BAYESIALAB

Spatial Optimization

With Bayesian Networks & BayesiaLab

The webinar will start at:

13:00:00

The current time is:

13:00:54

Central Daylight Time, UTC-5

Today's Program

Introduction

- Our Team
- Our Company
- Our Technology

Introductory Software Demo

- Mapping with BayesiaLab and the Google Maps API

20 min.

Spatial Computation & Optimization

- Example 1: Drive Time Bands
- Example 2: Hub Location Optimization

40 min.

Your BayesiaLab Team Today

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stacey.blodgett@bayesia.us

clare.gora@bayesia.us

Disambiguation

BAYESIA
Your Decision Partner

Our Company

BAYESIALAB

Our Product

The Paradigm

BAYESIAN NETWORKS*

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Computer Science Department
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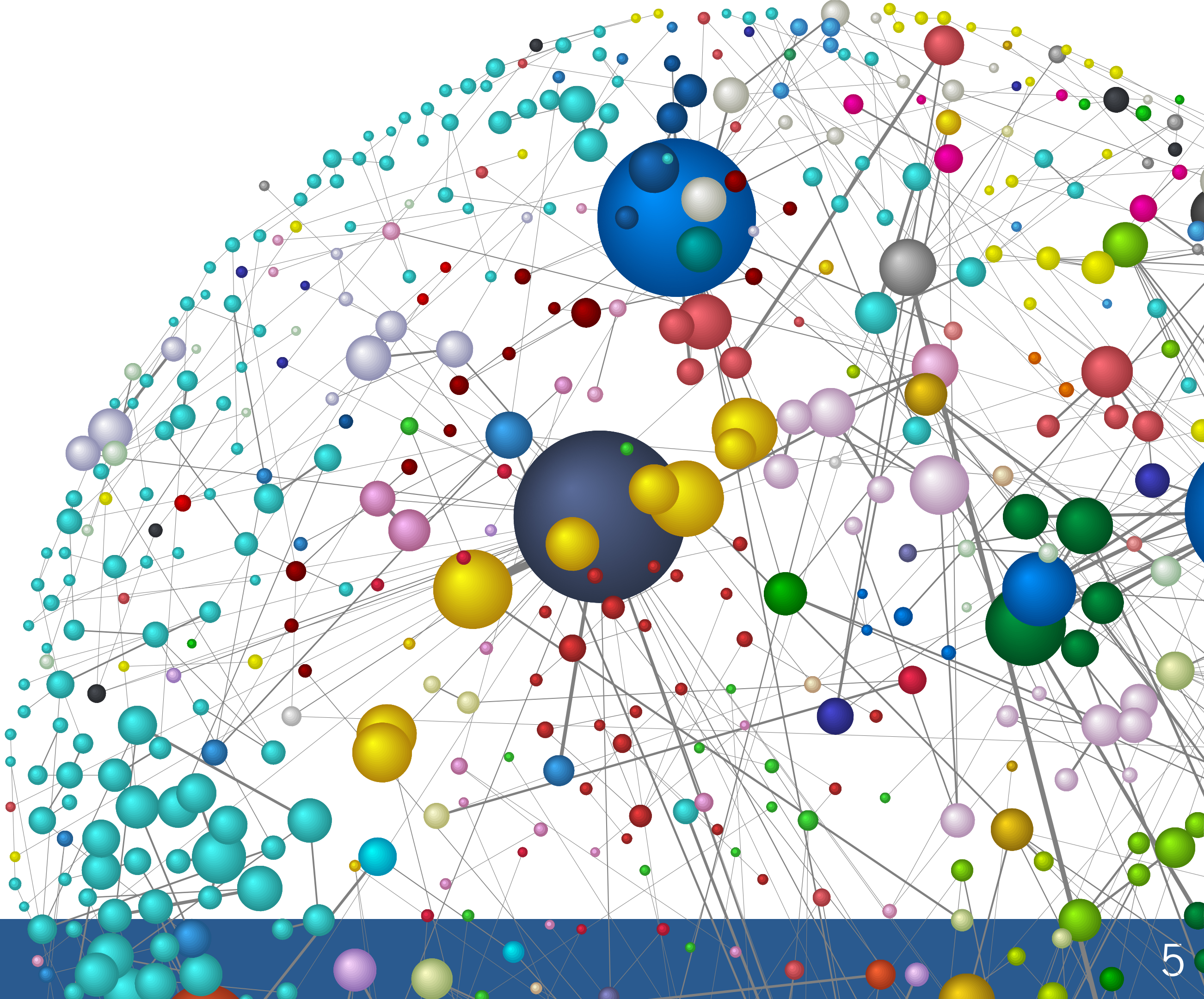
Bayesian networks were developed in the late 1970's to model distributed processing in reading comprehension, where both semantical expectations and perceptual evidence must be combined to form a coherent interpretation. The ability to coordinate bi-directional inferences filled a void in expert systems technology of the early 1980's, and Bayesian networks have emerged as a general representation scheme for uncertain knowledge [Pearl, 1988, Heckerman *et al.*, 1995, Jensen, 1996, Castillo *et al.*, 1997].

Bayesian networks are directed acyclic graphs (DAGs) in which the nodes represent vari-

BAYESIA

Your Decision Partner

Co-founded in 2001
by Dr. Lionel Jouffe &
Dr. Paul Munteanu



BAYESIALAB

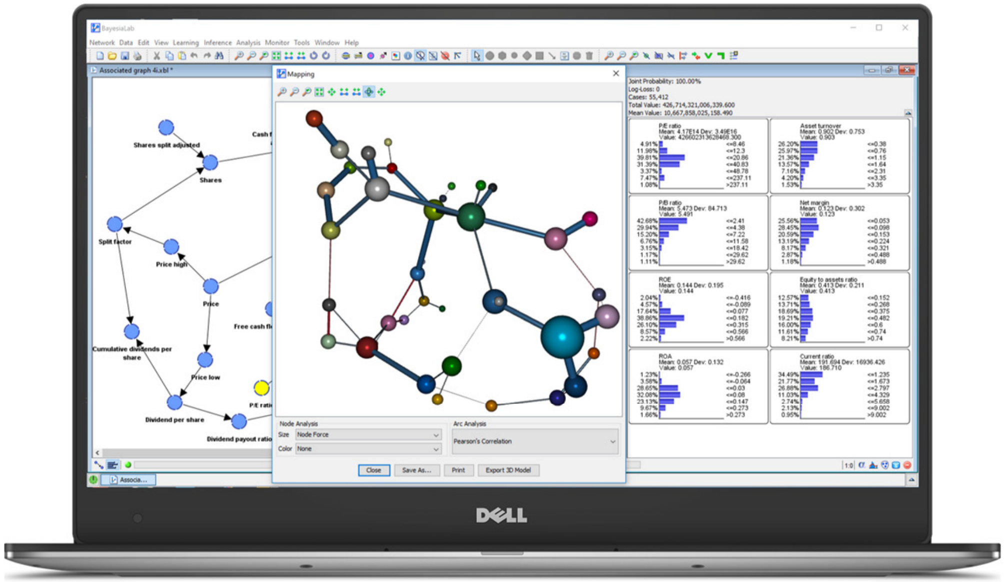
Bayesian Networks & BayesiaLab

A Practical Introduction for Researchers

- Free download:
  www.bayesia.com/book
- Hardcopy available on Amazon:
  http://amzn.com/0996533303

20,000
Downloads

BAYESIALAB



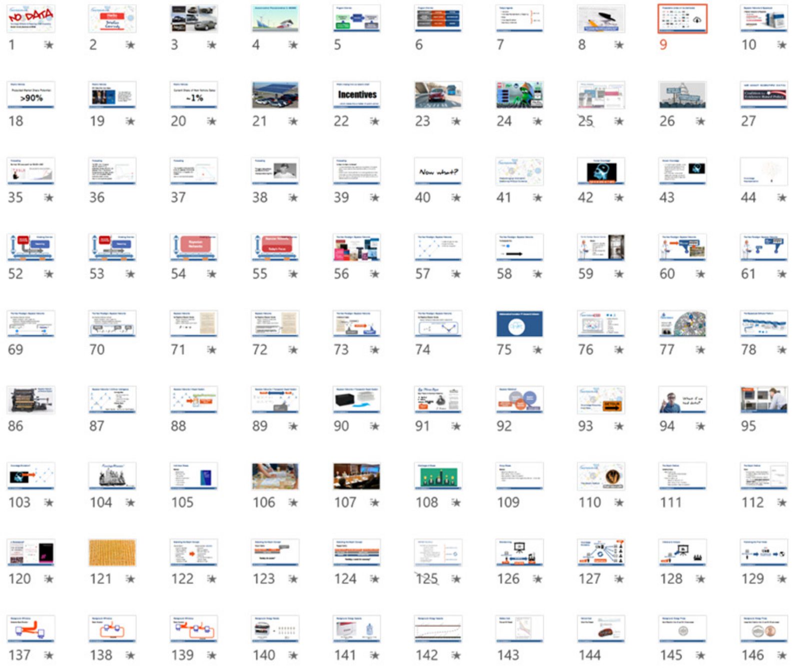
A desktop software for:

- encoding
- learning
- editing
- performing inference
- analyzing
- simulating
- optimizing

& GIS Mapping

with Bayesian networks.

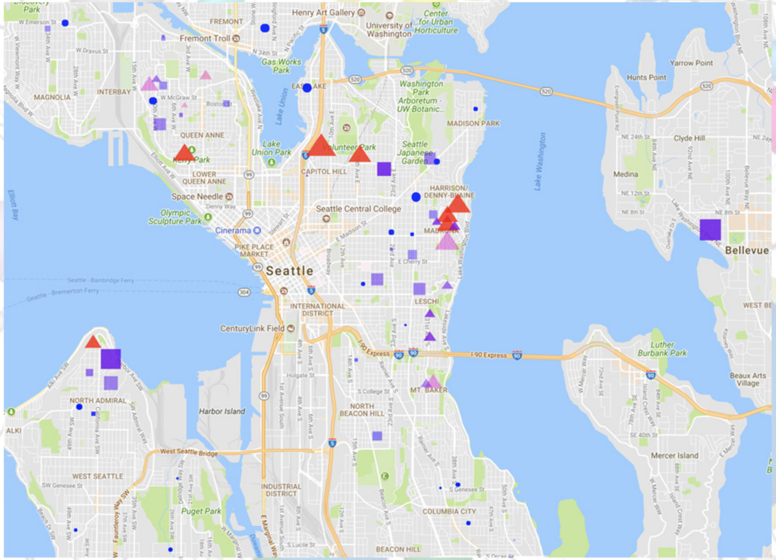
Webinar Slides, Data, and Recording Available



Motivation

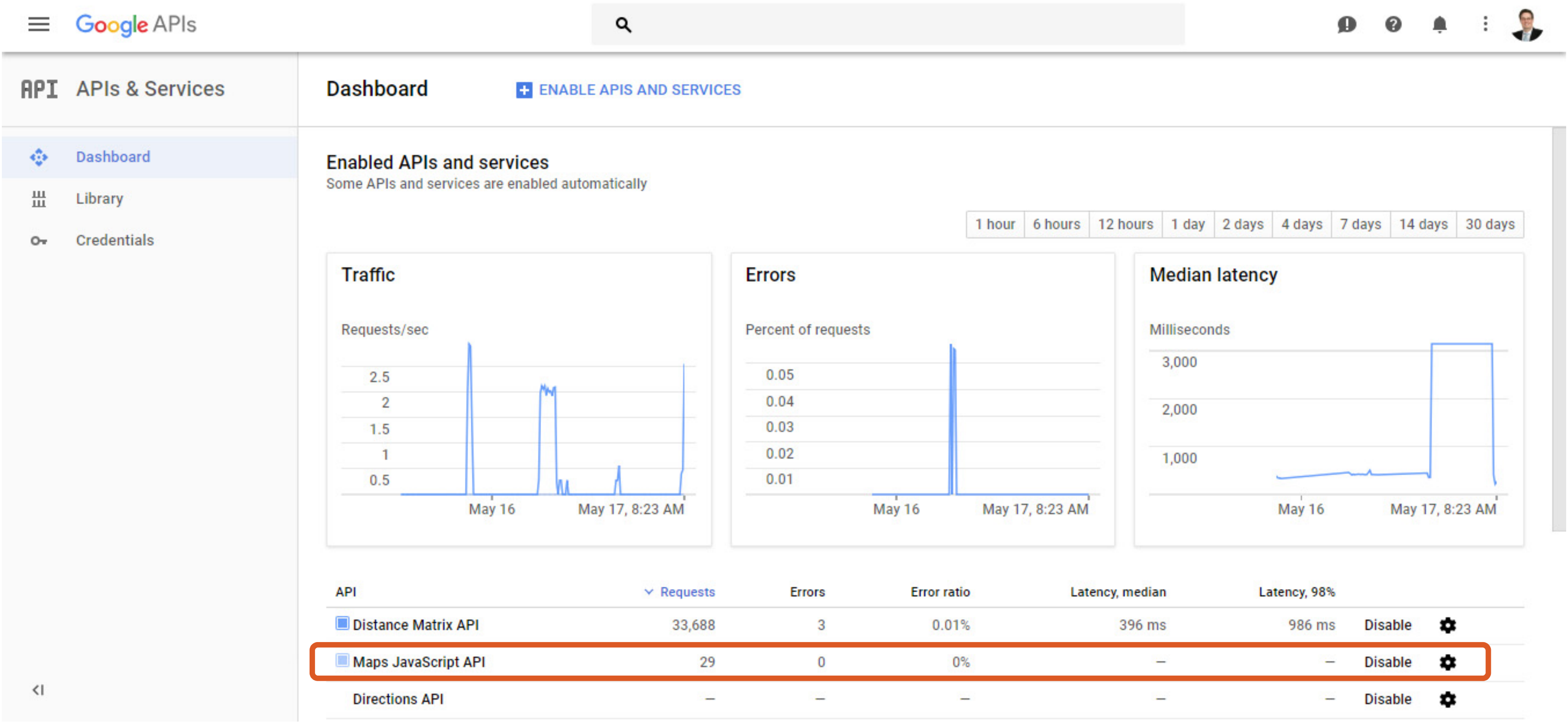
WASHINGTON
Seattle
Olympia
Spokane
Portland
Salem
Eugene
OREGON
IDAHO
Boise
Pocatello
MONTANA
Missoula
Helena
Butte
Billings
NORTH DAKOTA
Bismarck
Fargo
Grand Forks
SOUTH DAKOTA
Pierre
Rapid City
Sioux Falls
WYOMING
Casper
Cheyenne
MINNESOTA
Duluth
Minneapolis
St Paul
WISCONSIN
Green Bay
Milwaukee
Madison
MICHIGAN
Grand Rapids
Lansing
Detroit
NEVADA
Reno
Carson City
UTAH
Salt Lake City
Provo
NEBRASKA
Omaha
Lincoln
IOWA
Sioux City
Des Moines
Cedar Rapids
ILLINOIS
Chicago
Peoria
Springfield
INDIANA
Fort Wayne
Indianapolis
OHIO
Toledo
Cleveland
Columbus
Cincinnati
PENNSYLVANIA
Pittsburgh
Harrisburg
Philadelphia
Scranton
NEW YORK
Buffalo
Syracuse
Albany
New York
Burlington
Montpelier
Concord
Augusta
Bangor
Portland
MAINE
VERMONT
NEW HAMPSHIRE
MASSACHUSETTS
Boston
Springfield
Providence
RHODE ISLAND
Hartford
CONNECTICUT
NEW JERSEY
Trenton
DELAWARE
Dover
MARYLAND
Baltimore
Annapolis
Washington
DC
San Francisco
Oakland
San Jose
Sacramento
CALIFORNIA
Fresno
Bakersfield
Los Angeles
San Bernardino
San Diego
Las Vegas
COLORADO
Fort Collins
Denver
Pueblo
KANSAS
Topeka
Kansas City
Wichita
MISSOURI
Jefferson City
St Louis
Springfield
KENTUCKY
Louisville
Frankfort
Lexington
Evansville
WEST VIRGINIA
Charleston
VIRGINIA
Richmond
Norfolk
Virginia Beach
ARIZONA
Flagstaff
Phoenix
Tucson
NEW MEXICO
Santa Fe
Albuquerque
Roswell
El Paso
OKLAHOMA
Tulsa
Oklahoma City
Amarillo
Lubbock
TEXAS
Fort Worth
Dallas
Austin
San Antonio
Houston
ARKANSAS
Fort Smith
Little Rock
TENNESSEE
Nashville
Knoxville
Memphis
NORTH CAROLINA
Winston-Salem
Greensboro
Raleigh
Charlotte
Wilmington
SOUTH CAROLINA
Greenville
Columbia
Charleston
MISSISSIPPI
Jackson
Meridian
Biloxi
LOUISIANA
Shreveport
Baton Rouge
New Orleans
ALABAMA
Birmingham
Montgomery
Mobile
GEORGIA
Atlanta
Macon
Columbus
Savannah
FLORIDA
Tallahassee
Jacksonville
Orlando
Tampa
Miami


MASSACHUSETTS AVE NW
Franklin Park
50 ft
0.20 mi
N

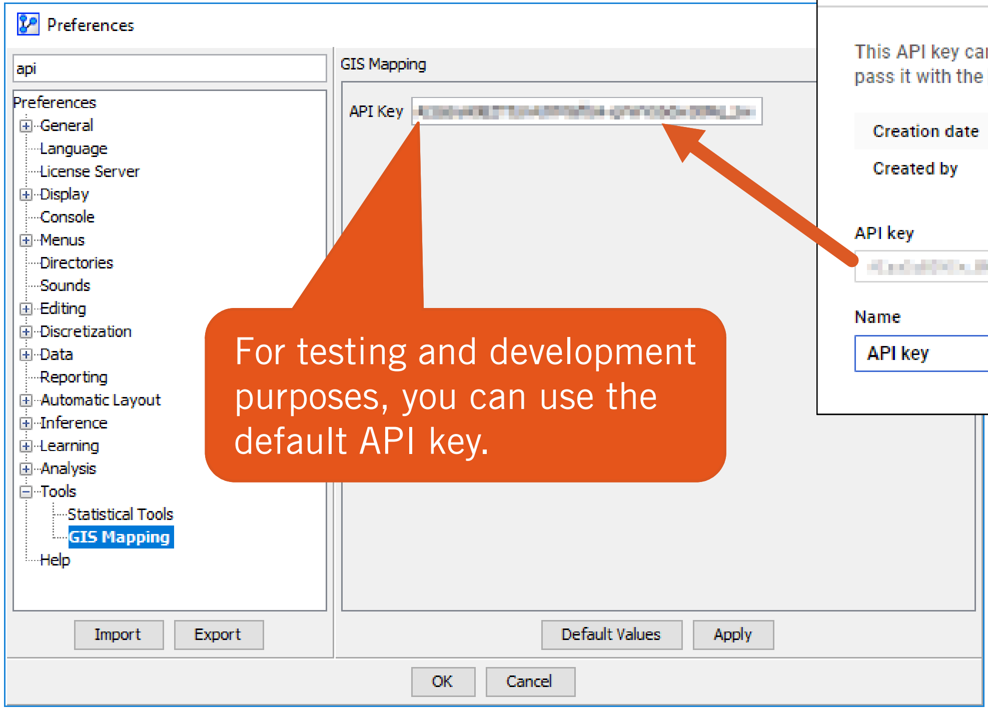


GIS Mapping with BayesiaLab and the Google API

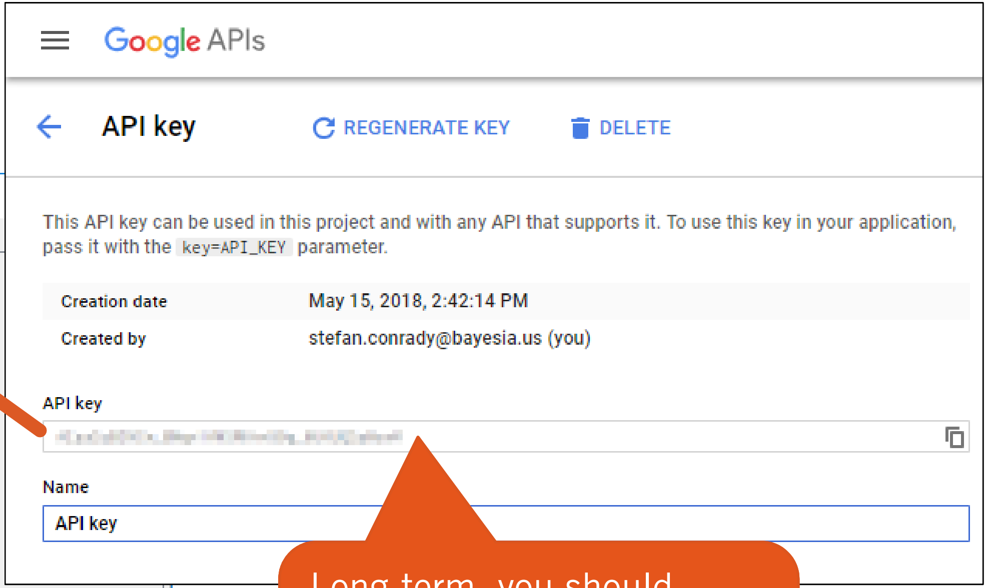
Google Maps JavaScript API



BayesiaLab Setup



For testing and development purposes, you can use the default API key.

