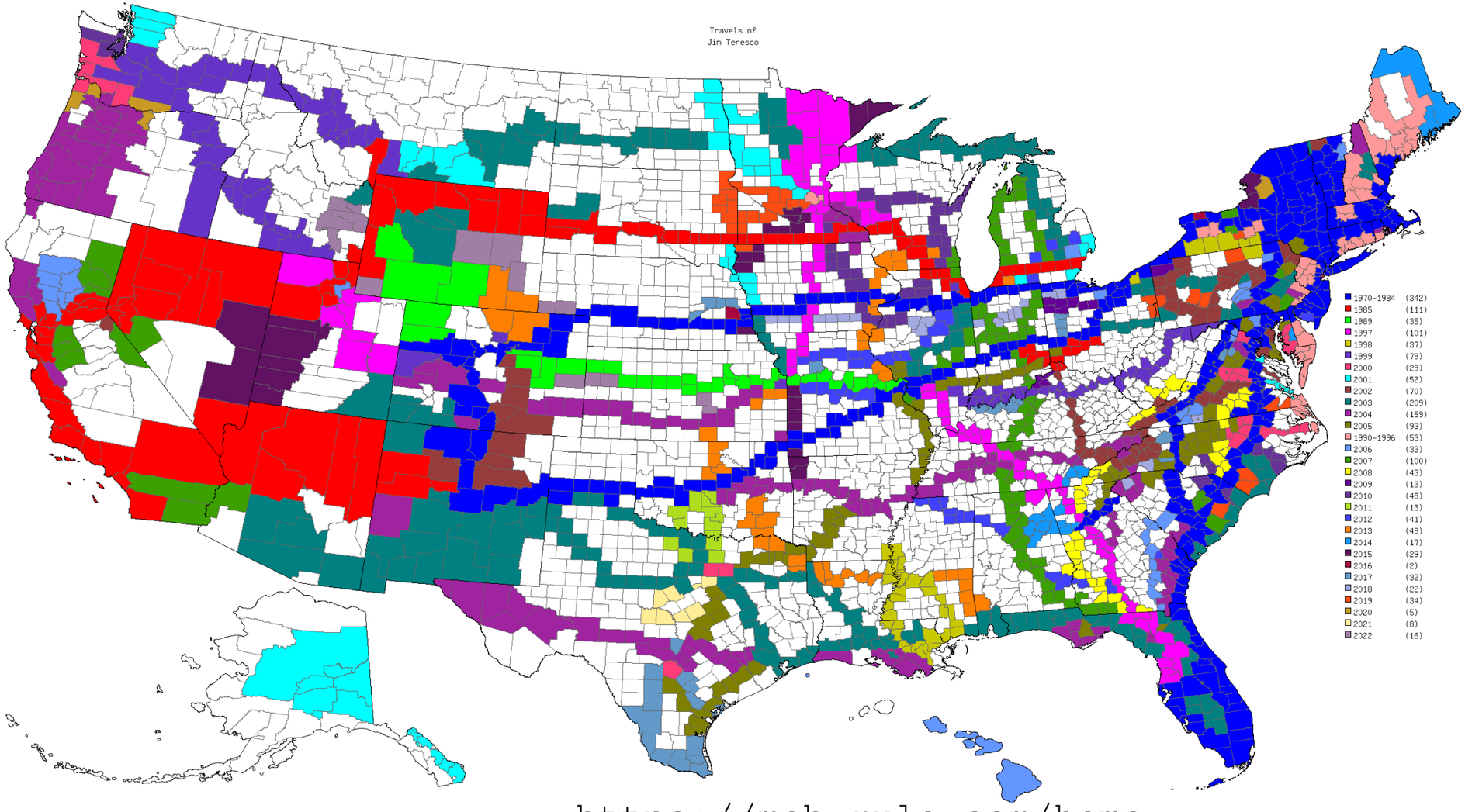
# The Well-Worn Rand McNally Road Atlas Collection


Each marked up with a highlighter to track travels.

# And I Used Highway Photography to Document my Travels


(Knuth has road sign pictures, so why not me?)

# And I Like to “Collect” Things



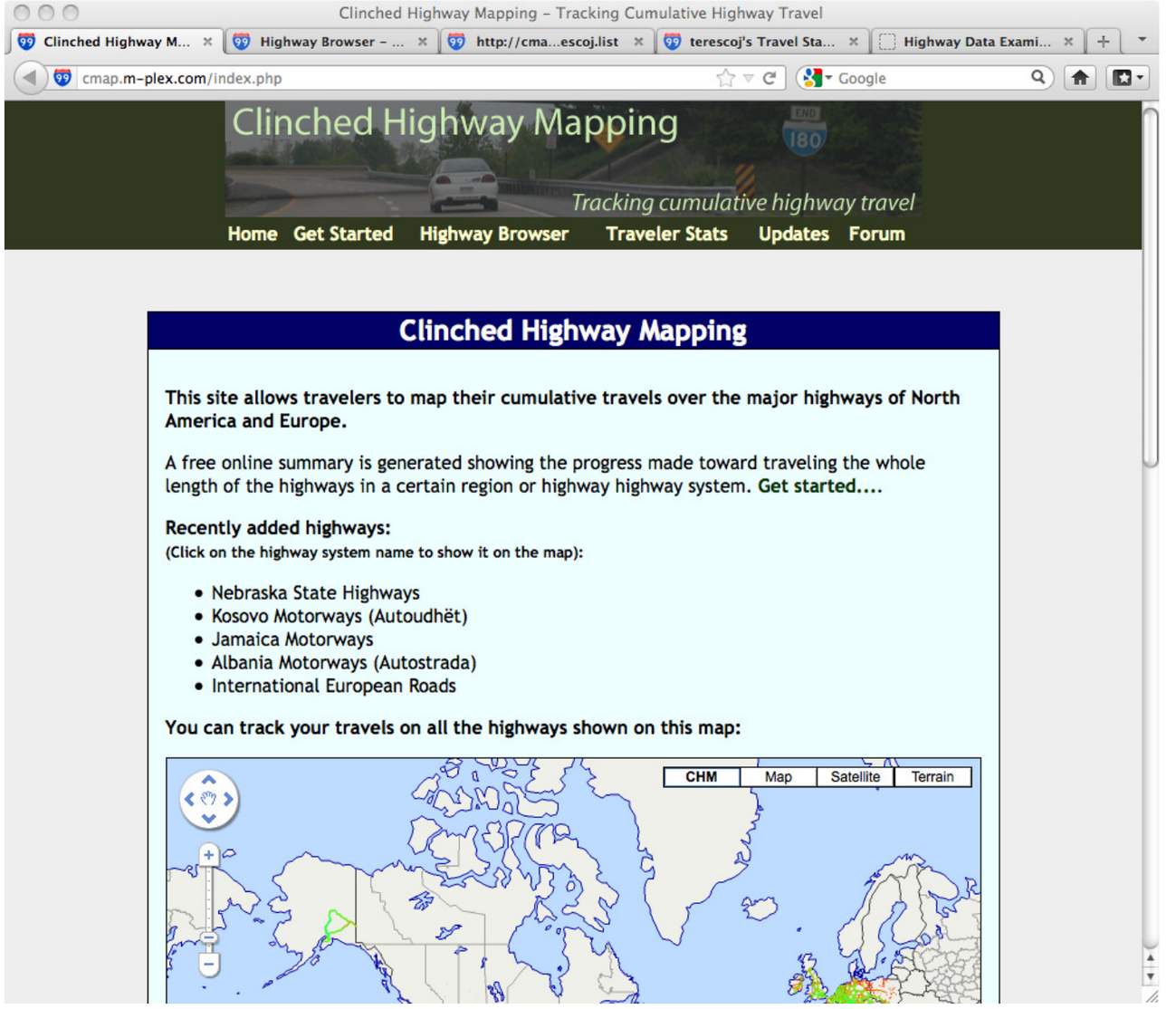

My current county count: 1875 of 3144 (59.7%)

(no new ones on this trip..)