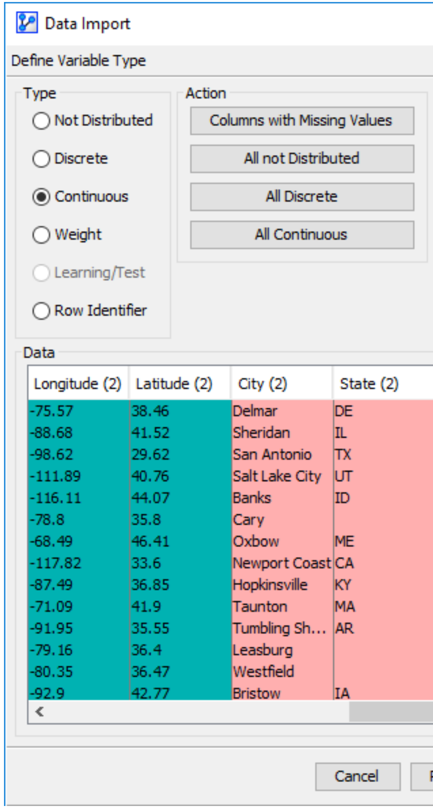


Long-term, you should obtain your own Google API key so you are not subject to any API call limitations.

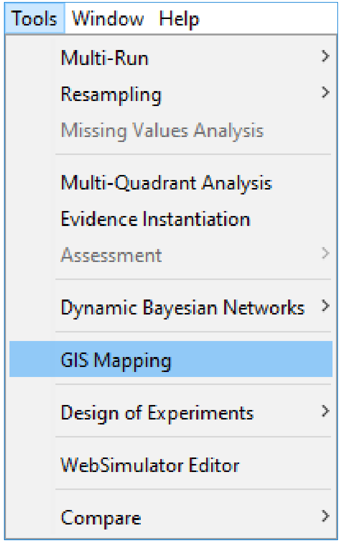
GIS Mapping with BayesiaLab and the Google API

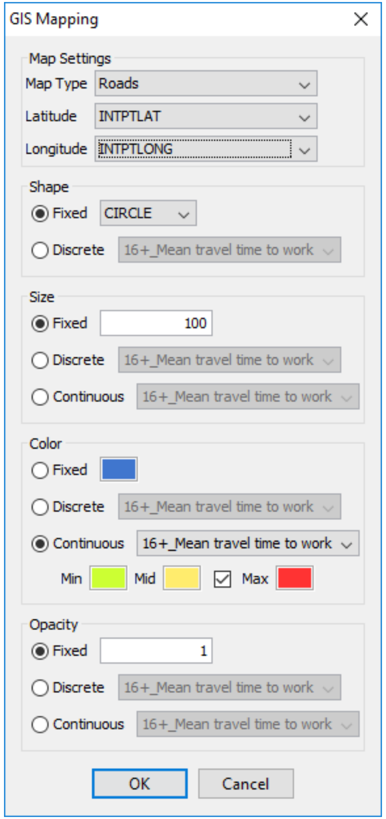
The Basics

- BayesiaLab can display observed or inferred values with coordinates on a Google map.
- Longitude and latitude are used as coordinates.
- Longitude and latitude must be defined as continuous variables and **discretized** during import, even though they will be used as **undiscretized** values for map display.



GIS Mapping with BayesiaLab and the Google API



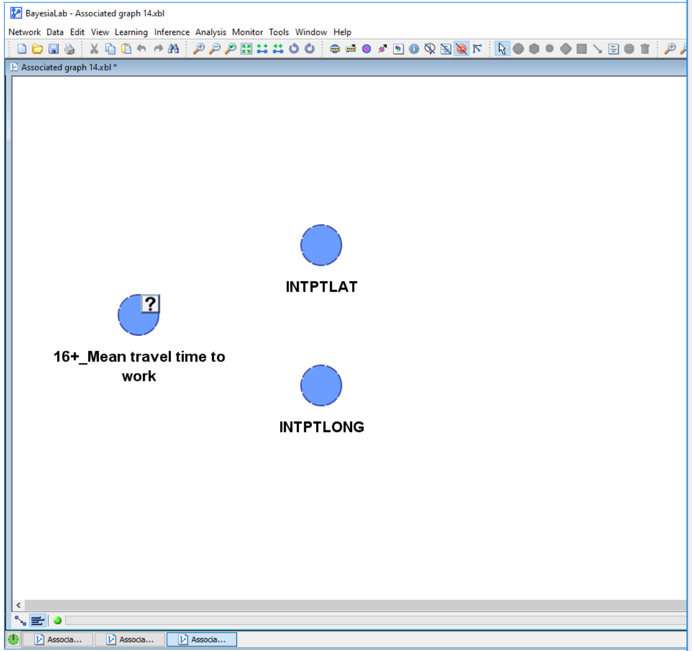


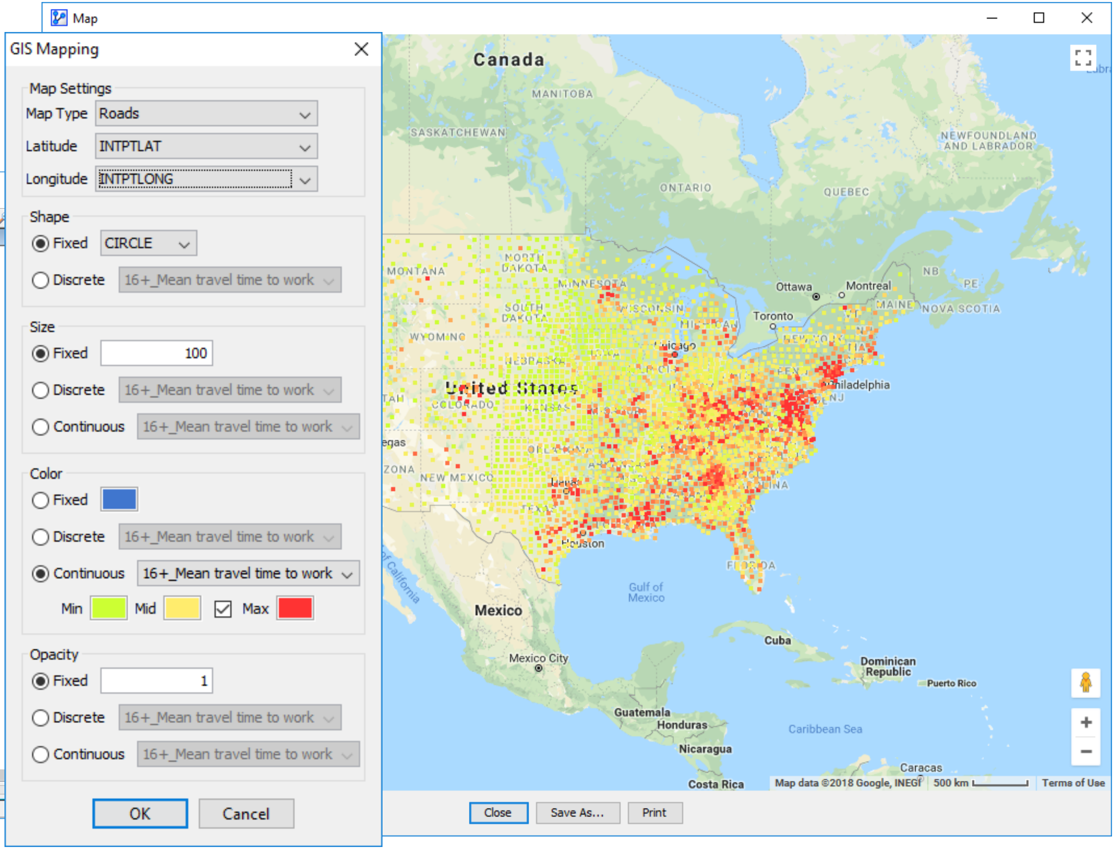
Four attributes can be displayed per observations:

- Shape
- Size
- Color
- Opacity

Introductory Example: Mapping Commuting Time

Commuting Time by County





Spatial Learning and Optimization

Bayesian Networks & BayesiaLab

Spatial Learning and Optimization

Optimization Problems Under Consideration

1. One origin, one destination → Shortest Path Problem
2. One origin, many destinations → Drive Time Bands
3. Many origins, one destination → Store Location Problem
4. Many origins, one hub, many destinations → Hub Location Problem
5. Many origins, multiple hubs, many destinations → Multi-Hub Location Problem

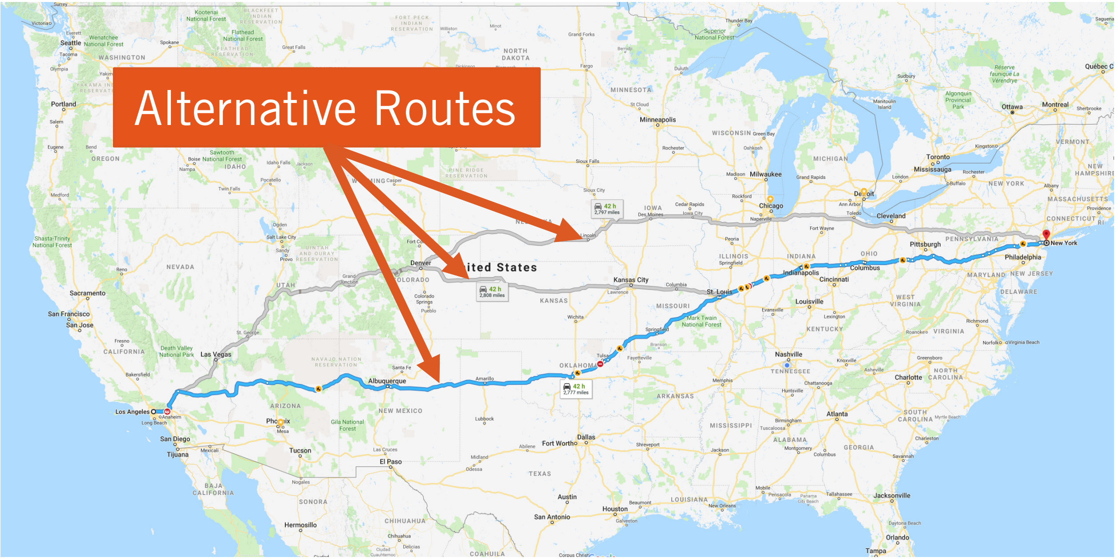
Common Objective

- Minimize "cost function," e.g., travel time, distance, fuel consumption, number of turns, etc.
- Further assumption: all "participants" have same objective.

Drive Time Bands

Computing the “Cost” for One Origin and One Destination

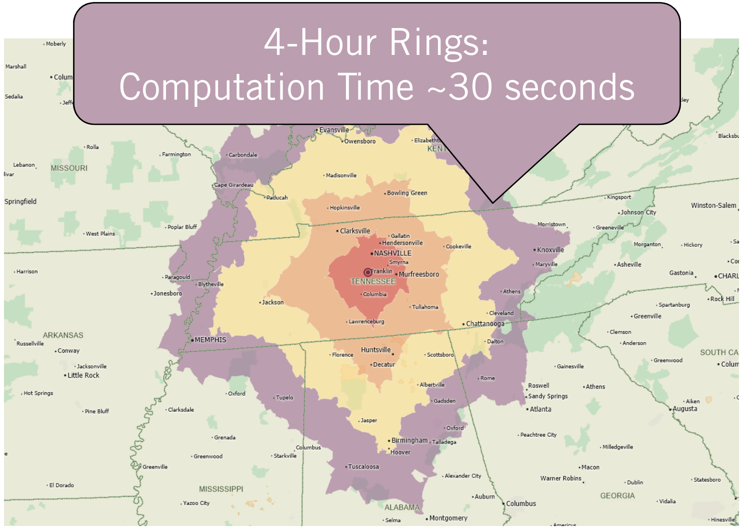
- “Search the Map” ➔ slow, but accurate



Drive Time Bands

Computing the Cost for One Origin and Many Destinations

- “Search the Map” ➔ slow, but accurate



Drive Time Bands

Computing the Cost

- "Search the Map" ➔ slow, but accurate

- Great-Circle Distance Computation

$$d = 2r \arcsin\left(\sqrt{\operatorname{hav}(\varphi_2 - \varphi_1) + \cos(\varphi_1)\cos(\varphi_2)\operatorname{hav}(\lambda_2 - \lambda_1)}\right)$$

$$= 2r \arcsin\left(\sqrt{\sin^2\left(\frac{\varphi_2 - \varphi_1}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right)$$

- Easy and fast to calculate.
- "As the crow flies" may be an unrealistic assumption.
- Travel time may be more relevant that distance.

Drive Time Bands

Idea: “Create a Look-Up Table for All Origin-Destination Pairs”

- 29,788 ZIP Codes in the U.S.
- A complete distance matrix would contain 887,324,944 cells.
- Current computation speed with Google Distance Matrix API: 2 requests/sec.
- Estimated computation time: ~14 years.

Approximate!

Drive Time Bands

Idea

- Approximation through machine learning.

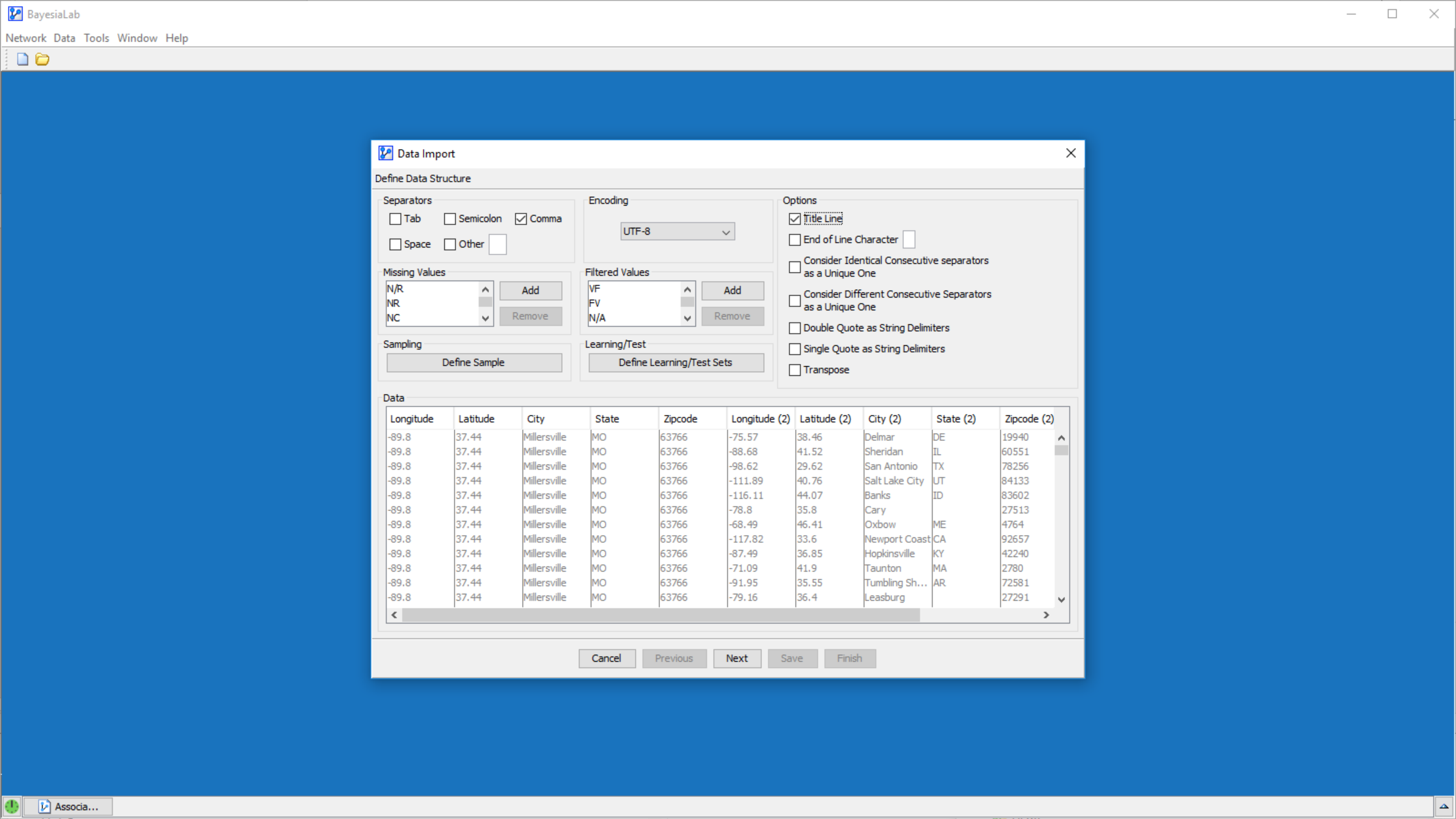
Proposed Approach

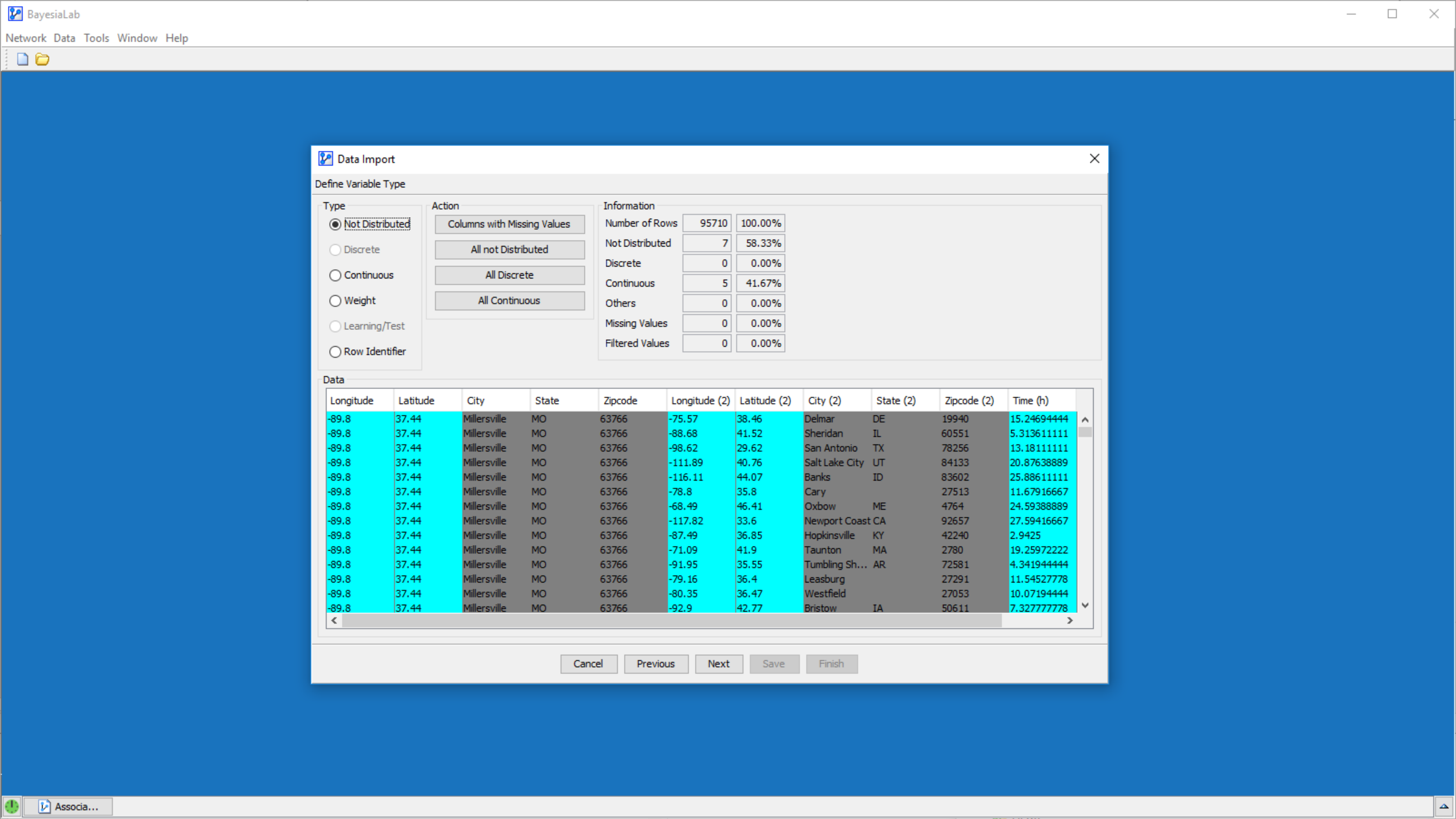
- Utilize database of actual point-to-point travel data.
- Learn a Bayesian network from this dataset.
- Now we can infer the "cost" as a function of origin and destination.