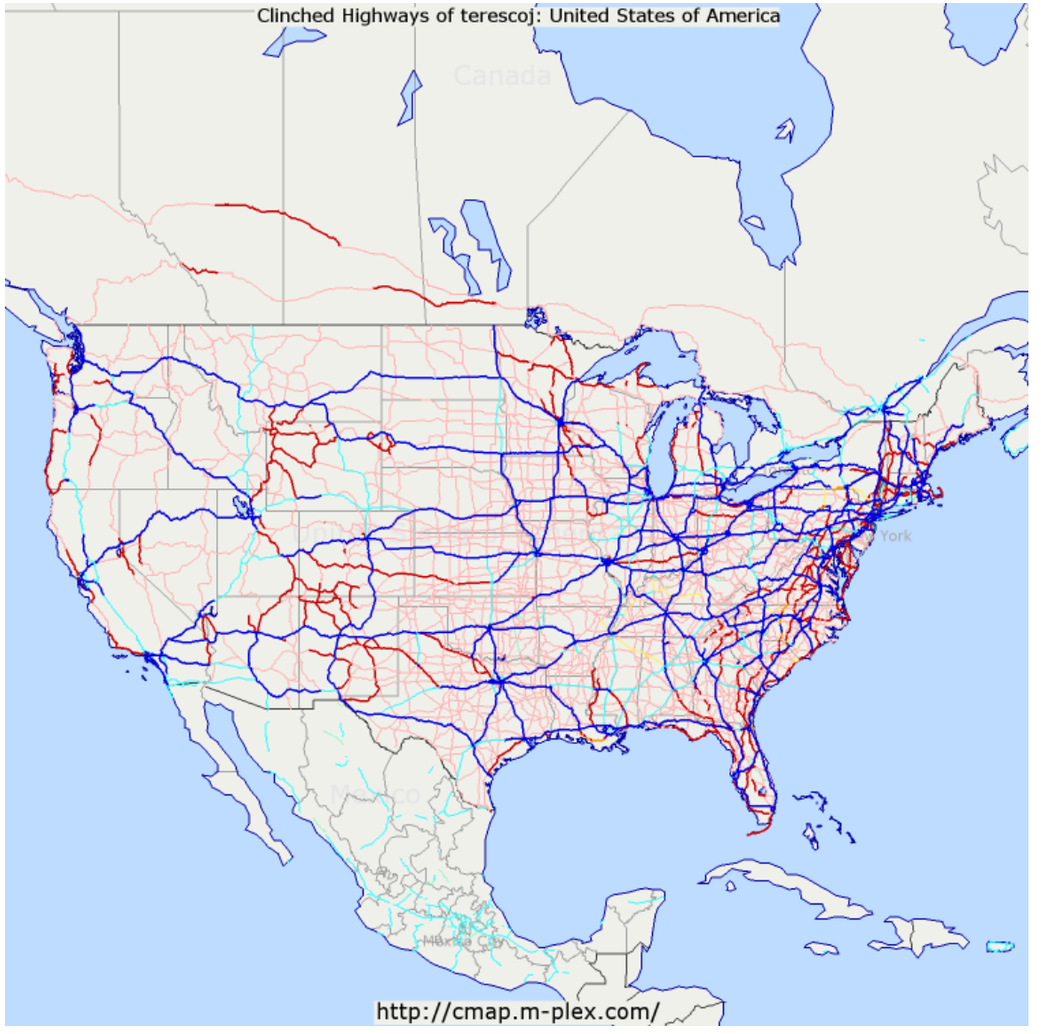
https://mob-rule.com/home

# As a “Roadgeek”, I Could Not Resist

## The Clinched Highway Mapping Project



# To Track Highway Segments I’ve Traveled



# Bringing my “Roadgeek” Side to Work

The observations, questions, and ideas that have led to the development of the tools that have evolved into today’s

**Map-Based Educational Tools for Algorithm Learning (METAL)**

- Hey, some of my data structures examples and labs are pretty boring...
- Could I use CHM (now TM) data for class examples and assignments?
- If I could do that, could I plot it on maps like CHM does?
- Can I do all this before the Dijkstra’s algorithm lab I am not really happy with that I need to assign next week?
- Hmmm, Dijkstra’s algorithm. I think I need graph data, not a bunch of individual routes.
- Who needs sleep for the next week? I can do this! I’ll create graphs and build a visualization tool too!
- All these years later, I’m still working on it!

# CHM $\longrightarrow$ Travel Mapping

- Clinched Highway Mapping went dormant in 2014...
  - my role there was as a data contributor and user, but not administrator
  - the site exists, but is not actively maintained
  - CHM users and contributors decided to build a replacement
- Summer 2015: Birth of the Travel Mapping project
  - main site: `https://travelmapping.net/`
  - GitHub organization: `https://github.com/TravelMapping`
  - my role is as primary developer and project manager
  - highway data is constantly improving and expanding: now over 66,000 commits to the highway data repository by 24 contributors
- Site users create and submit list of highway segments, e.g.,

  `https://github.com/TravelMapping/UserData/blob/master/list_files/terescoj.list`
- Enjoy the maps and statistics of your and others' travels!

  `https://travelmapping.net/user/mapview.php?u=terescoj&rg=SC`

# METAL Graph Data

METAL generates graphs from TM data for many countries, regions, highway systems, and local areas.

`https://travelmapping.net/graphs/`

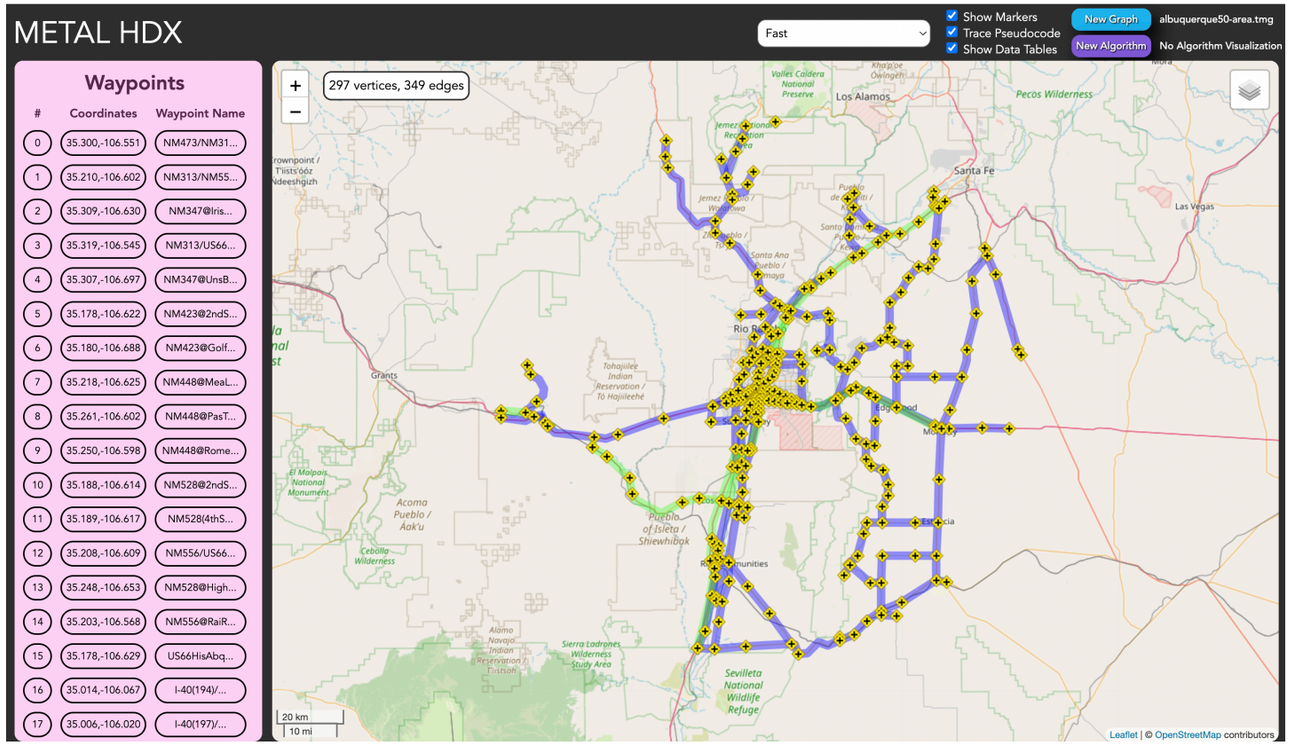
A selection from among the 1200+ graphs provided by METAL:

| Data set | $\|V\|$ | $\|E\|$ |
|---|---|---|
| ABW-region: All Aruba highways | 28 | 37 |
| DC-region: All District of Columbia highways | 97 | 94 |
| YT-region: All Yukon highways | 225 | 221 |
| albuquerque50-area: All plotted routes within 50 miles of Albuquerque | 298 | 350 |
| siena50-area: All plotted routes within 50 miles of Siena College | 1244 | 1464 |
| SC-region: All South Carolina highways | 3596 | 4575 |
| west-indies: All plotted routes in the West Indies | 4697 | 6027 |
| usai-system: United States Interstate highway system | 18,342 | 18,735 |
| USA-national: All plotted NHS routes in the U.S. | 73,055 | 78,266 |
| USA-country: All plotted (state and national) highways in the U.S. | 185,177 | 220,534 |
| tm-master: All plotted highways Worldwide | 625,257 | 767,013 |

Graphs are archived periodically to avoid disruptive changes.

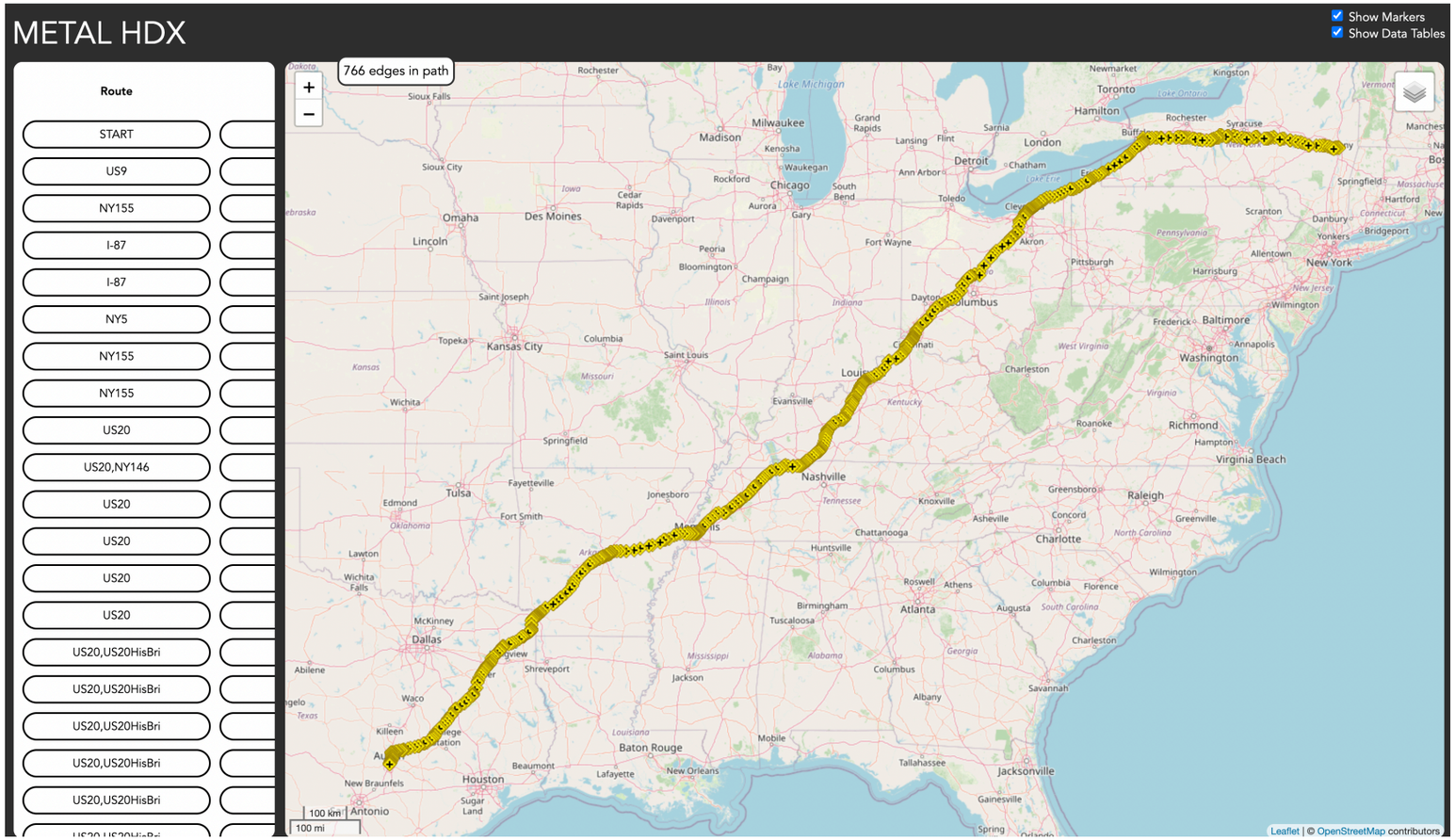
# Visualizing the Results: Leaflet and OpenStreetMaps