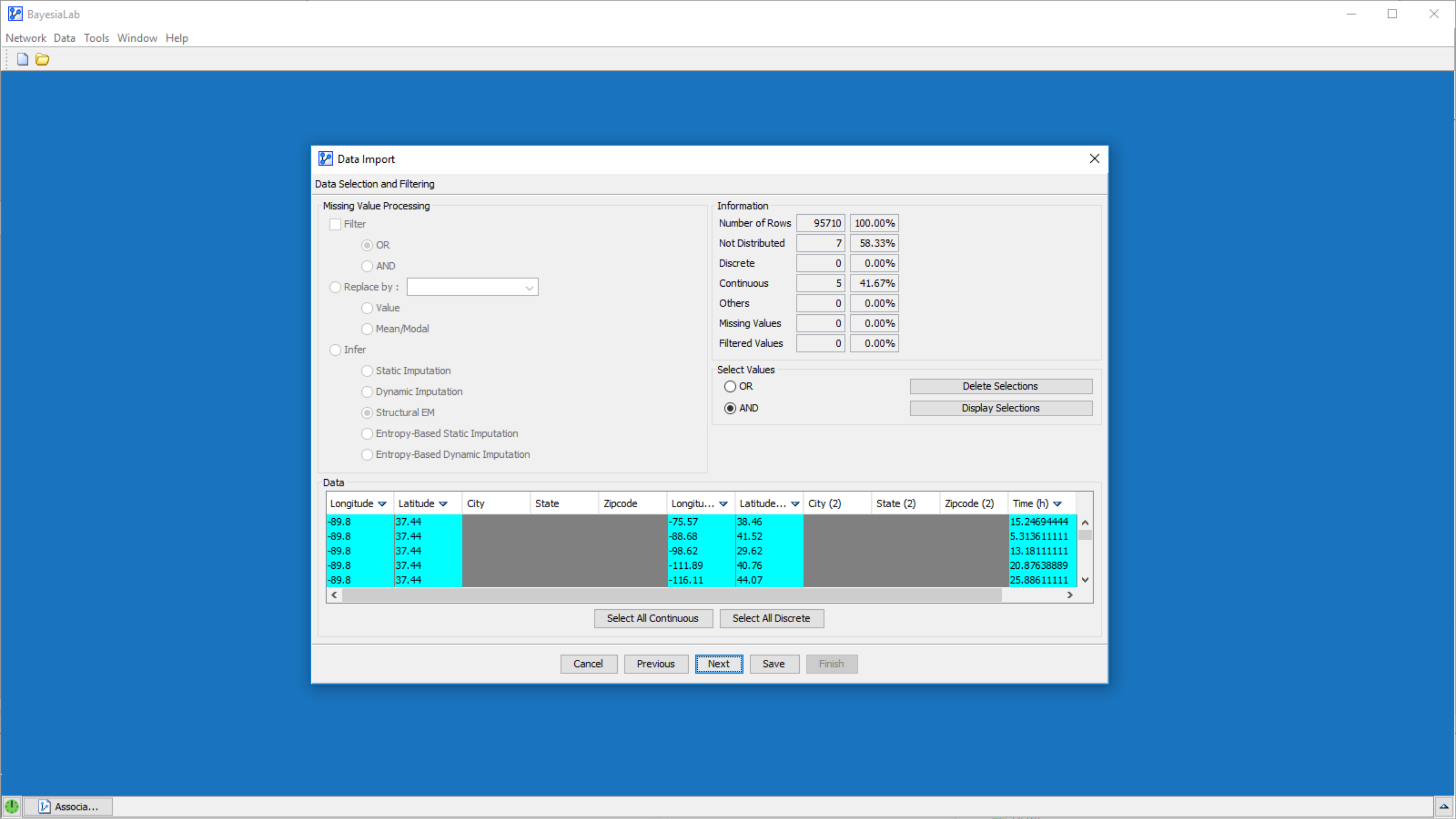
Drive Time Bands

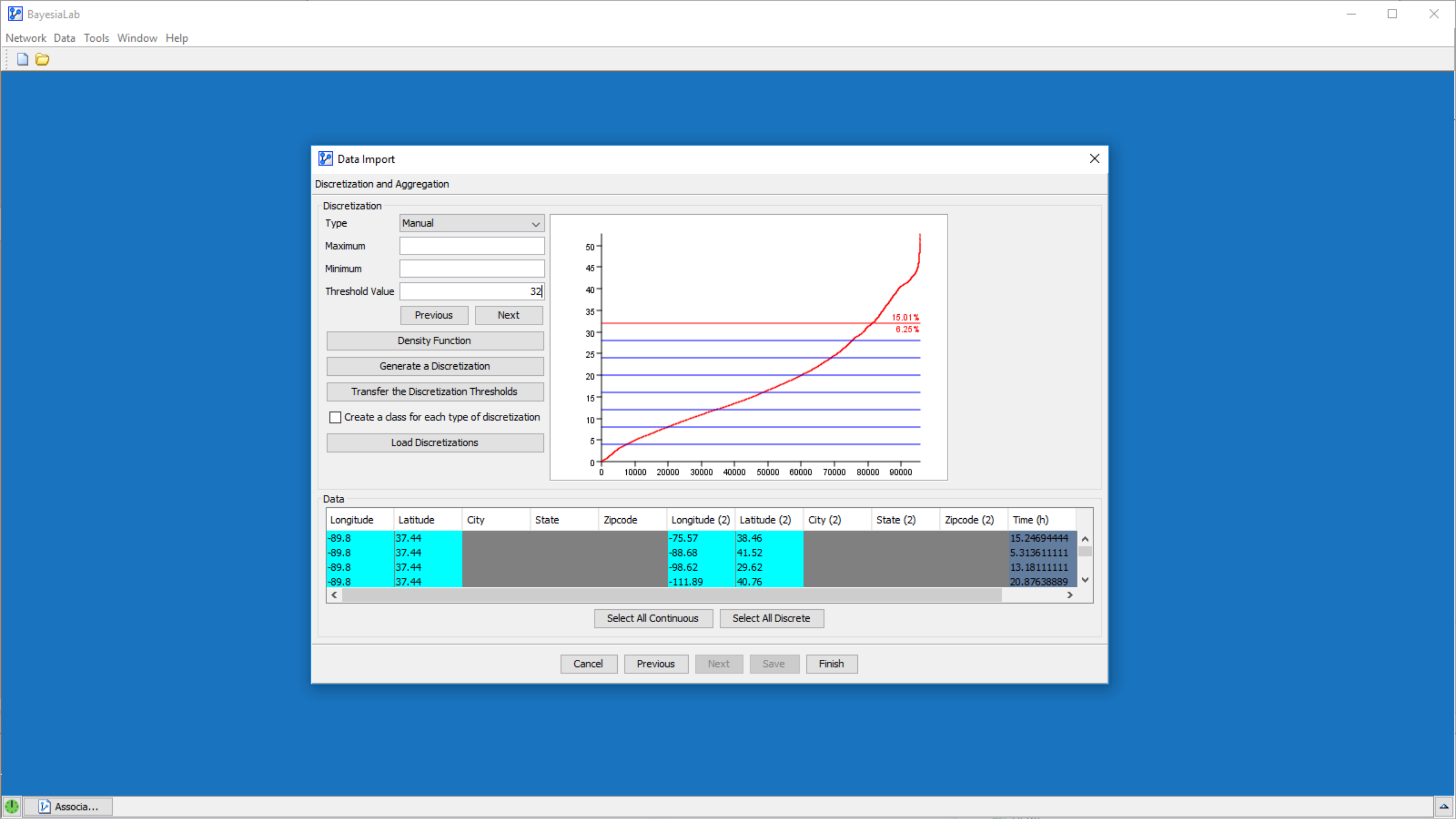
Workflow in Detail

- Take a random sample (~100,000) of origin-destination ZIP code pairs and calculate routes with the Google Distance Matrix API.
- Perform Augmented Naïve Learning.
- Evaluate Target Performance.
- Associate new data set with points to be evaluated.
- Generate map.

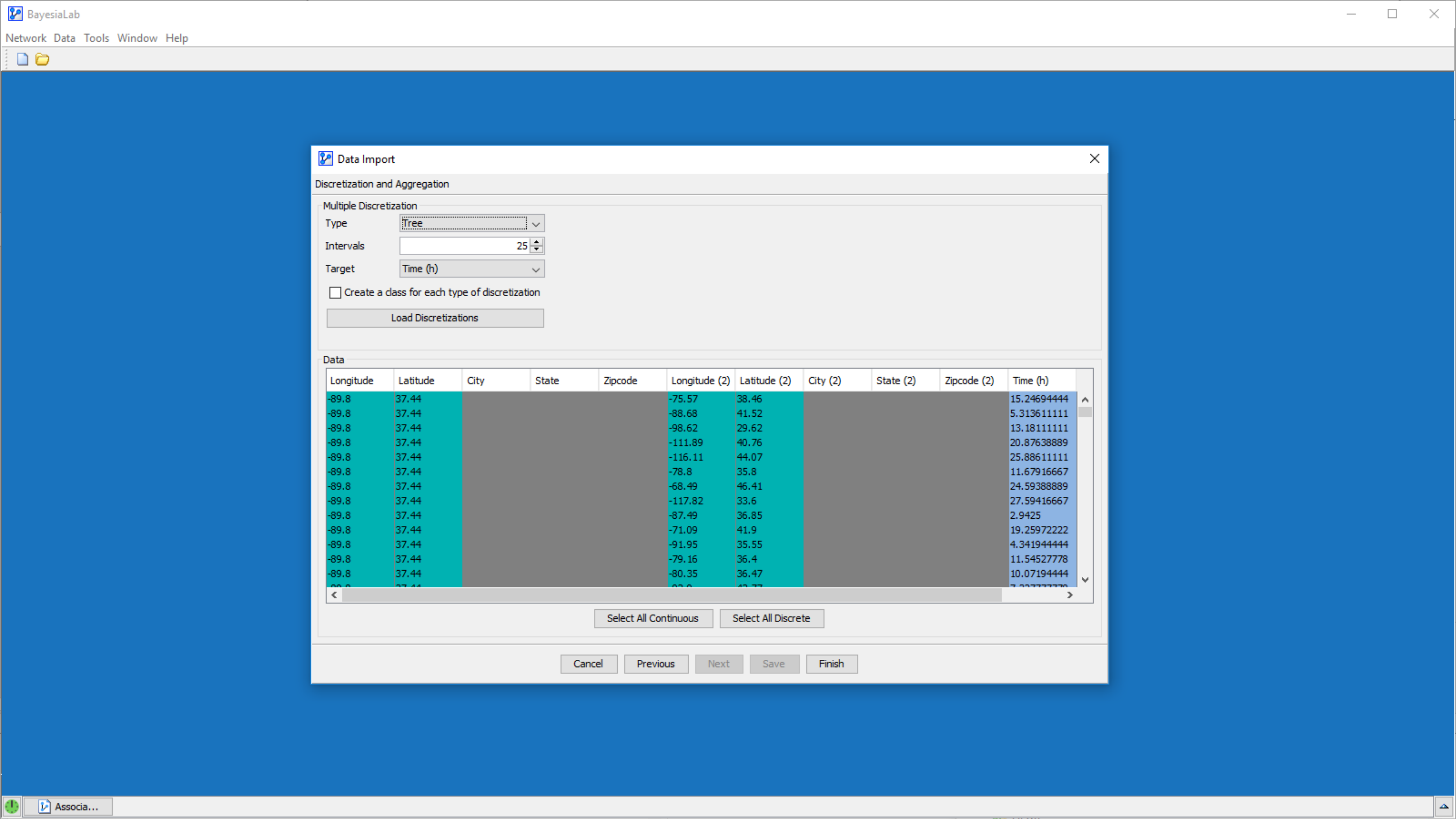

BayesiaLab
Network Data Tools Window Help
Data Import
Define Data Structure
Separators
Tab
Semicolon
Comma
Space
Other
Encoding
UTF-8
Options
Title Line
End of Line Character
Consider Identical Consecutive separators as a Unique One
Consider Different Consecutive Separators as a Unique One
Double Quote as String Delimiters
Single Quote as String Delimiters
Transpose
Missing Values
N/R
NR
NC
Add
Remove
Filtered Values
VF
FV
N/A
Add
Remove
Sampling
Define Sample
Learning/Test
Define Learning/Test Sets
Data
Longitude Latitude City State Zipcode Longitude (2) Latitude (2) City (2) State (2) Zipcode (2)
-89.8 37.44 Millersville MO 63766 -75.57 38.46 Delmar DE 19940
-89.8 37.44 Millersville MO 63766 -88.68 41.52 Sheridan IL 60551
-89.8 37.44 Millersville MO 63766 -98.62 29.62 San Antonio TX 78256
-89.8 37.44 Millersville MO 63766 -111.89 40.76 Salt Lake City UT 84133
-89.8 37.44 Millersville MO 63766 -116.11 44.07 Banks ID 83602
-89.8 37.44 Millersville MO 63766 -78.8 35.8 Cary 27513
-89.8 37.44 Millersville MO 63766 -68.49 46.41 Oxbow ME 4764
-89.8 37.44 Millersville MO 63766 -117.82 33.6 Newport Coast CA 92657
-89.8 37.44 Millersville MO 63766 -87.49 36.85 Hopkinsville KY 42240
-89.8 37.44 Millersville MO 63766 -71.09 41.9 Taunton MA 2780
-89.8 37.44 Millersville MO 63766 -91.95 35.55 Tumbling Sh... AR 72581
-89.8 37.44 Millersville MO 63766 -79.16 36.4 Leasburg 27291
Cancel
Previous
Next
Save
Finish
Associa...

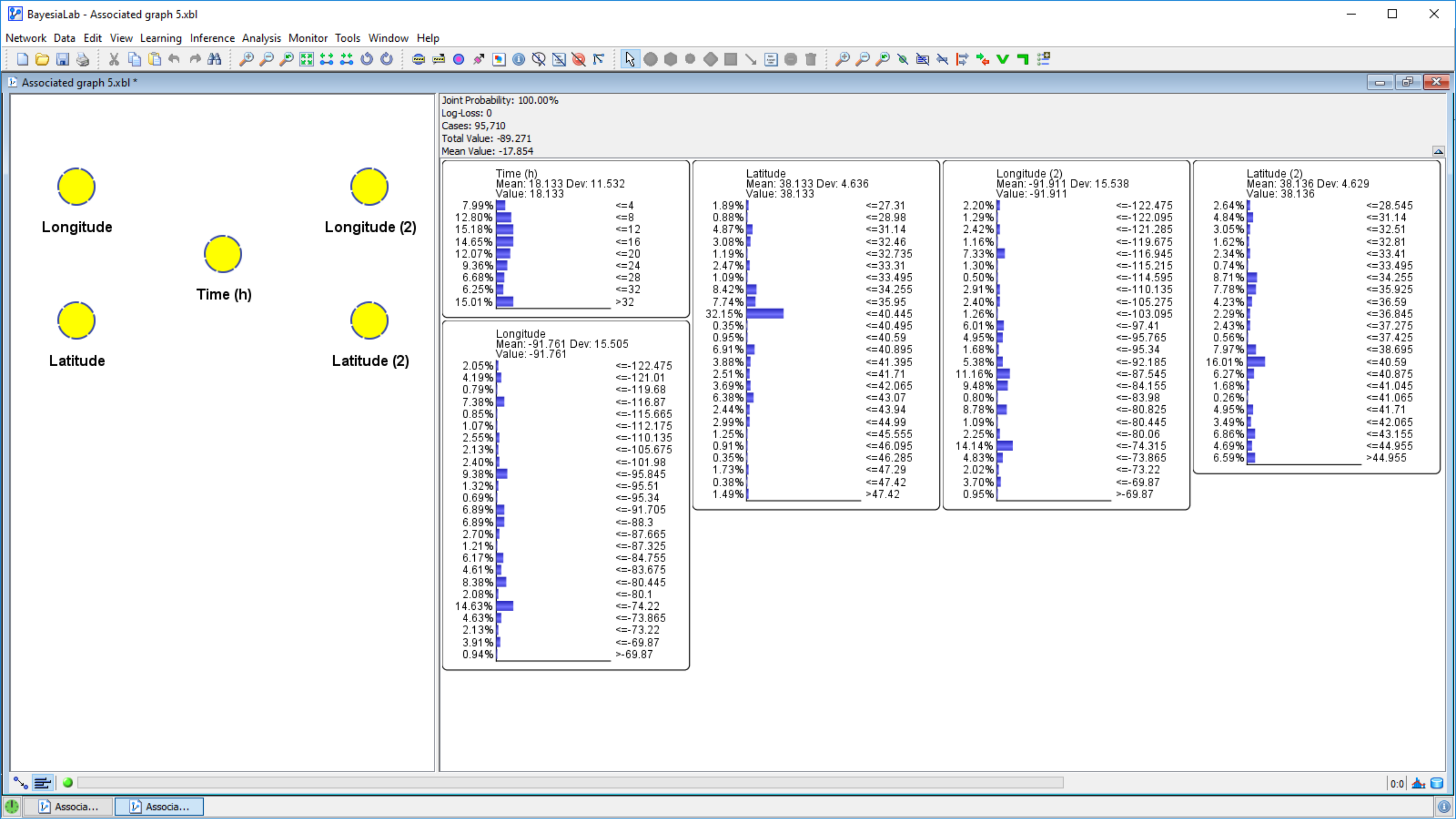

BayesiaLab
Network Data Tools Window Help
Data Import
Define Variable Type
Type
Not Distributed
Discrete
Continuous
Weight
Learning/Test
Row Identifier
Action
Columns with Missing Values
All not Distributed
All Discrete
All Continuous
Information
Number of Rows 95710 100.00%
Not Distributed 7 58.33%
Discrete 0 0.00%
Continuous 5 41.67%
Others 0 0.00%
Missing Values 0 0.00%
Filtered Values 0 0.00%
Data
Longitude Latitude City State Zipcode Longitude (2) Latitude (2) City (2) State (2) Zipcode (2) Time (h)
-89.8 37.44 Millersville MO 63766 -75.57 38.46 Delmar DE 19940 15.24694444
-89.8 37.44 Millersville MO 63766 -88.68 41.52 Sheridan IL 60551 5.313611111
-89.8 37.44 Millersville MO 63766 -98.62 29.62 San Antonio TX 78256 13.18111111
-89.8 37.44 Millersville MO 63766 -111.89 40.76 Salt Lake City UT 84133 20.87638889
-89.8 37.44 Millersville MO 63766 -116.11 44.07 Banks ID 83602 25.88611111
-89.8 37.44 Millersville MO 63766 -78.8 35.8 Cary 27513 11.67916667
-89.8 37.44 Millersville MO 63766 -68.49 46.41 Oxbow ME 4764 24.59388889
-89.8 37.44 Millersville MO 63766 -117.82 33.6 Newport Coast CA 92657 27.59416667
-89.8 37.44 Millersville MO 63766 -87.49 36.85 Hopkinsville KY 42240 2.9425
-89.8 37.44 Millersville MO 63766 -71.09 41.9 Taunton MA 2780 19.25972222
-89.8 37.44 Millersville MO 63766 -91.95 35.55 Tumbling Sh... AR 72581 4.341944444
-89.8 37.44 Millersville MO 63766 -79.16 36.4 Leasburg 27291 11.54527778
-89.8 37.44 Millersville MO 63766 -80.35 36.47 Westfield 27053 10.07194444
-89.8 37.44 Millersville MO 63766 -92.9 42.77 Bristow IA 50611 7.327777778
Cancel
Previous
Next
Save
Finish
Associa...