- Leaflet provides a free application programmer interface (API) to overlay custom data on OpenStreetMap (and other) map tiles
  - API's Javascript classes and methods are fairly easy to learn and use
  - Formerly used Google Maps, but free non-commercial use terminated
- METAL's **Highway Data Examiner (HDX)** overlays TM/METAL data
  - Graph of plotted highways within 50 miles of Albuquerque:



# A Shortest Path Result

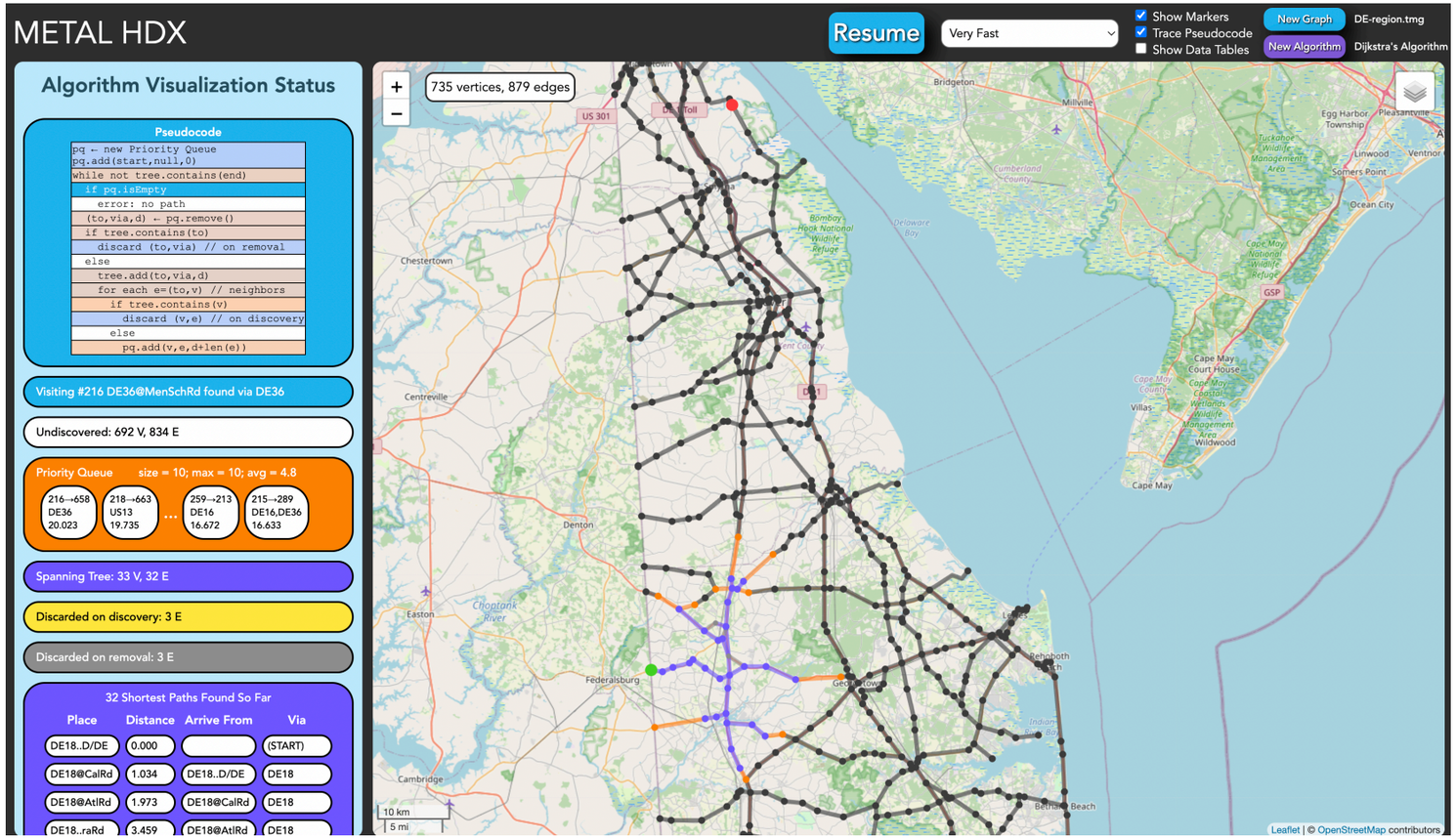
HDX can also visualize the results of programs that use METAL data.




Shortest path from Siena College to Austin, Texas, generated using “Dijkstra’s Road Trip” reference solution, displayed in HDX as a “pth” file.

# METAL's Interactive Algorithm Visualization

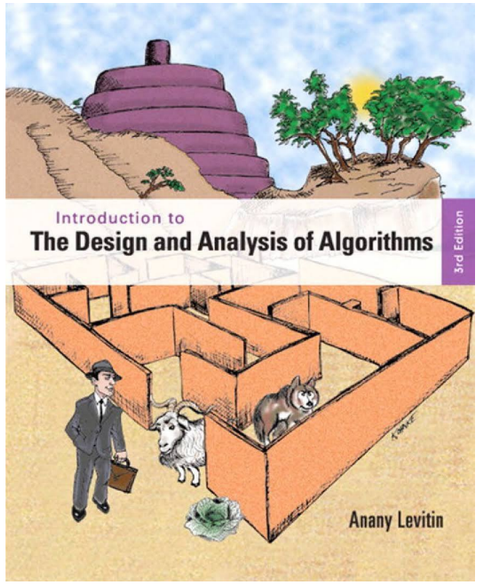
- Interactive visualizations of algorithms rather than just the data and results
- The focus of a 2018 SIGCSE paper
- Implemented in HDX



# My Nifty Assignment

## Divide and Conquer Closest Pairs AV and Learning Module

- Goal: learn the divide and conquer closest pairs algorithm more quickly and at a deeper level
- 60-90 minute in-class, lab, or homework activity
- First used in Spring 2023 Analysis of Algorithms course
- Based on the algorithm as presented in Levitin's text




## Let's go to the learning module

https://bit.ly/47hjV3q

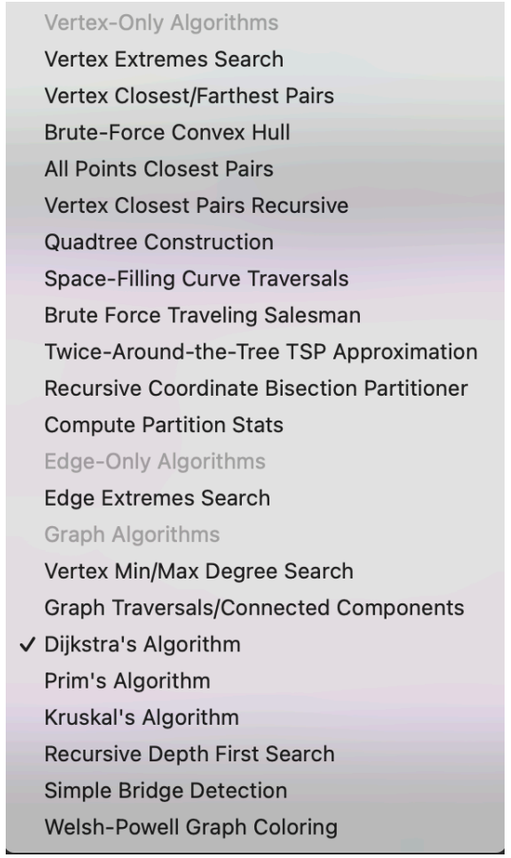
# Key METAL Project Components

We have seen METAL's main components.

1. Large set of graphs for a variety of highway systems generated from TM highway data
   - real world connection and visualization on maps
   - wide variety of sizes
2. HDX to visualize graphs
   - graph data as provided by METAL
   - also can visualize data in other formats generated by programs that use the graphs, such as shortest paths, sets of points, and lists of points
3. Interactive algorithm visualizations within HDX
   - Our experience: the *scalability* matters: small graphs to see the details and larger to see big picture behavior (think: BFS vs. DFS)

# Recent METAL Enhancements

- Graph variants and file formats
  - graph files with traveler data
  - partitioned graph file format
  - intersection-only graphs
- User interface and usability
  - redesigned and more intuitive interface
  - conditional breakpoints
  - more execution speeds
- Many algorithm visualizations
  - see current list at the right
- Instructor suppport
  - graph archives
  - query string parameters to load graphs, select AVs and parameters
  - just started: creation of learning modules