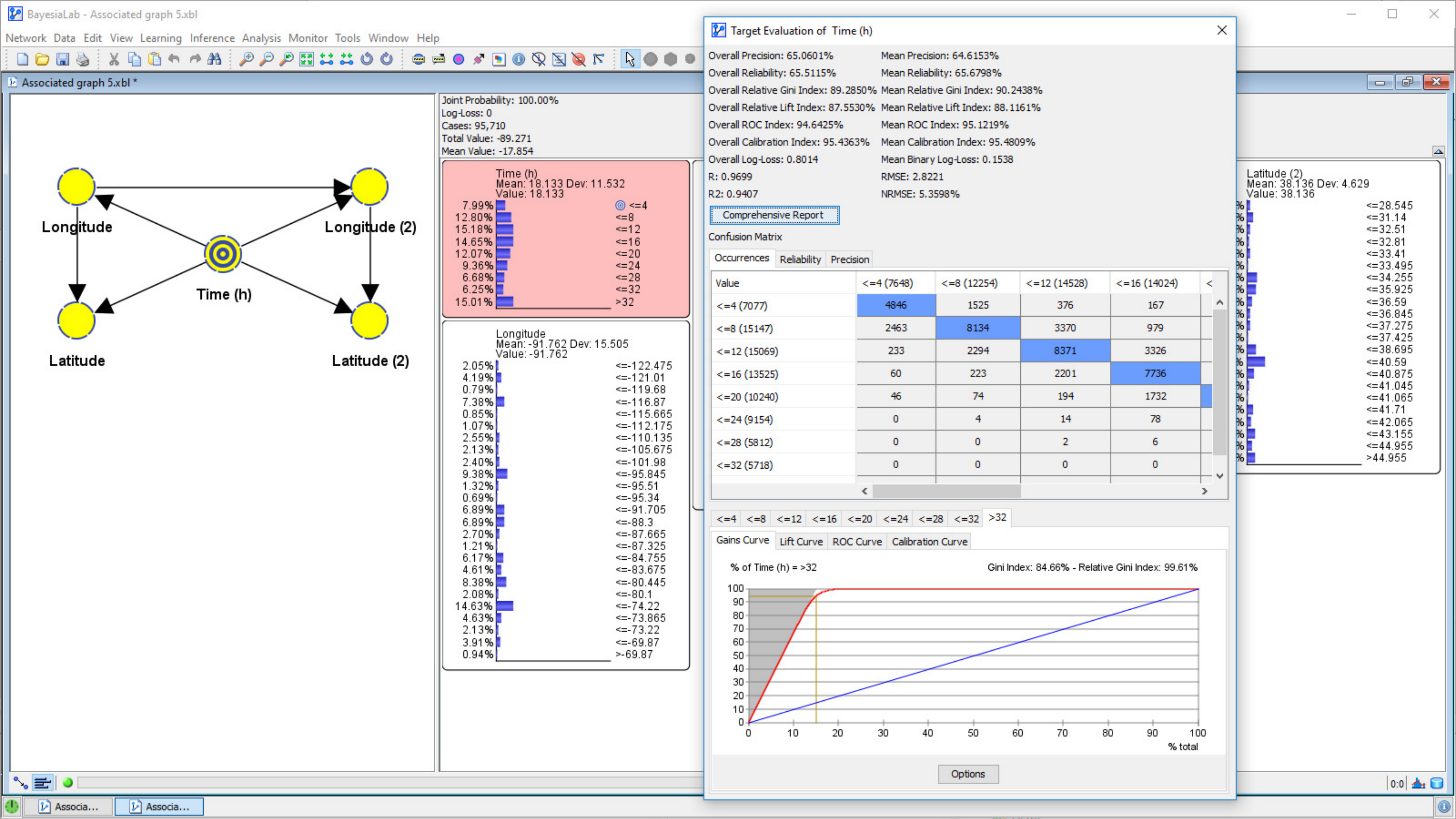

BayesiaLab
Network Data Tools Window Help
Data Import
Data Selection and Filtering
Missing Value Processing
Filter
OR
AND
Replace by :
Value
Mean/Modal
Infer
Static Imputation
Dynamic Imputation
Structural EM
Entropy-Based Static Imputation
Entropy-Based Dynamic Imputation
Information
Number of Rows 95710 100.00%
Not Distributed 7 58.33%
Discrete 0 0.00%
Continuous 5 41.67%
Others 0 0.00%
Missing Values 0 0.00%
Filtered Values 0 0.00%
Select Values
OR
AND
Delete Selections
Display Selections
Data
Longitude Latitude City State Zipcode Longitu... Latitude... City (2) State (2) Zipcode (2) Time (h)
-89.8 37.44 -75.57 38.46 15.24694444
-89.8 37.44 -88.68 41.52 5.313611111
-89.8 37.44 -98.62 29.62 13.18111111
-89.8 37.44 -111.89 40.76 20.87638889
-89.8 37.44 -116.11 44.07 25.88611111
Select All Continuous
Select All Discrete
Cancel
Previous
Next
Save
Finish
Associa...

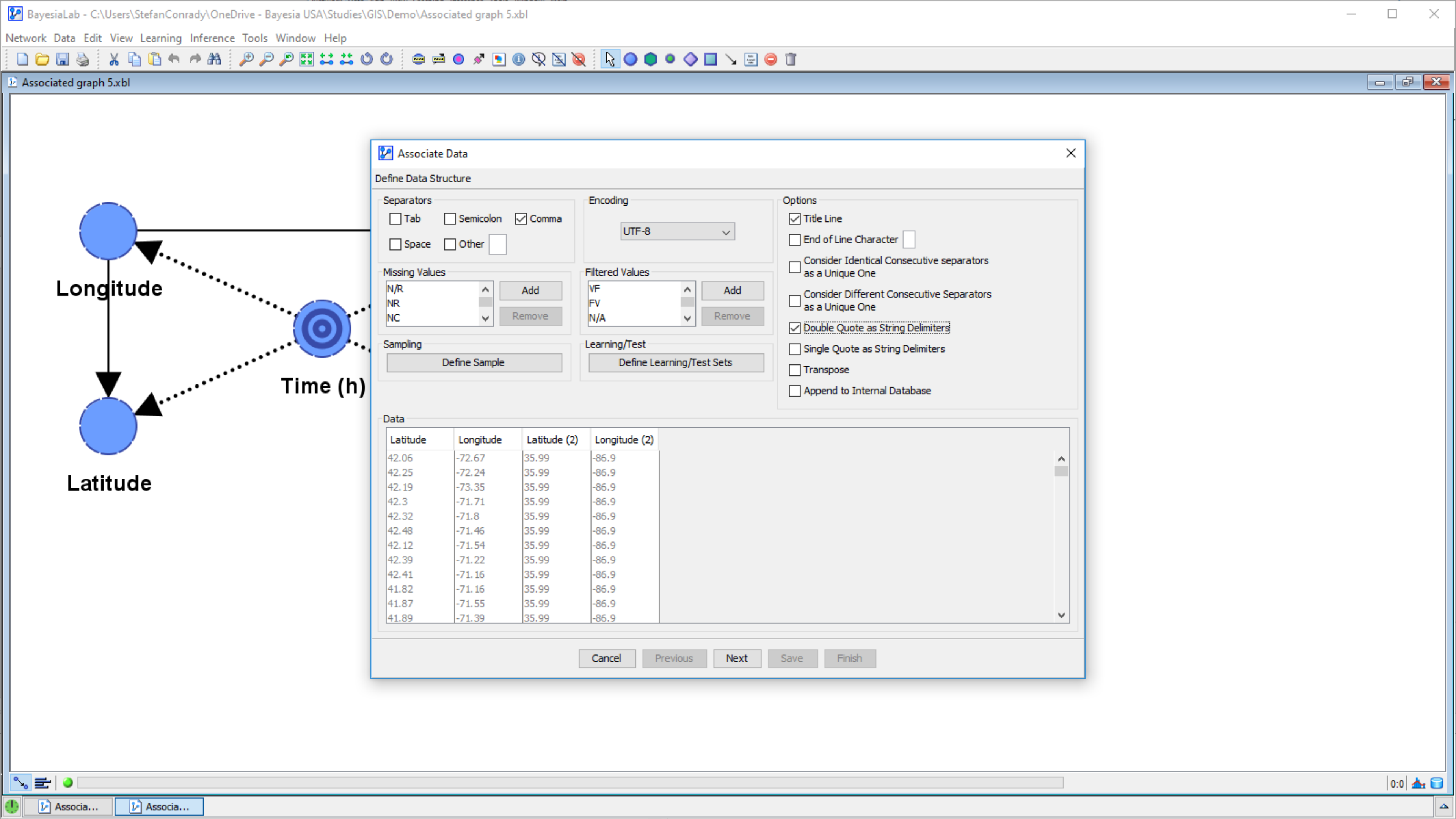


BayesiaLab
Network Data Tools Window Help
Data Import
Discretization and Aggregation
Discretization
Type
Manual
Maximum
Minimum
Threshold Value
32
Previous
Next
Density Function
Generate a Discretization
Transfer the Discretization Thresholds
Create a class for each type of discretization
Load Discretizations
15.01 %
6.25 %
50
45
40
35
30
25
20
15
10
5
0
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
Data
Longitude
Latitude
City
State
Zipcode
Longitude (2)
Latitude (2)
City (2)
State (2)
Zipcode (2)
Time (h)
-89.8 37.44 -75.57 38.46 15.24694444
-89.8 37.44 -88.68 41.52 5.313611111
-89.8 37.44 -98.62 29.62 13.18111111
-89.8 37.44 -111.89 40.76 20.87638889
Select All Continuous
Select All Discrete
Cancel
Previous
Next
Save
Finish
Associa...

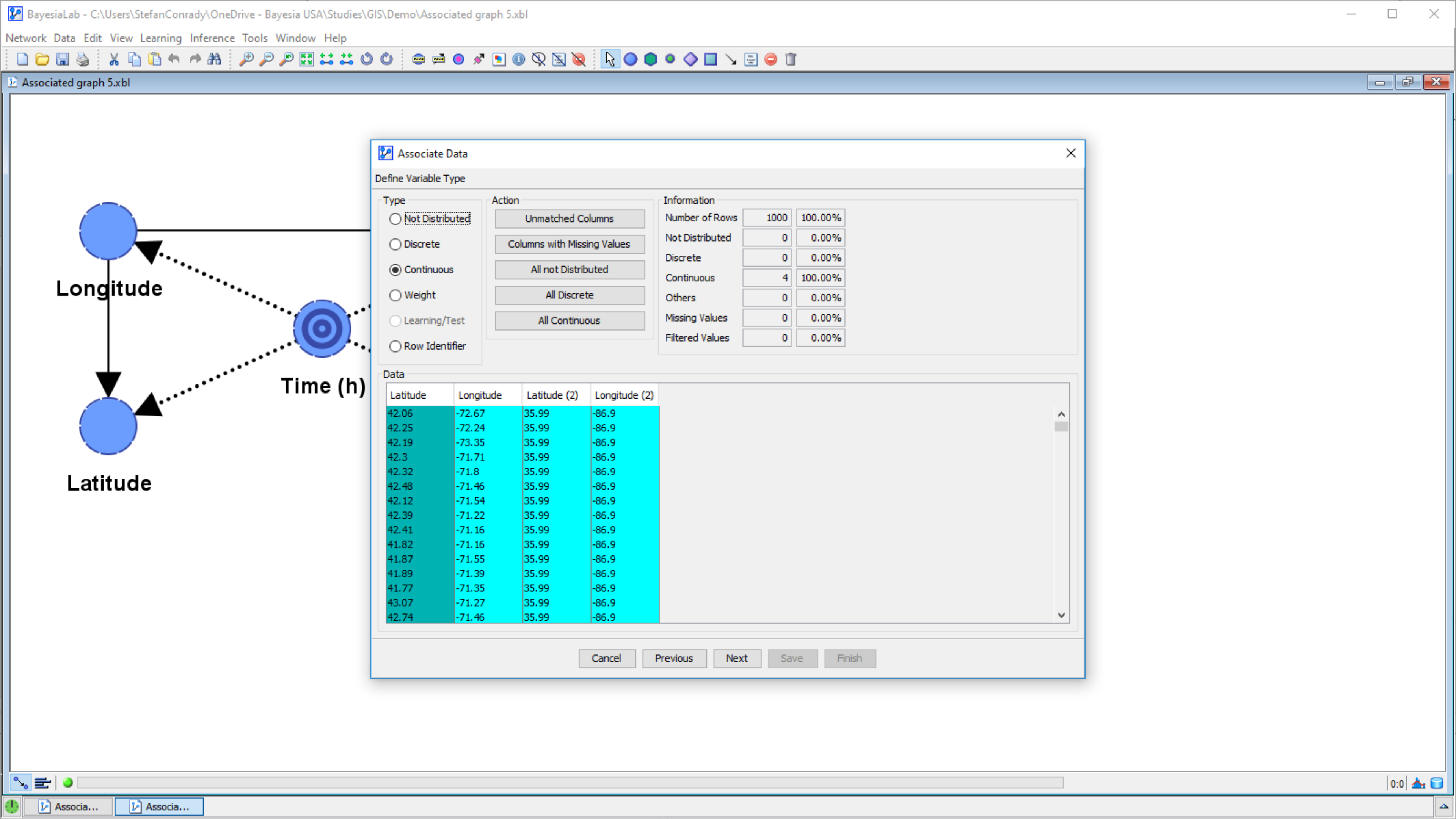

BayesiaLab
Network Data Tools Window Help
Data Import
Discretization and Aggregation
Multiple Discretization
Type
Tree
Intervals
25
Target
Time (h)
Create a class for each type of discretization
Load Discretizations
Data
Longitude Latitude City State Zipcode Longitude (2) Latitude (2) City (2) State (2) Zipcode (2) Time (h)
-89.8 37.44 -75.57 38.46 15.24694444
-89.8 37.44 -88.68 41.52 5.313611111
-89.8 37.44 -98.62 29.62 13.18111111
-89.8 37.44 -111.89 40.76 20.87638889
-89.8 37.44 -116.11 44.07 25.88611111
-89.8 37.44 -78.8 35.8 11.67916667
-89.8 37.44 -68.49 46.41 24.59388889
-89.8 37.44 -117.82 33.6 27.59416667
-89.8 37.44 -87.49 36.85 2.9425
-89.8 37.44 -71.09 41.9 19.25972222
-89.8 37.44 -91.95 35.55 4.341944444
-89.8 37.44 -79.16 36.4 11.54527778
-89.8 37.44 -80.35 36.47 10.07194444
Select All Continuous
Select All Discrete
Cancel
Previous
Next
Save
Finish
Associa...