# Acknowledgements


- TM credits at `https://travelmapping.net/credits.php`
- Thank you to the Saint Rose students who have contributed to the project, especially Razie Fathi (now at Smith and still a key project contributor), Dan Priddle, Kevin Bayly, Shipra Goel, Rashmi Reddy Podduturi, and Paul Amodeo.
- Thank you to my Summer 2017, Summer 2018, and Summer 2019, Summer 2021, Summer 2022, and Summer 2023 students: MariaRose Bamundo, Arjol Pengu, Clarice Tarbay, Michael Dagostino, Abdul Samad, Eric Sauer, Zach Goodsell, Tyler Gorman, Alissa Ronca, Bailey Cross, Spencer Moon, Luke Jennings (x2), Mark Verra, and Michael Plekan (x2). Their work was made possible through the support of the Summer Scholars Program, Center for Undergraduate Research and Creative Activity (CURCA), at Siena College.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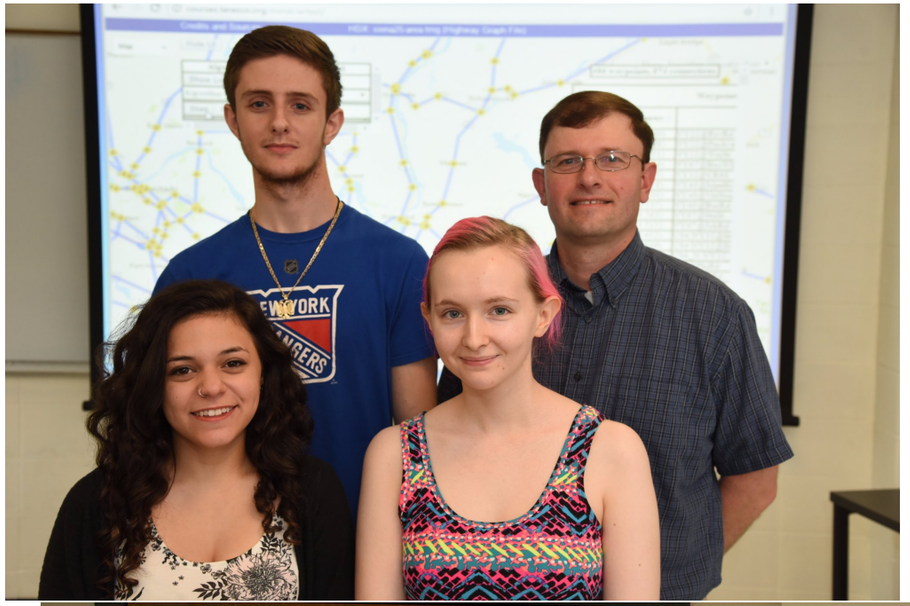