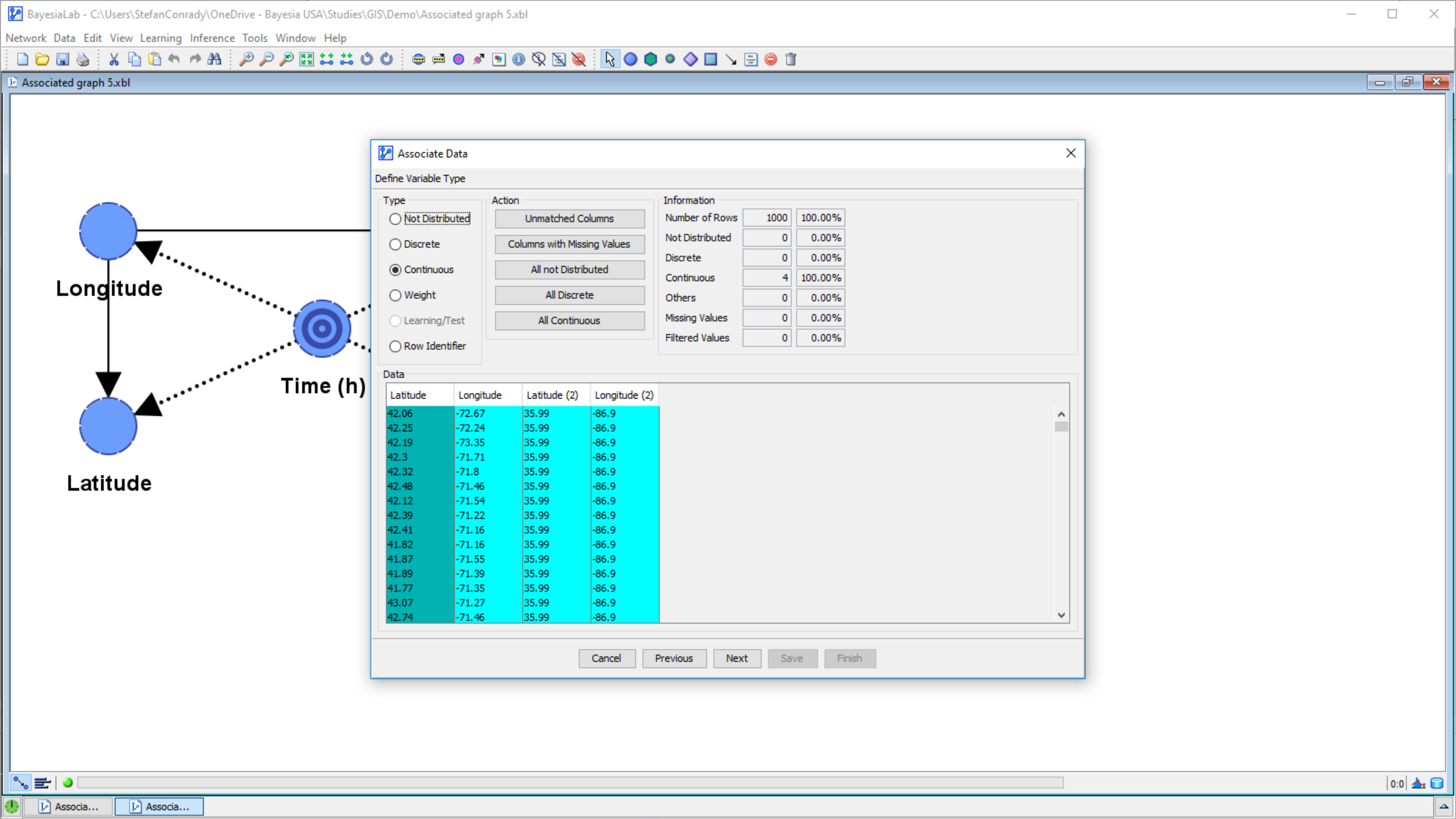

BayesiaLab - Associated graph 5.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Associated graph 5.xbl *
Longitude
Longitude (2)
Time (h)
Latitude
Latitude (2)
Joint Probability: 100.00%
Log-Loss: 0
Cases: 95,710
Total Value: -89.271
Mean Value: -17.854
Time (h)
Mean: 18.133 Dev: 11.532
Value: 18.133
7.99% <=4
12.80% <=8
15.18% <=12
14.65% <=16
12.07% <=20
9.36% <=24
6.68% <=28
6.25% <=32
15.01% >32
Longitude
Mean: -91.761 Dev: 15.505
Value: -91.761
2.05% <=-122.475
4.19% <=-121.01
0.79% <=-119.68
7.38% <=-116.87
0.85% <=-115.665
1.07% <=-112.175
2.55% <=-110.135
2.13% <=-105.675
2.40% <=-101.98
9.38% <=-95.845
1.32% <=-95.51
0.69% <=-95.34
6.89% <=-91.705
6.89% <=-88.3
2.70% <=-87.665
1.21% <=-87.325
6.17% <=-84.755
4.61% <=-83.675
8.38% <=-80.445
2.08% <=-80.1
14.63% <=-74.22
4.63% <=-73.865
2.13% <=-73.22
3.91% <=-69.87
0.94% >-69.87
Latitude
Mean: 38.133 Dev: 4.636
Value: 38.133
1.89% <=27.31
0.88% <=28.98
4.87% <=31.14
3.08% <=32.46
1.19% <=32.735
2.47% <=33.31
1.09% <=33.495
8.42% <=34.255
7.74% <=35.95
32.15% <=40.445
0.35% <=40.495
0.95% <=40.59
6.91% <=40.895
3.88% <=41.395
2.51% <=41.71
3.69% <=42.065
6.38% <=43.07
2.44% <=43.94
2.99% <=44.99
1.25% <=45.555
0.91% <=46.095
0.35% <=46.285
1.73% <=47.29
0.38% <=47.42
1.49% >47.42
Longitude (2)
Mean: -91.911 Dev: 15.538
Value: -91.911
2.20% <=-122.475
1.29% <=-122.095
2.42% <=-121.285
1.16% <=-119.675
7.33% <=-116.945
1.30% <=-115.215
0.50% <=-114.595
2.91% <=-110.135
2.40% <=-105.275
1.26% <=-103.095
6.01% <=-97.41
4.95% <=-95.765
1.68% <=-95.34
5.38% <=-92.185
11.16% <=-87.545
9.48% <=-84.155
0.80% <=-83.98
8.78% <=-80.825
1.09% <=-80.445
2.25% <=-80.06
14.14% <=-74.315
4.83% <=-73.865
2.02% <=-73.22
3.70% <=-69.87
0.95% >-69.87
Latitude (2)
Mean: 38.136 Dev: 4.629
Value: 38.136
2.64% <=28.545
4.84% <=31.14
3.05% <=32.51
1.62% <=32.81
2.34% <=33.41
0.74% <=33.495
8.71% <=34.255
7.78% <=35.925
4.23% <=36.59
2.29% <=36.845
2.43% <=37.275
0.56% <=37.425
7.97% <=38.695
16.01% <=40.59
6.27% <=40.875
1.68% <=41.045
0.26% <=41.065
4.95% <=41.71
3.49% <=42.065
6.86% <=43.155
4.69% <=44.955
6.59% >44.955
0:0
Associa...
Associa...

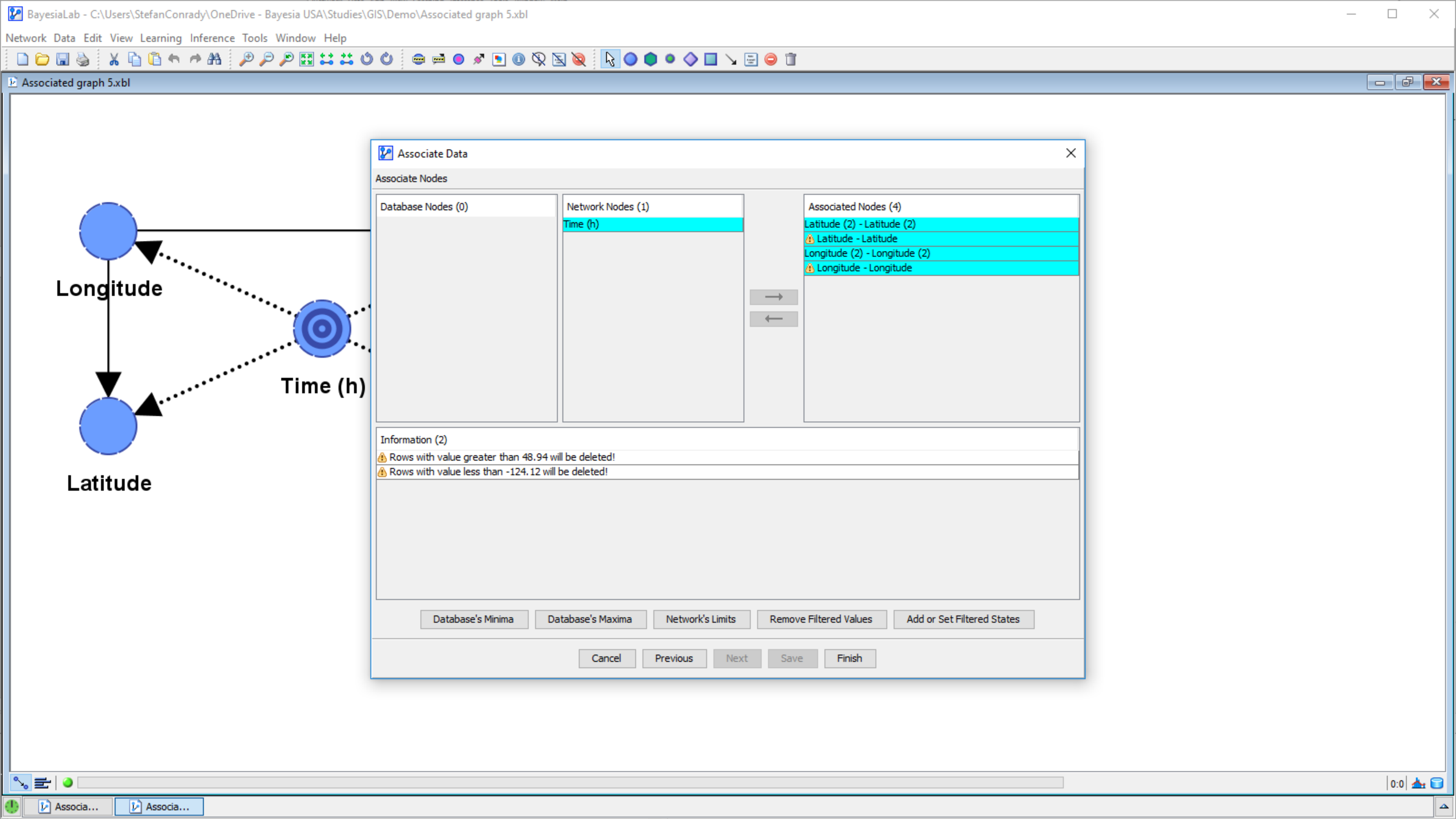

BayesiaLab - Associated graph 5.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Associated graph 5.xbl *
Longitude
Longitude (2)
Time (h)
Latitude
Latitude (2)
Joint Probability: 100.00%
Log-Loss: 0
Cases: 95,710
Total Value: -89.271
Mean Value: -17.854
Time (h)
Mean: 18.133 Dev: 11.532
Value: 18.133
7.99% <=4
12.80% <=8
15.18% <=12
14.65% <=16
12.07% <=20
9.36% <=24
6.68% <=28
6.25% <=32
15.01% >32
Longitude
Mean: -91.762 Dev: 15.505
Value: -91.762
2.05% <=-122.475
4.19% <=-121.01
0.79% <=-119.68
7.38% <=-116.87
0.85% <=-115.665
1.07% <=-112.175
2.55% <=-110.135
2.13% <=-105.675
2.40% <=-101.98
9.38% <=-95.845
1.32% <=-95.51
0.69% <=-95.34
6.89% <=-91.705
6.89% <=-88.3
2.70% <=-87.665
1.21% <=-87.325
6.17% <=-84.755
4.61% <=-83.675
8.38% <=-80.445
2.08% <=-80.1
14.63% <=-74.22
4.63% <=-73.865
2.13% <=-73.22
3.91% <=-69.87
0.94% >-69.87
Latitude (2)
Mean: 38.136 Dev: 4.629
Value: 38.136
<=28.545
<=31.14
<=32.51
<=32.81
<=33.41
<=33.495
<=34.255
<=35.925
<=36.59
<=36.845
<=37.275
<=37.425
<=38.695
<=40.59
<=40.875
<=41.045
<=41.065
<=41.71
<=42.065
<=43.155
<=44.955
>44.955
Target Evaluation of Time (h)
Overall Precision: 65.0601%
Mean Precision: 64.6153%
Overall Reliability: 65.5115%
Mean Reliability: 65.6798%
Overall Relative Gini Index: 89.2850%
Mean Relative Gini Index: 90.2438%
Overall Relative Lift Index: 87.5530%
Mean Relative Lift Index: 88.1161%
Overall ROC Index: 94.6425%
Mean ROC Index: 95.1219%
Overall Calibration Index: 95.4363%
Mean Calibration Index: 95.4809%
Overall Log-Loss: 0.8014
Mean Binary Log-Loss: 0.1538
R: 0.9699
RMSE: 2.8221
R2: 0.9407
NRMSE: 5.3598%
Comprehensive Report
Confusion Matrix
Occurrences Reliability Precision
Value | <=4 (7648) | <=8 (12254) | <=12 (14528) | <=16 (14024)
<=4 (7077) | 4846 | 1525 | 376 | 167
<=8 (15147) | 2463 | 8134 | 3370 | 979
<=12 (15069) | 233 | 2294 | 8371 | 3326
<=16 (13525) | 60 | 223 | 2201 | 7736
<=20 (10240) | 46 | 74 | 194 | 1732
<=24 (9154) | 0 | 4 | 14 | 78
<=28 (5812) | 0 | 0 | 2 | 6
<=32 (5718) | 0 | 0 | 0 | 0
<=4 <=8 <=12 <=16 <=20 <=24 <=28 <=32 >32
Gains Curve Lift Curve ROC Curve Calibration Curve
% of Time (h) = >32
Gini Index: 84.66% - Relative Gini Index: 99.61%
% total
Options
Associa... Associa...

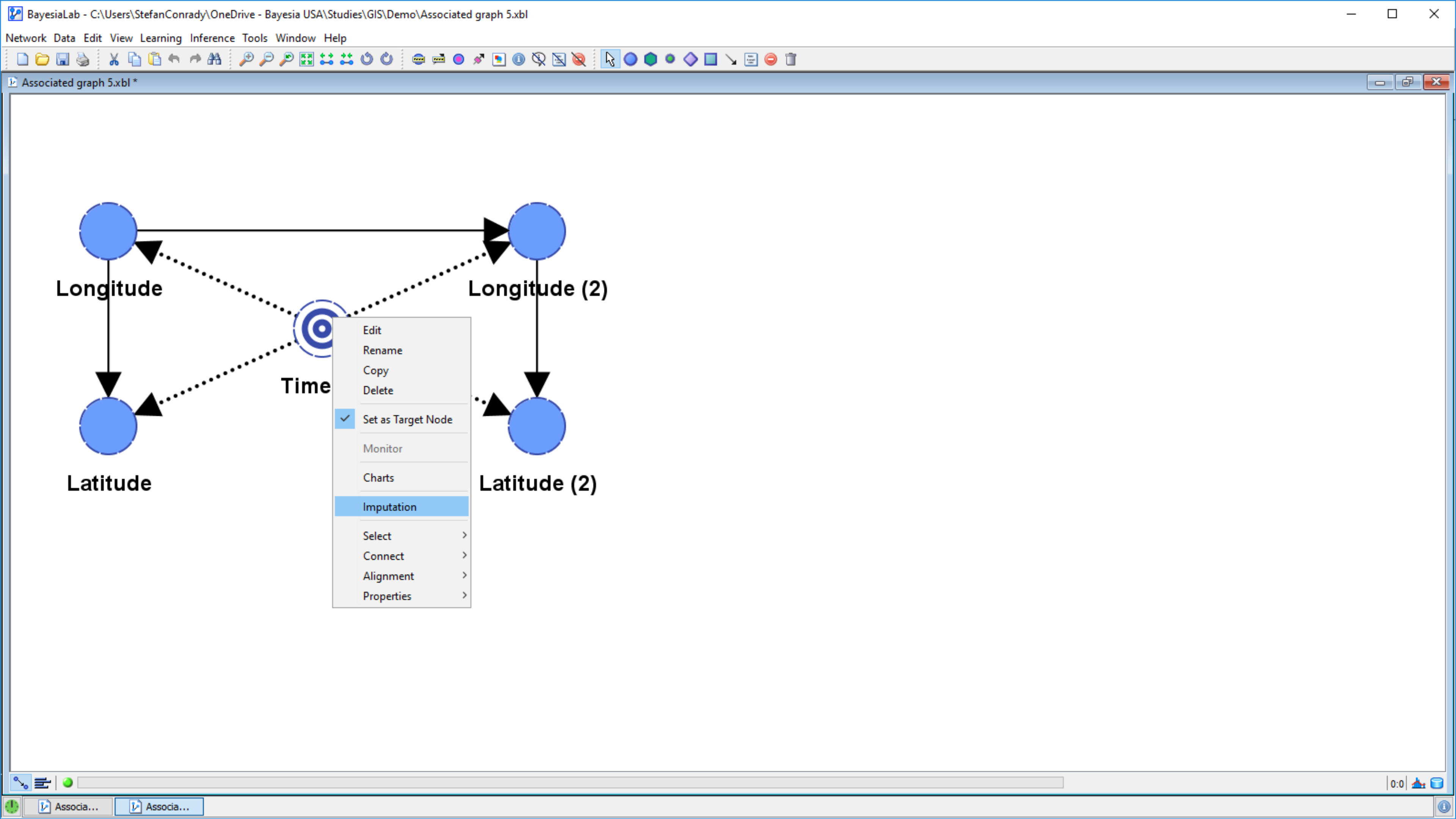


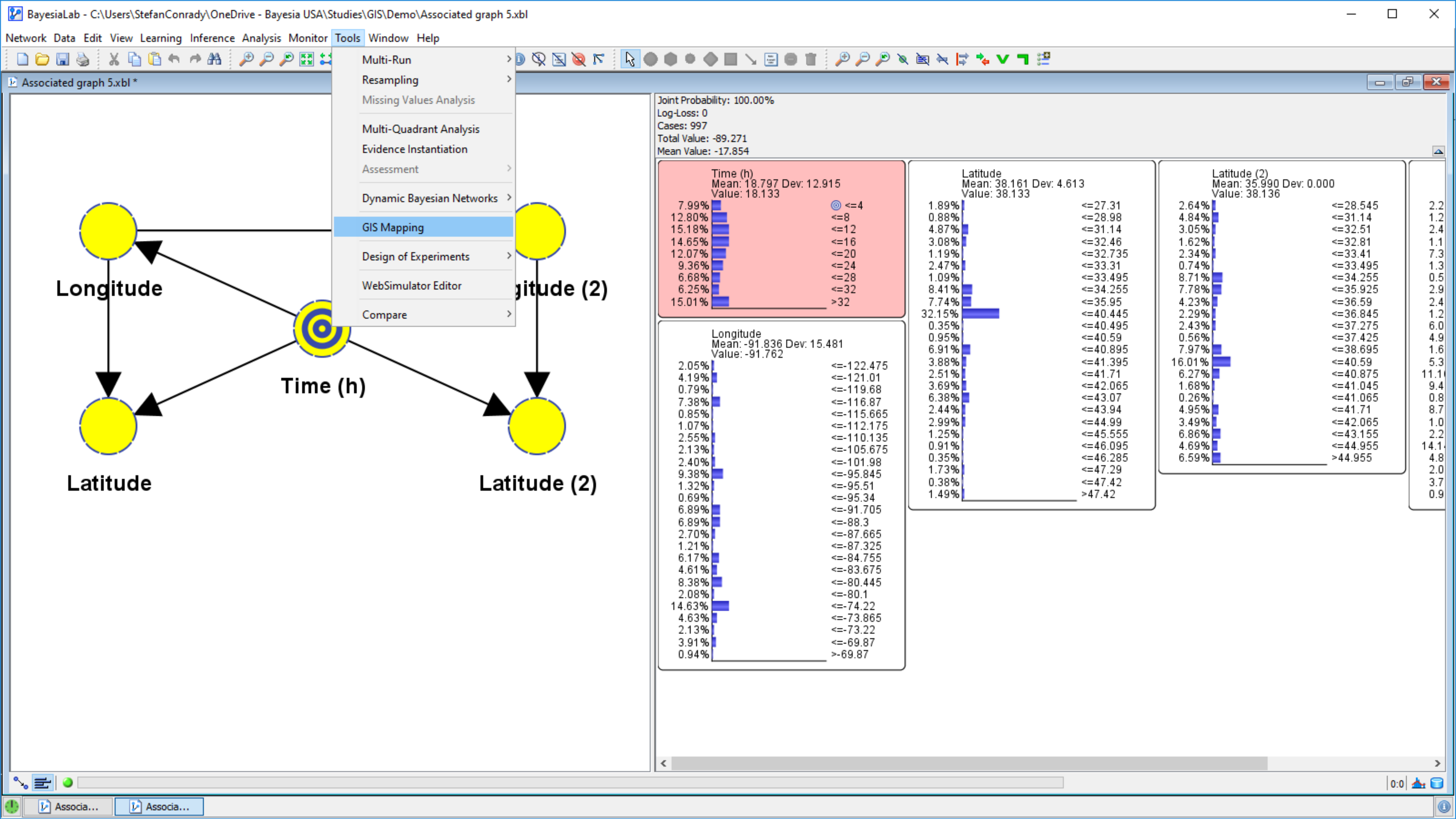
BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\Demo\Associated graph 5.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 5.xbl
Longitude
Latitude
Time (h)
Associate Data
Define Data Structure
Separators
Tab
Semicolon
Comma
Space
Other
Encoding
UTF-8
Options
Title Line
End of Line Character
Consider Identical Consecutive separators as a Unique One
Consider Different Consecutive Separators as a Unique One
Double Quote as String Delimiters
Single Quote as String Delimiters
Transpose
Append to Internal Database
Missing Values
N/R
NR
NC
Add
Remove
Filtered Values
VF
FV
N/A
Add
Remove
Sampling
Define Sample
Learning/Test
Define Learning/Test Sets
Data
Latitude Longitude Latitude (2) Longitude (2)
42.06 -72.67 35.99 -86.9
42.25 -72.24 35.99 -86.9
42.19 -73.35 35.99 -86.9
42.3 -71.71 35.99 -86.9
42.32 -71.8 35.99 -86.9
42.48 -71.46 35.99 -86.9
42.12 -71.54 35.99 -86.9
42.39 -71.22 35.99 -86.9
42.41 -71.16 35.99 -86.9
41.82 -71.16 35.99 -86.9
41.87 -71.55 35.99 -86.9
41.89 -71.39 35.99 -86.9
Cancel Previous Next Save Finish
Associa...
Associa...
0:0

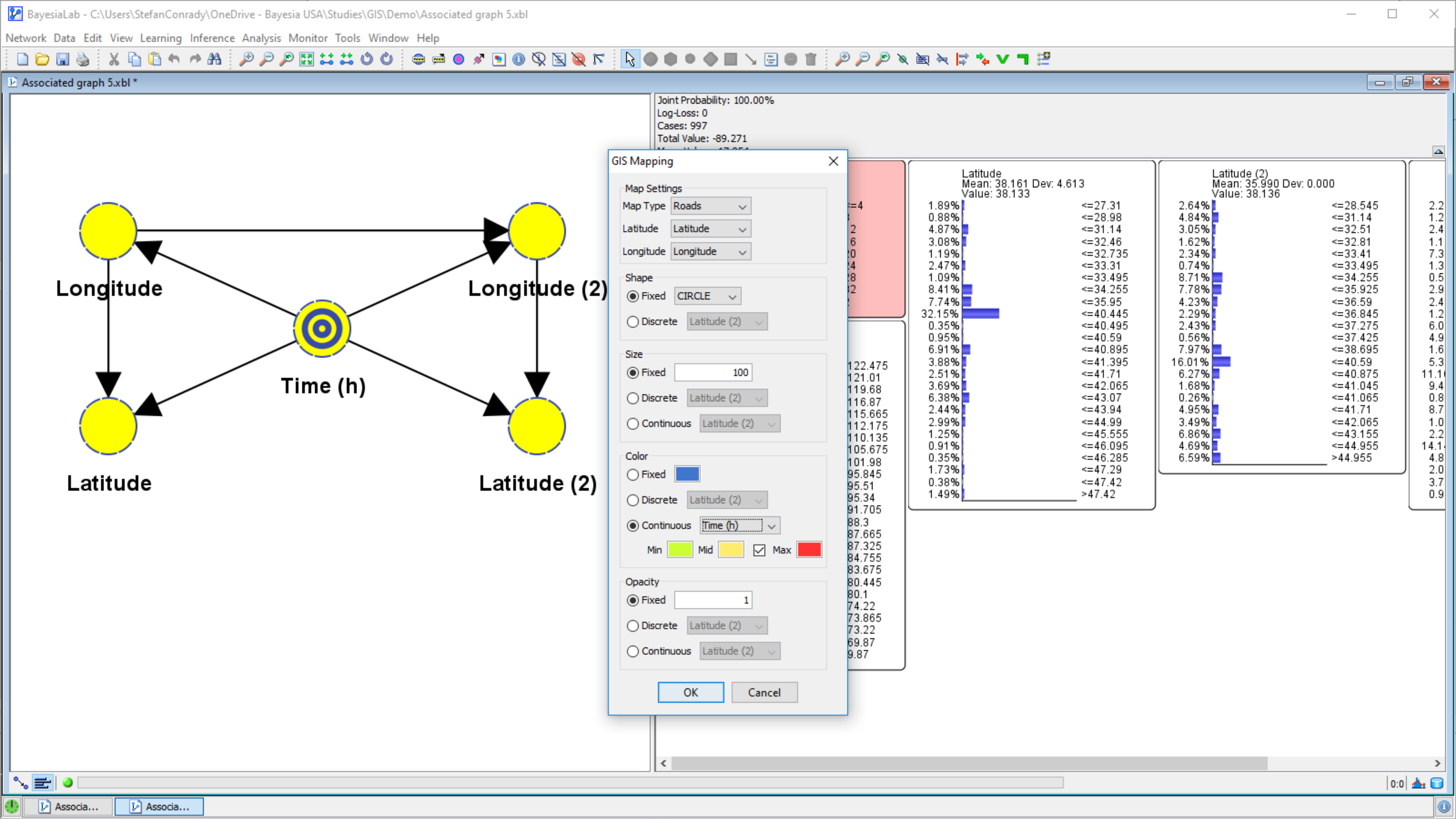

BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\Demo\Associated graph 5.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 5.xbl
Longitude
Latitude
Time (h)
Associate Data
Define Variable Type
Type
Not Distributed
Discrete
Continuous
Weight
Learning/Test
Row Identifier
Action
Unmatched Columns
Columns with Missing Values
All not Distributed
All Discrete
All Continuous
Information
Number of Rows 1000 100.00%
Not Distributed 0 0.00%
Discrete 0 0.00%
Continuous 4 100.00%
Others 0 0.00%
Missing Values 0 0.00%
Filtered Values 0 0.00%
Data
Latitude Longitude Latitude (2) Longitude (2)
42.06 -72.67 35.99 -86.9
42.25 -72.24 35.99 -86.9
42.19 -73.35 35.99 -86.9
42.3 -71.71 35.99 -86.9
42.32 -71.8 35.99 -86.9
42.48 -71.46 35.99 -86.9
42.12 -71.54 35.99 -86.9
42.39 -71.22 35.99 -86.9
42.41 -71.16 35.99 -86.9
41.82 -71.16 35.99 -86.9
41.87 -71.55 35.99 -86.9
41.89 -71.39 35.99 -86.9
41.77 -71.35 35.99 -86.9
43.07 -71.27 35.99 -86.9
42.74 -71.46 35.99 -86.9
Cancel Previous Next Save Finish
Associa... Associa...


BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\Demo\Associated graph 5.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 5.xbl
Longitude
Latitude
Time (h)
Associate Data
Define Variable Type
Type
Not Distributed
Discrete
Continuous
Weight
Learning/Test
Row Identifier
Action
Unmatched Columns
Columns with Missing Values
All not Distributed
All Discrete
All Continuous
Information
Number of Rows 1000 100.00%
Not Distributed 0 0.00%
Discrete 0 0.00%
Continuous 4 100.00%
Others 0 0.00%
Missing Values 0 0.00%
Filtered Values 0 0.00%
Data
Latitude Longitude Latitude (2) Longitude (2)
42.06 -72.67 35.99 -86.9
42.25 -72.24 35.99 -86.9
42.19 -73.35 35.99 -86.9
42.3 -71.71 35.99 -86.9
42.32 -71.8 35.99 -86.9
42.48 -71.46 35.99 -86.9
42.12 -71.54 35.99 -86.9
42.39 -71.22 35.99 -86.9
42.41 -71.16 35.99 -86.9
41.82 -71.16 35.99 -86.9
41.87 -71.55 35.99 -86.9
41.89 -71.39 35.99 -86.9
41.77 -71.35 35.99 -86.9
43.07 -71.27 35.99 -86.9
42.74 -71.46 35.99 -86.9
Cancel Previous Next Save Finish
Associa... Associa...

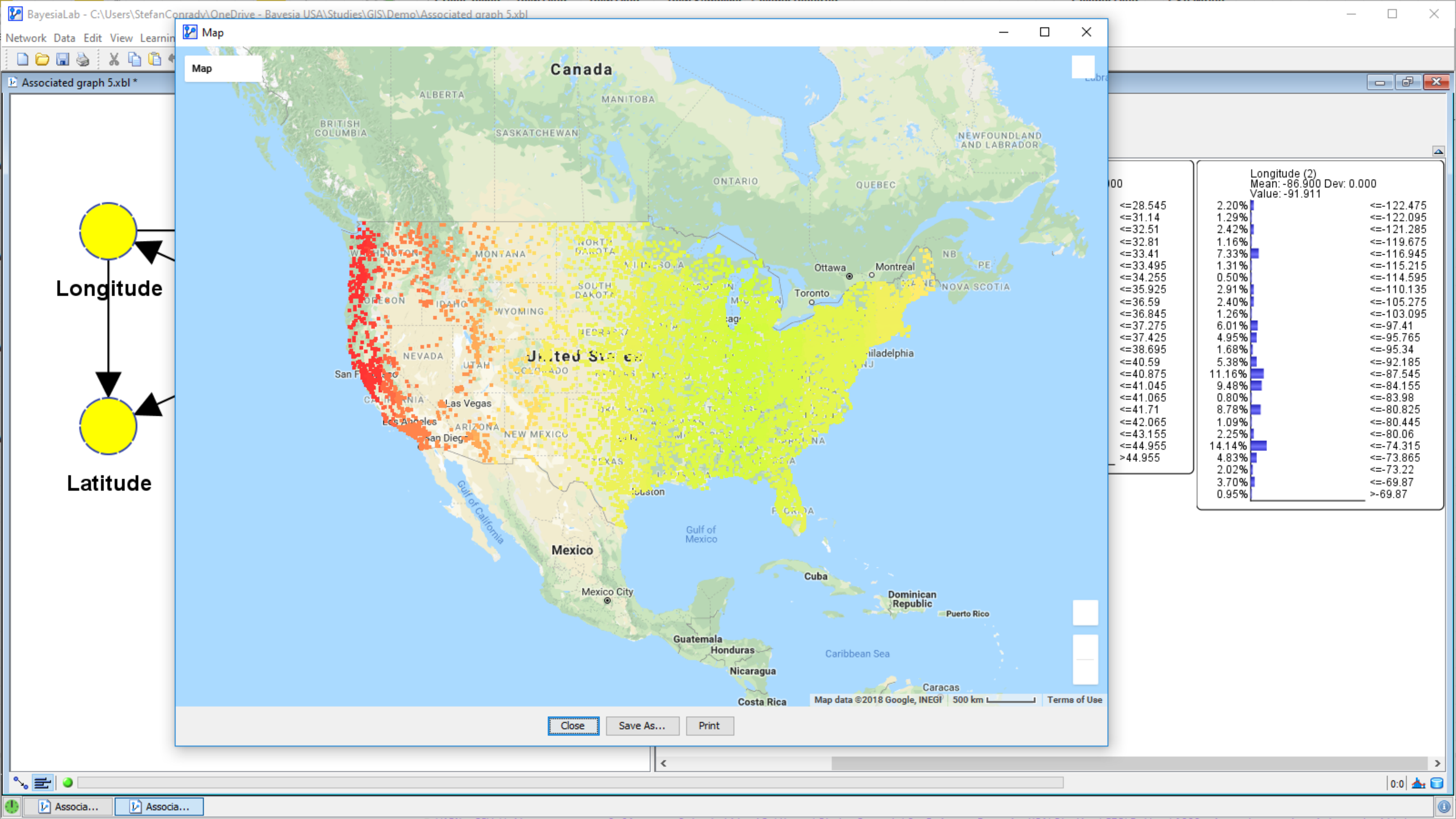

BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\Demo\Associated graph 5.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 5.xbl
Longitude
Time (h)
Latitude
Associate Data
Associate Nodes
Database Nodes (0)
Network Nodes (1)
Time (h)
Associated Nodes (4)
Latitude (2) - Latitude (2)
Latitude - Latitude
Longitude (2) - Longitude (2)
Longitude - Longitude
Information (2)
Rows with value greater than 48.94 will be deleted!
Rows with value less than -124.12 will be deleted!
Database's Minima
Database's Maxima
Network's Limits
Remove Filtered Values
Add or Set Filtered States
Cancel
Previous
Next
Save
Finish


BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\Demo\Associated graph 5.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 5.xbl *
Longitude
Longitude (2)
Time
Latitude
Latitude (2)
Edit
Rename
Copy
Delete
Set as Target Node
Monitor
Charts
Imputation
Select
Connect
Alignment
Properties
Associa...
Associa...
0:0


BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\Demo\Associated graph 5.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Associated graph 5.xbl *
Multi-Run
Resampling
Missing Values Analysis
Multi-Quadrant Analysis
Evidence Instantiation
Assessment
Dynamic Bayesian Networks
GIS Mapping
Design of Experiments
WebSimulator Editor
Compare
Longitude
Latitude
Time (h)
Latitude (2)
Joint Probability: 100.00%
Log-Loss: 0
Cases: 997
Total Value: -89.271
Mean Value: -17.854
Time (h)
Mean: 18.797 Dev: 12.915
Value: 18.133
7.99% <=4
12.80% <=8
15.18% <=12
14.65% <=16
12.07% <=20
9.36% <=24
6.68% <=28
6.25% <=32
15.01% >32
Longitude
Mean: -91.836 Dev: 15.481
Value: -91.762
2.05% <=-122.475
4.19% <=-121.01
0.79% <=-119.68
7.38% <=-116.87
0.85% <=-115.665
1.07% <=-112.175
2.55% <=-110.135
2.13% <=-105.675
2.40% <=-101.98
9.38% <=-95.845
1.32% <=-95.51
0.69% <=-95.34
6.89% <=-91.705
6.89% <=-88.3
2.70% <=-87.665
1.21% <=-87.325
6.17% <=-84.755
4.61% <=-83.675
8.38% <=-80.445
2.08% <=-80.1
14.63% <=-74.22
4.63% <=-73.865
2.13% <=-73.22
3.91% <=-69.87
0.94% >-69.87
Latitude
Mean: 38.161 Dev: 4.613
Value: 38.133
1.89% <=27.31
0.88% <=28.98
4.87% <=31.14
3.08% <=32.46
1.19% <=32.735
2.47% <=33.31
1.09% <=33.495
8.41% <=34.255
7.74% <=35.95
32.15% <=40.445
0.35% <=40.495
0.95% <=40.59
6.91% <=40.895
3.88% <=41.395
2.51% <=41.71
3.69% <=42.065
6.38% <=43.07
2.44% <=43.94
2.99% <=44.99
1.25% <=45.555
0.91% <=46.095
0.35% <=46.285
1.73% <=47.29
0.38% <=47.42
1.49% >47.42
Latitude (2)
Mean: 35.990 Dev: 0.000
Value: 38.136
2.64% <=28.545
4.84% <=31.14
3.05% <=32.51
1.62% <=32.81
2.34% <=33.41
0.74% <=33.495
8.71% <=34.255
7.78% <=35.925
4.23% <=36.59
2.29% <=36.845
2.43% <=37.275
0.56% <=37.425
7.97% <=38.695
16.01% <=40.59
6.27% <=40.875
1.68% <=41.045
0.26% <=41.065
4.95% <=41.71
3.49% <=42.065
6.86% <=43.155
4.69% <=44.955
6.59% >44.955
Associa...
Associa...



BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\Demo\Associated graph 5.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Associated graph 5.xbl *
Longitude
Longitude (2)
Time (h)
Latitude
Latitude (2)
Joint Probability: 100.00%
Log-Loss: 0
Cases: 997
Total Value: -89.271
GIS Mapping
Map Settings
Map Type Roads
Latitude Latitude
Longitude Longitude
Shape
Fixed CIRCLE
Discrete Latitude (2)
Size
Fixed 100
Discrete Latitude (2)
Continuous Latitude (2)
Color
Fixed
Discrete Latitude (2)
Continuous Time (h)
Min Mid Max
Opacity
Fixed 1
Discrete Latitude (2)
Continuous Latitude (2)
OK Cancel
Latitude
Mean: 38.161 Dev: 4.613
Value: 38.133
1.89% <=27.31
0.88% <=28.98
4.87% <=31.14
3.08% <=32.46
1.19% <=32.735
2.47% <=33.31
1.09% <=33.495
8.41% <=34.255
7.74% <=35.95
32.15% <=40.445
0.35% <=40.495
0.95% <=40.59
6.91% <=40.895
3.88% <=41.395
2.51% <=41.71
3.69% <=42.065
6.38% <=43.07
2.44% <=43.94
2.99% <=44.99
1.25% <=45.555
0.91% <=46.095
0.35% <=46.285
1.73% <=47.29
0.38% <=47.42
1.49% >47.42
Latitude (2)
Mean: 35.990 Dev: 0.000
Value: 38.136
2.64% <=28.545
4.84% <=31.14
3.05% <=32.51
1.62% <=32.81
2.34% <=33.41
0.74% <=33.495
8.71% <=34.255
7.78% <=35.925
4.23% <=36.59
2.29% <=36.845
2.43% <=37.275
0.56% <=37.425
7.97% <=38.695
16.01% <=40.59
6.27% <=40.875
1.68% <=41.045
0.26% <=41.065
4.95% <=41.71
3.49% <=42.065
6.86% <=43.155
4.69% <=44.955
6.59% >44.955
Associa... Associa...



BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\Demo\Associated graph 5.xbl
Network Data Edit View Learnin
Associated graph 5.xbl *
Longitude
Latitude
Map
Map
Canada
ALBERTA
MANITOBA
BRITISH COLUMBIA
SASKATCHEWAN
NEWFOUNDLAND AND LABRADOR
ONTARIO
QUEBEC
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
WYOMING
NEVADA
UTAH
COLORADO
NEW MEXICO
ARIZONA
Ottawa
Montreal
Toronto
NB
PE
NOVA SCOTIA
San Francisco
Las Vegas
Los Angeles
San Diego
Philadelphia
Houston
Gulf of Mexico
Gulf of California
Mexico
Mexico City
Cuba
Dominican Republic
Puerto Rico
Caribbean Sea
Guatemala
Honduras
Nicaragua
Costa Rica
Caracas
Map data ©2018 Google, INEGI 500 km Terms of Use
Close
Save As...
Print
<=28.545
<=31.14
<=32.51
<=32.81
<=33.41
<=33.495
<=34.255
<=35.925
<=36.59
<=36.845
<=37.275
<=37.425
<=38.695
<=40.59
<=40.875
<=41.045
<=41.065
<=41.71
<=42.065
<=43.155
<=44.955
>44.955
Longitude (2)
Mean: -86.900 Dev: 0.000
Value: -91.911
2.20% <=-122.475
1.29% <=-122.095
2.42% <=-121.285
1.16% <=-119.675
7.33% <=-116.945
1.31% <=-115.215
0.50% <=-114.595
2.91% <=-110.135
2.40% <=-105.275
1.26% <=-103.095
6.01% <=-97.41
4.95% <=-95.765
1.68% <=-95.34
5.38% <=-92.185
11.16% <=-87.545
9.48% <=-84.155
0.80% <=-83.98
8.78% <=-80.825
1.09% <=-80.445
2.25% <=-80.06
14.14% <=-74.315
4.83% <=-73.865
2.02% <=-73.22
3.70% <=-69.87
0.95% >-69.87
Associa...
Associa...