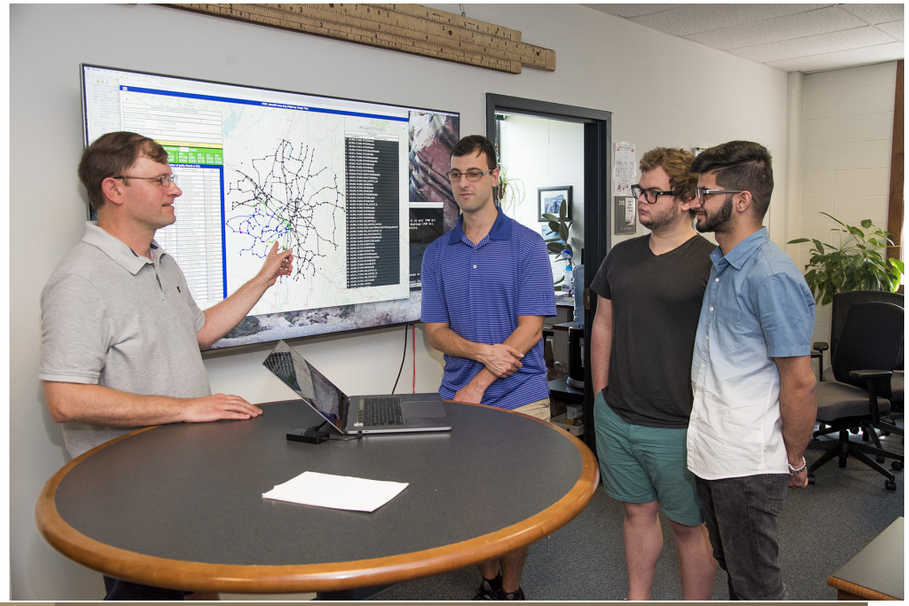

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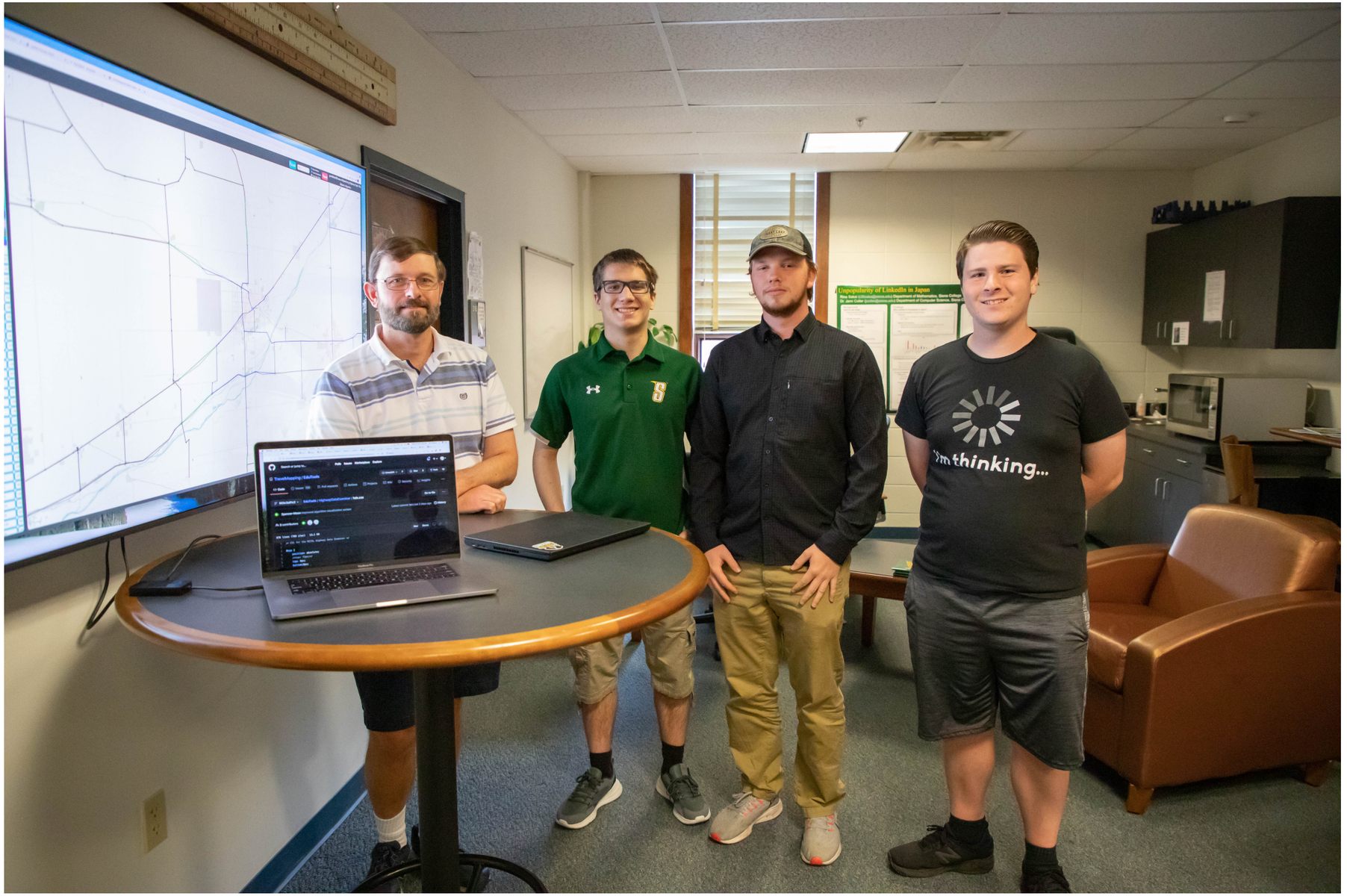

# Acknowledgements

# Use It!

- METAL has been used various courses
- See `https://courses.teresco.org/metal/using.html` for examples including
  - an introductory assignment early in data structures
  - an introductory assignment early in algorithms
  - usage in a "Best Of" data structure
  - convex hull class example
  - assignment to analyze convex hulls
  - Dijkstra's Road Trip
  - threading intro
- METAL data and HDX are publicly available
- Instructor resources – gradually being developed into learning modules – available on request
- **Please contact me if you want to give it a try!**

# New Feature: Graphs with Traveler Information

Spring 2019: Implemented an idea that had been tossed around for a while.

- Idea: take advantage of the traveler data from the TM project
- TM users indicate which highway segments they have traveled
- Those segments correspond directly to the edges in METAL graphs

# New Feature: Graphs with Traveler Information

- Augmented the `collapsed` format graphs to a new format called `traveled`
- Header includes the number of unique travelers across all graph edges

```
TMG 2.0 traveled
786 871 148
```

This is from `rmu25-area-traveled.tmg`, indicating 148 unique travelers.

- Each graph edge includes a hexadecimal string with enough bits to represent each traveler

```
653 640 PA978 00000000000040004001000004000000840
345 254 I-376,US22,US30 11FBC75BD5EDEDB5E7FF5BEECF587B227B8FD
```

We can see not too many ‘1’ bits on the segment of Route 978, but many more on the segment that carries I-376, US 22, and US 30 through the Pittsburgh area.

- Traveler usernames are included in the last line to allow mapping of bits to users, if desired

# Spring 2019 Project

- Part of a final project for *Analysis of Algorithms*

**`http://courses.teresco.org/cs385_s19/probsets/ac/`**

- Each individual or group was required to use METAL data in some form for at least one algorithm studied
- Projects included
  - simple variations on searches: most visited/traveled, least visited/traveled
  - variations on Dijkstra's/Prim's/graph traversals that gave weight to heavily- or lightly-traveled segments
  - convex hull of the places visited by a particular traveler
- Presented as a session in Siena's year-end "Academic Showcase" and was heavily attended!

# Current Work, Plans, and Ideas for the Future

- Continue to add new data sets and improve the quality of existing sets
- More examples/assignments/labs/teaching modules built around METAL's data and visualizations
- Expanded and improved interactive algorithm visualization
  - including traveler information
  - recursion
  - parallel algorithms
  - more complex algorithms
  - student algorithm "implementations"
- More studies measuring the effectiveness of METAL

# Interested?

http://courses.teresco.org/metal/