Drive Time Bands

Computing the Cost

- "Search the Map" → slow, but accurate
- Great-Circle Distance Computation → fast, but inaccurate
- Learn & Infer → fast and good approximation

Spatial Learning and Optimization

Example 2: Hub Location

Spatial Learning and Optimization

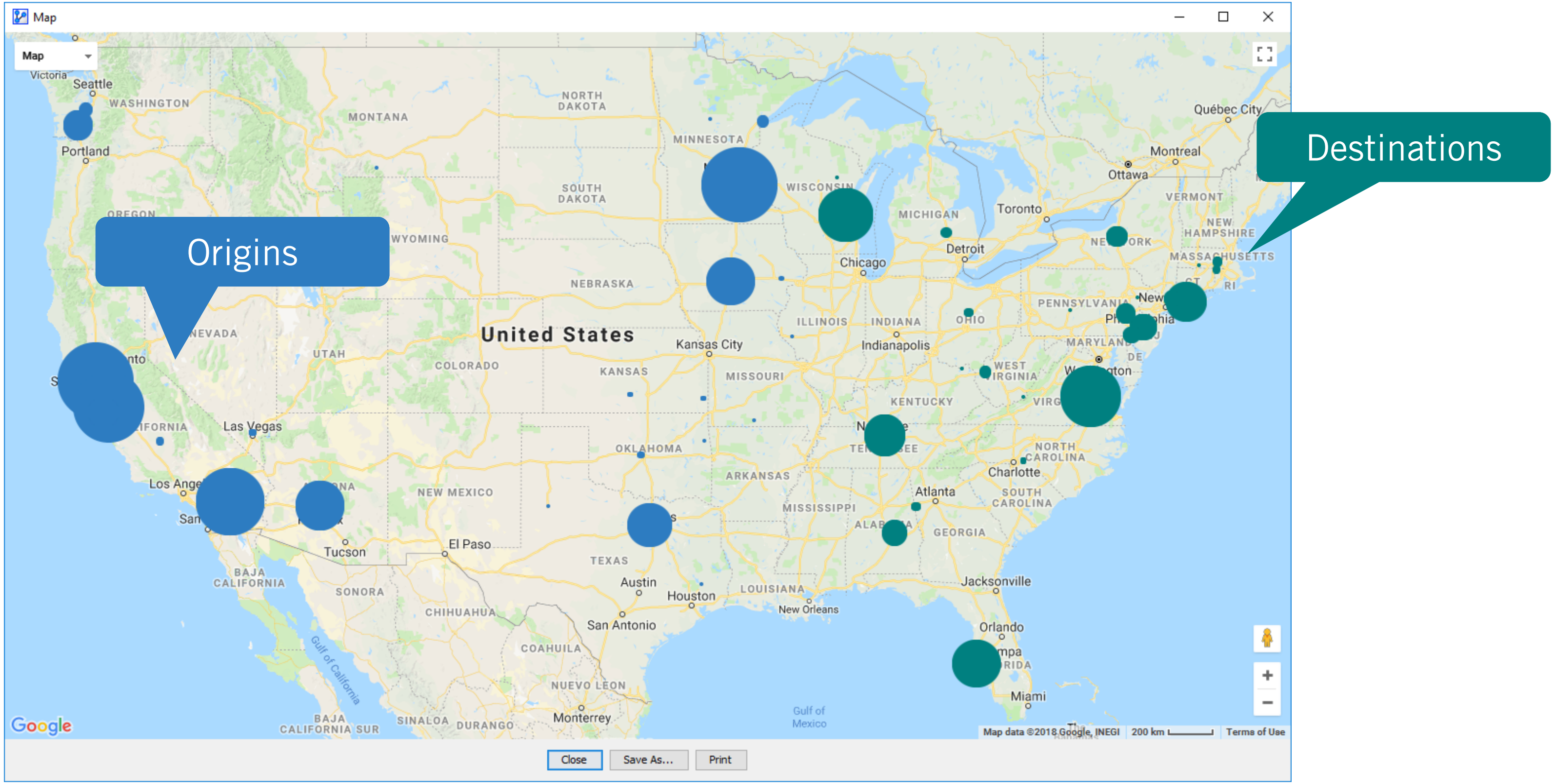
Optimization Problems Under Consideration

1. One origin, one destination → Shortest Path Problem
2. One origin, many destinations → Drive Time Bands
3. Many origins, one destination → Store Location Problem
4. Many origins, one hub, many destinations → Hub Location Problem
5. Many origins, multiple hubs, many destinations → Multi-Hub Location Problem

General Objective

- Minimize “cost function,” e.g., travel time, distance, fuel consumption, number of turns, etc.
- Further assumption: all “participants” have same objective.

Hub Location Problem

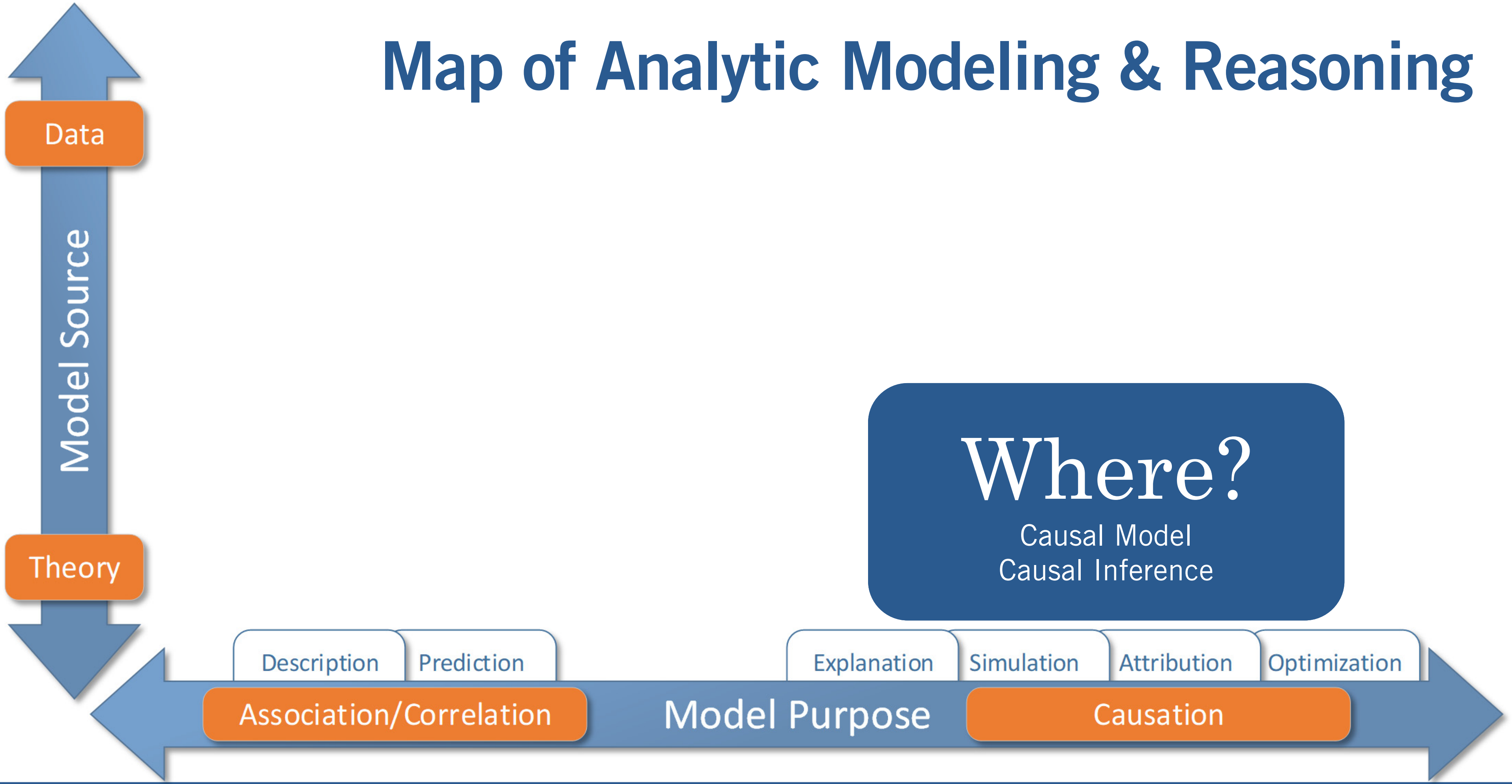


Hub Location Problem

Workflow

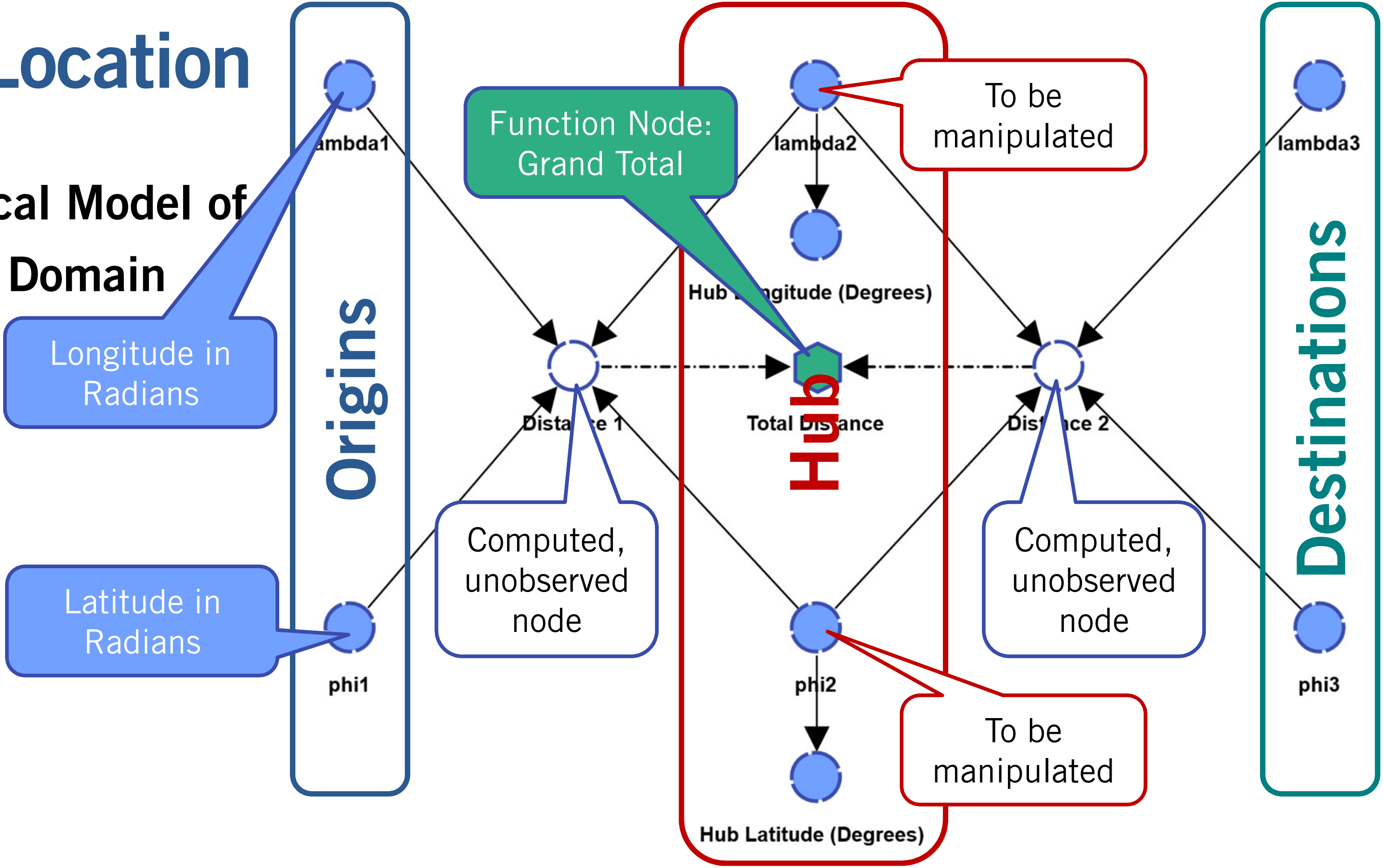
- Encode theoretical model of problem domain.
- Define Nodes
    - Observed
    - Unobserved
    - Functions
- Load data for origins and destinations.
- Perform Function Optimization.

Map of Analytic Modeling & Reasoning



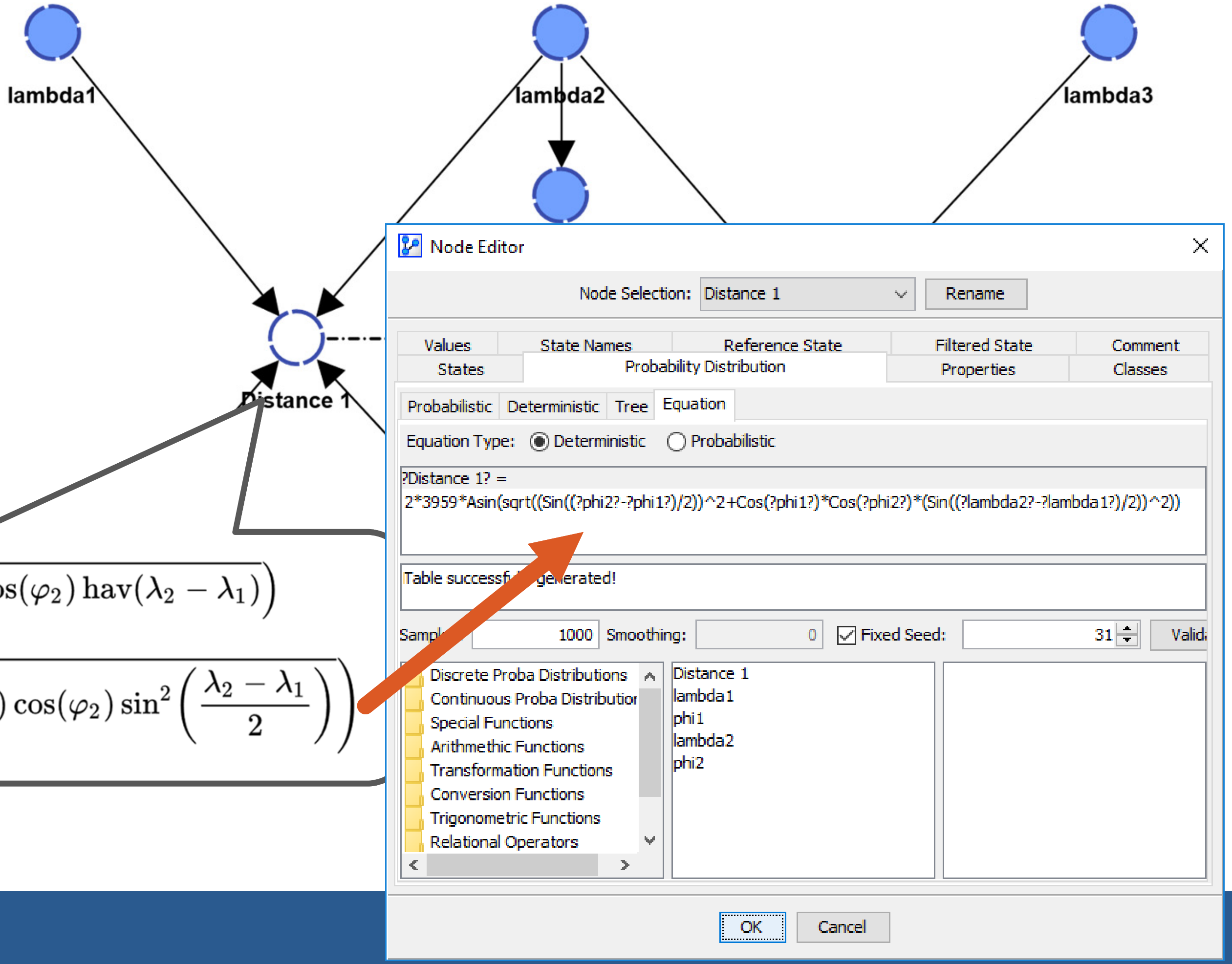
Hub Location

Theoretical Model of Problem Domain



Hub Location

Theoretical Model of Problem Domain

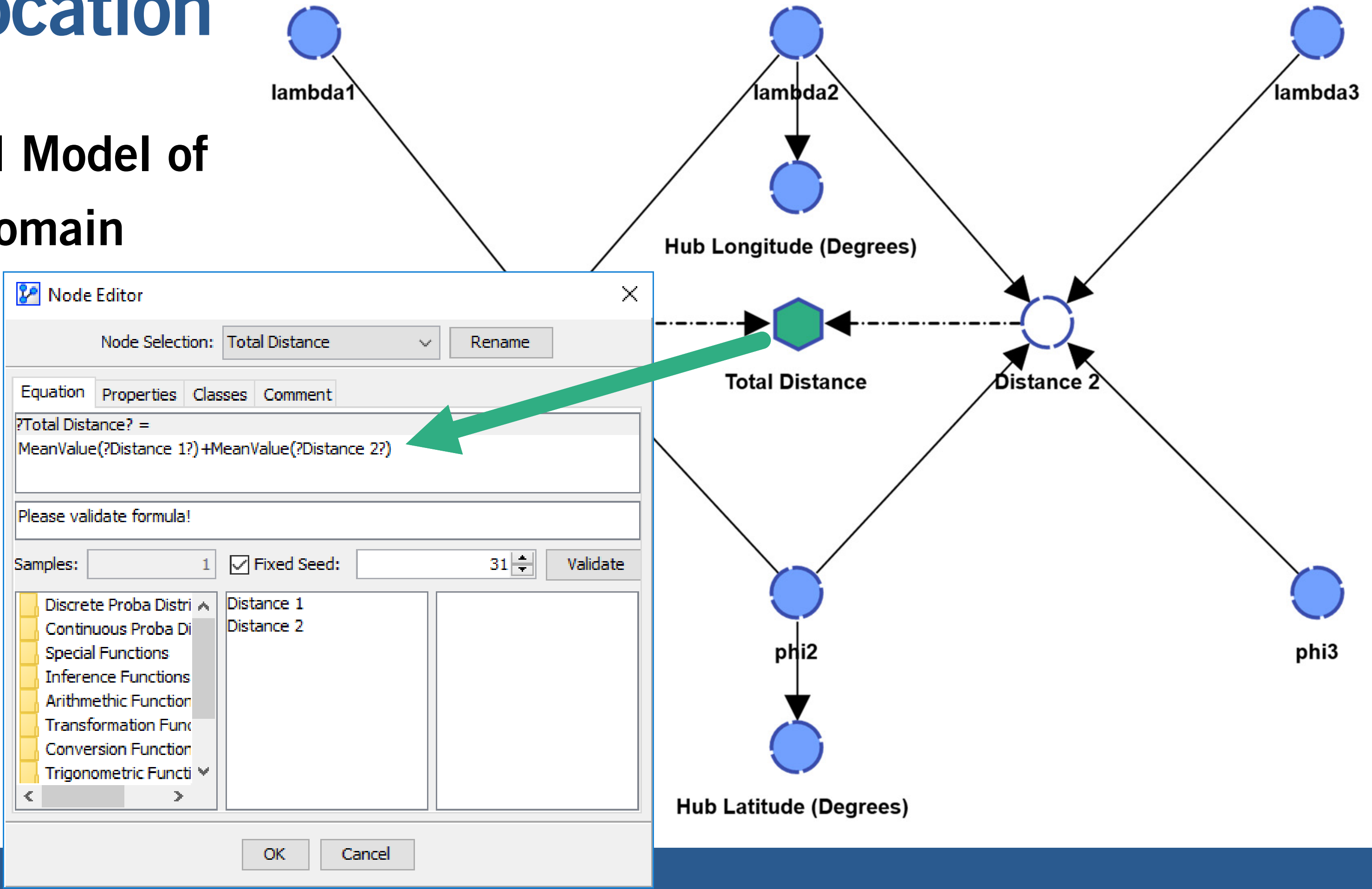


$$d = 2r \arcsin\left(\sqrt{\operatorname{hav}(\varphi_2 - \varphi_1) + \cos(\varphi_1)\cos(\varphi_2)\operatorname{hav}(\lambda_2 - \lambda_1)}\right)$$

$$= 2r \arcsin\left(\sqrt{\sin^2\left(\frac{\varphi_2 - \varphi_1}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right)$$

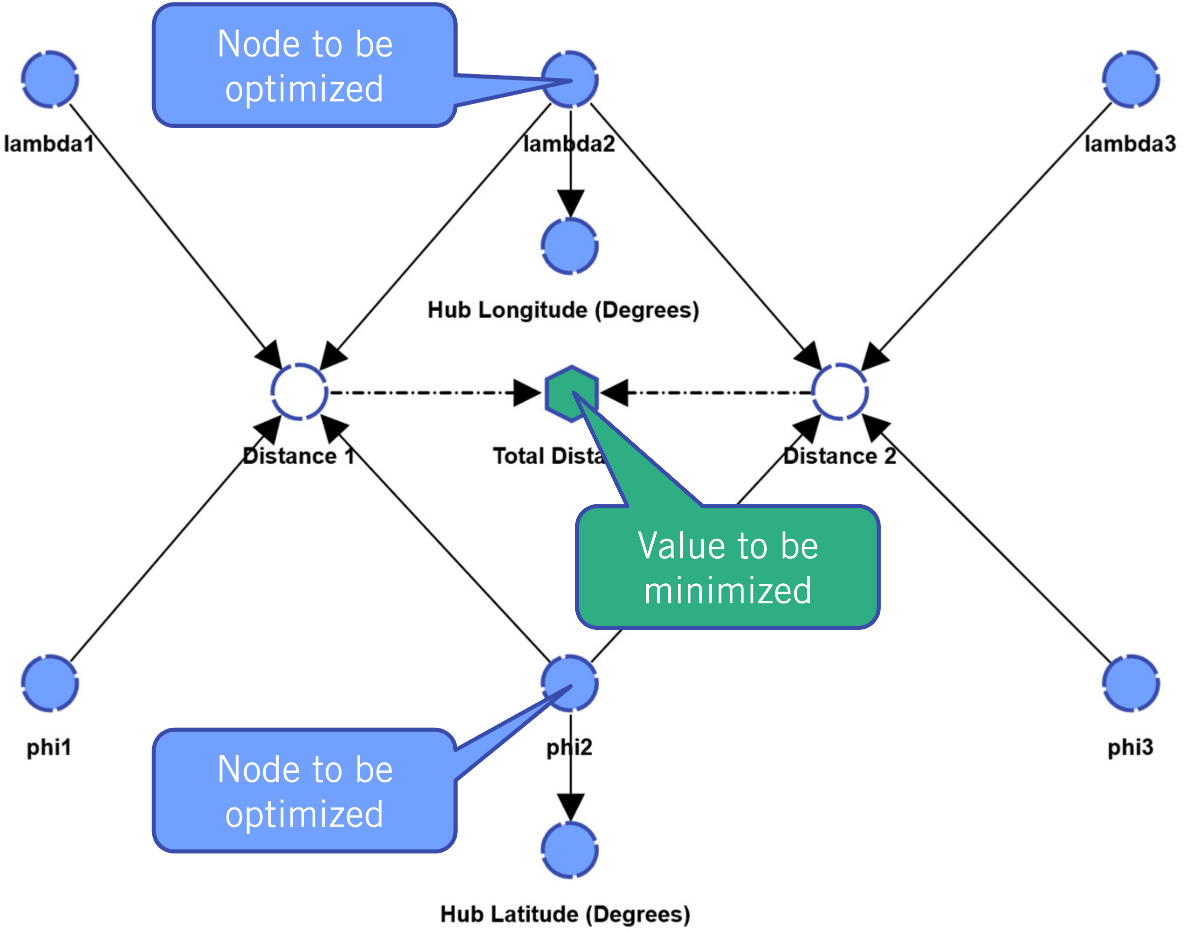
Hub Location

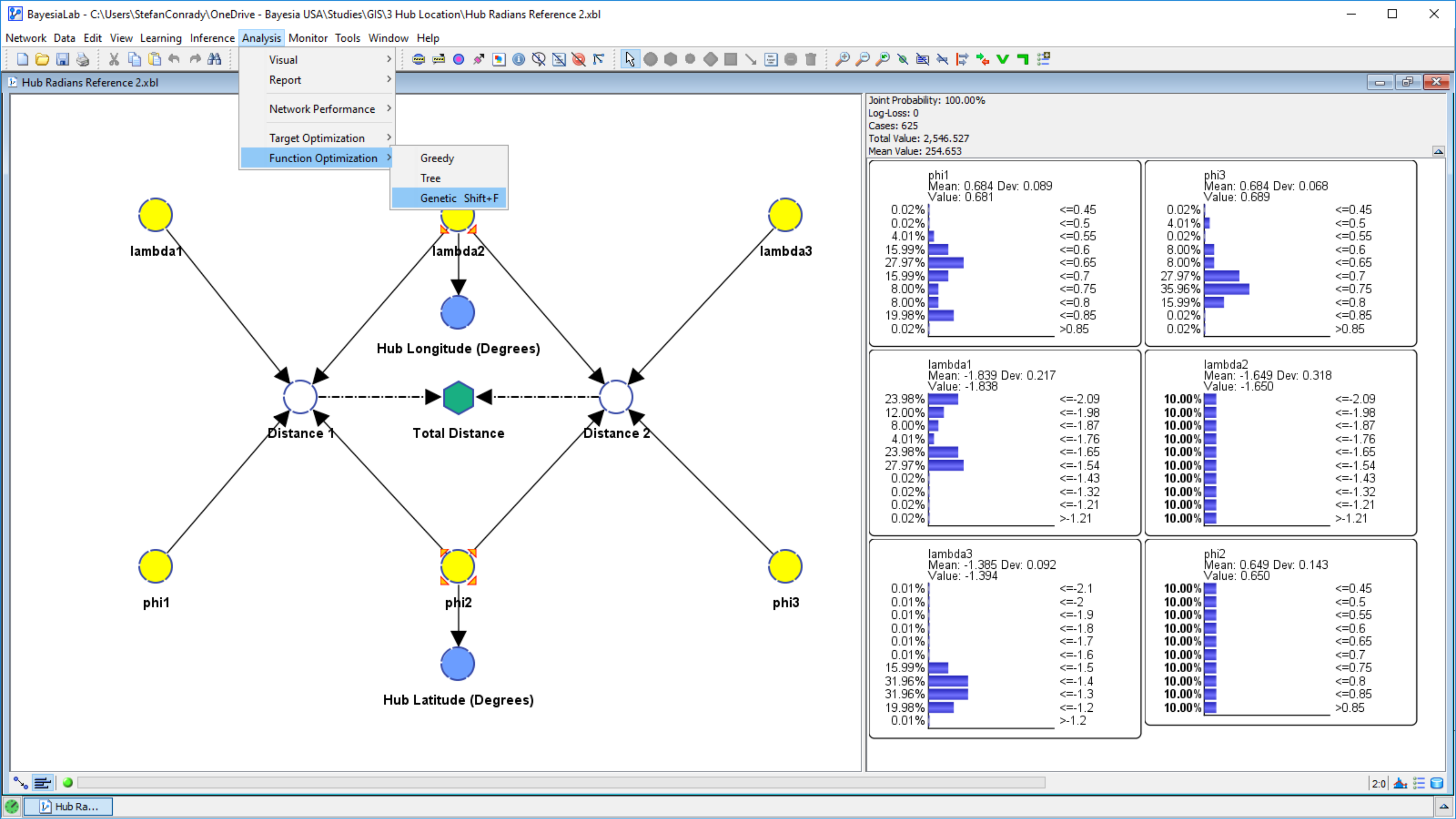
Theoretical Model of Problem Domain

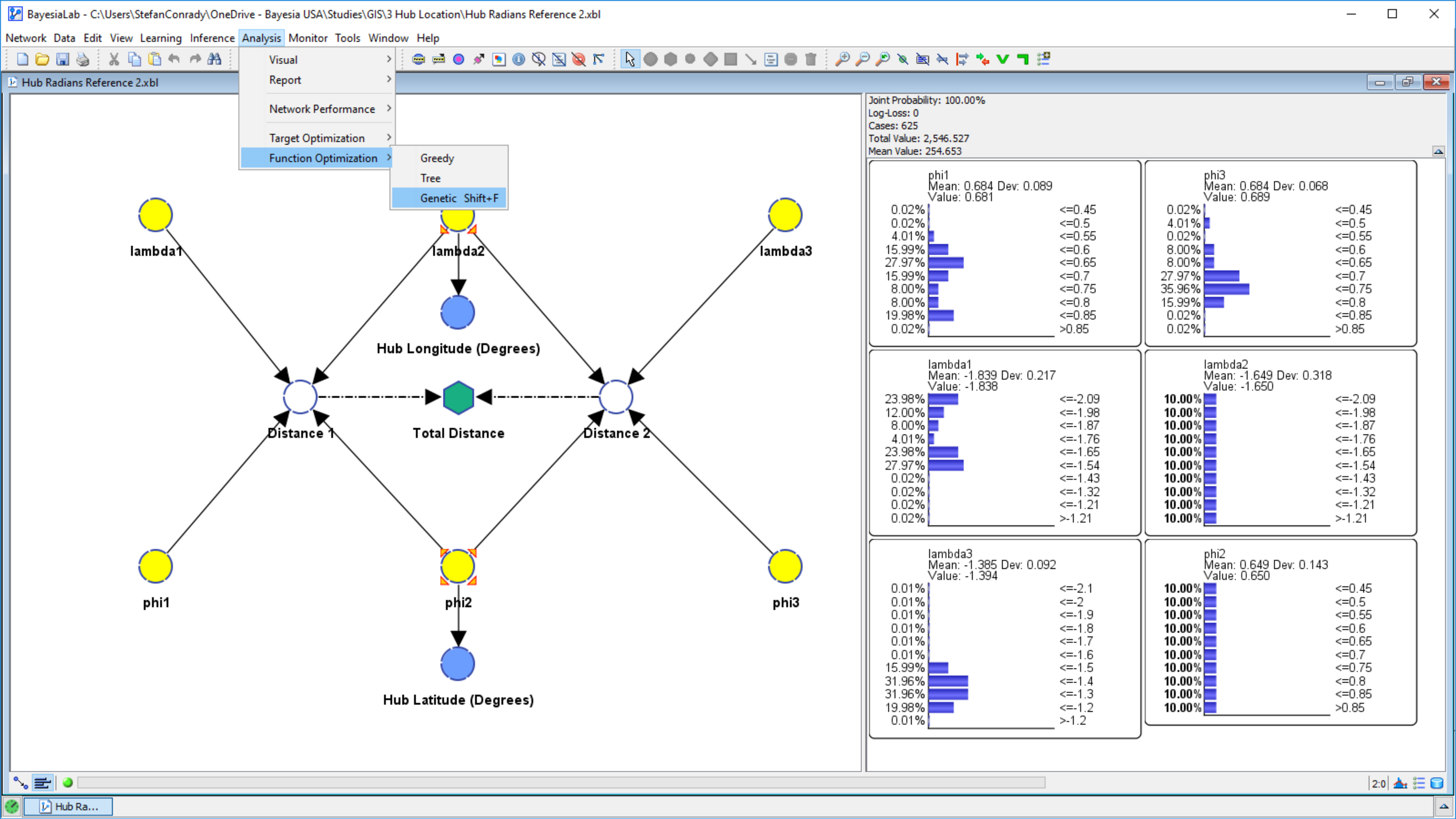


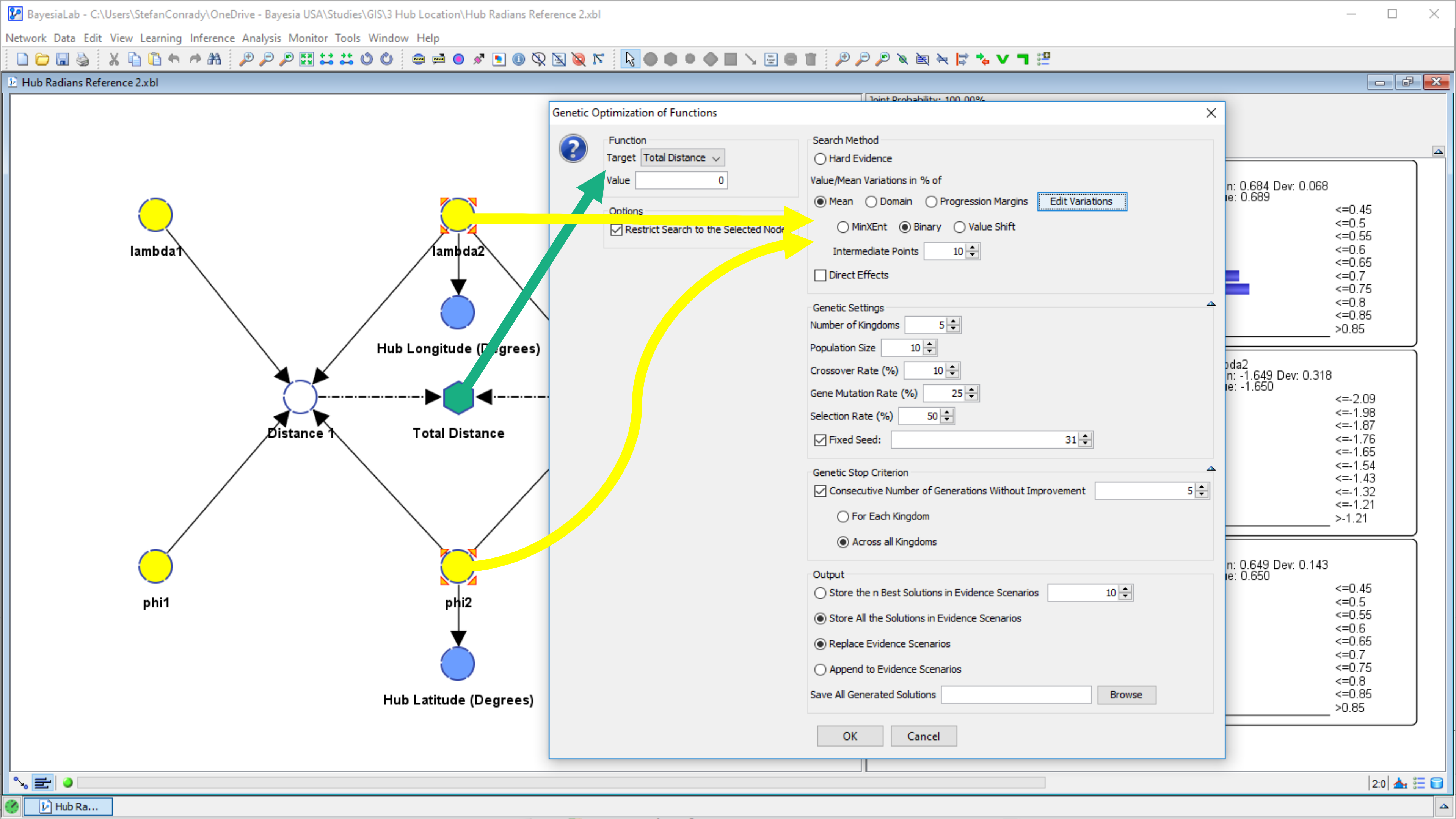
Hub Location

Theoretical Model of Problem Domain

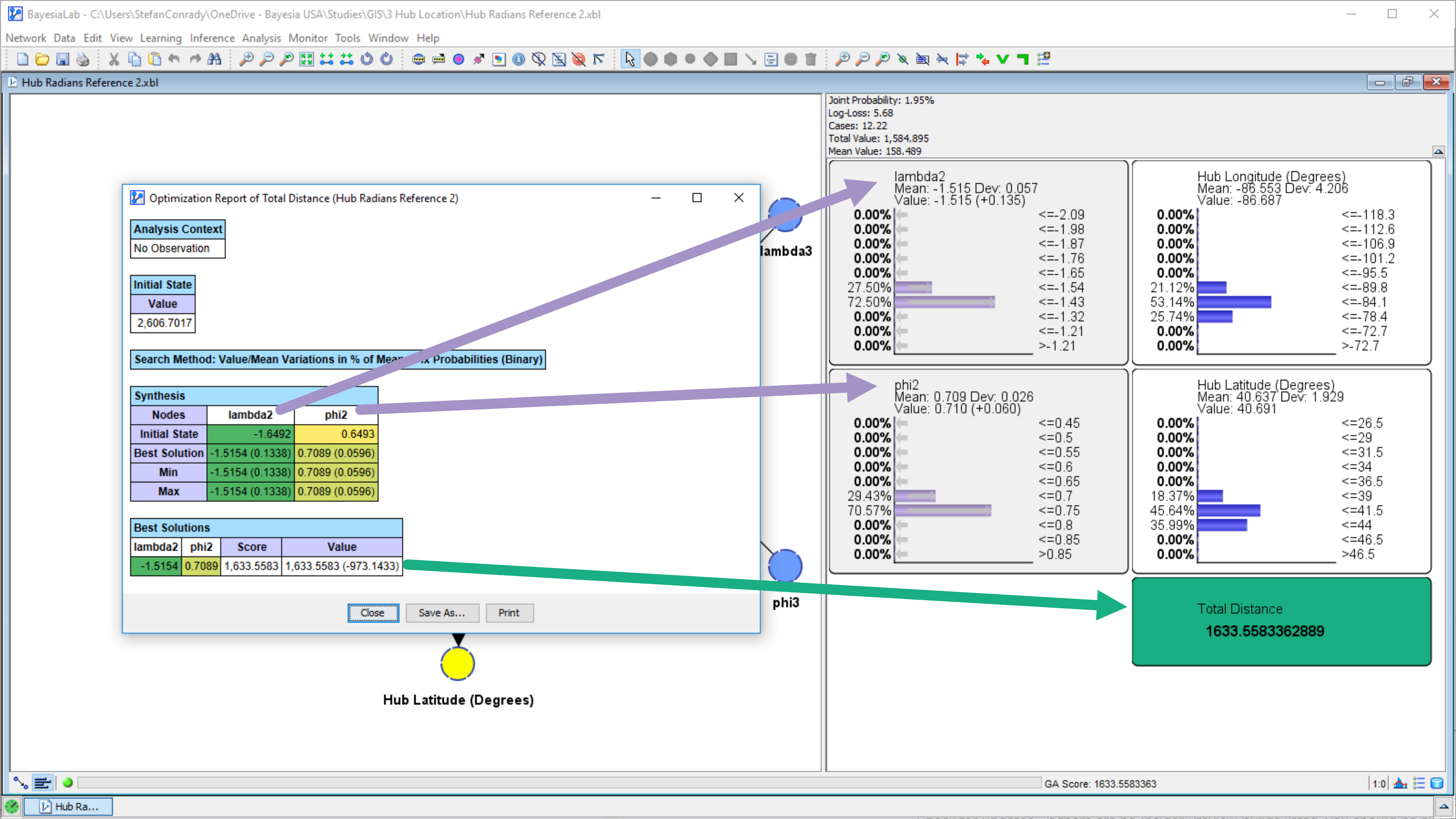



BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\3 Hub Location\Hub Radians Reference 2.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Hub Radians Reference 2.xbl
Visual
Report
Network Performance
Target Optimization
Function Optimization
Greedy
Tree
Genetic Shift+F
lambda1
lambda2
lambda3
Hub Longitude (Degrees)
Distance 1
Total Distance
Distance 2
phi1
phi2
phi3
Hub Latitude (Degrees)
Joint Probability: 100.00%
Log-Loss: 0
Cases: 625
Total Value: 2,546.527
Mean Value: 254.653
phi1
Mean: 0.684 Dev: 0.089
Value: 0.681
0.02% <=0.45
0.02% <=0.5
4.01% <=0.55
15.99% <=0.6
27.97% <=0.65
15.99% <=0.7
8.00% <=0.75
8.00% <=0.8
19.98% <=0.85
0.02% >0.85
phi3
Mean: 0.684 Dev: 0.068
Value: 0.689
0.02% <=0.45
4.01% <=0.5
0.02% <=0.55
8.00% <=0.6
8.00% <=0.65
27.97% <=0.7
35.96% <=0.75
15.99% <=0.8
0.02% <=0.85
0.02% >0.85
lambda1
Mean: -1.839 Dev: 0.217
Value: -1.838
23.98% <=-2.09
12.00% <=-1.98
8.00% <=-1.87
4.01% <=-1.76
23.98% <=-1.65
27.97% <=-1.54
0.02% <=-1.43
0.02% <=-1.32
0.02% <=-1.21
0.02% >-1.21
lambda2
Mean: -1.649 Dev: 0.318
Value: -1.650
10.00% <=-2.09
10.00% <=-1.98
10.00% <=-1.87
10.00% <=-1.76
10.00% <=-1.65
10.00% <=-1.54
10.00% <=-1.43
10.00% <=-1.32
10.00% <=-1.21
10.00% >-1.21
lambda3
Mean: -1.385 Dev: 0.092
Value: -1.394
0.01% <=-2.1
0.01% <=-2
0.01% <=-1.9
0.01% <=-1.8
0.01% <=-1.7
0.01% <=-1.6
15.99% <=-1.5
31.96% <=-1.4
31.96% <=-1.3
19.98% <=-1.2
0.01% >-1.2
phi2
Mean: 0.649 Dev: 0.143
Value: 0.650
10.00% <=0.45
10.00% <=0.5
10.00% <=0.55
10.00% <=0.6
10.00% <=0.65
10.00% <=0.7
10.00% <=0.75
10.00% <=0.8
10.00% <=0.85
10.00% >0.85
Hub Ra...


BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\3 Hub Location\Hub Radians Reference 2.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Hub Radians Reference 2.xbl
Visual
Report
Network Performance
Target Optimization
Function Optimization
Greedy
Tree
Genetic Shift+F
lambda1
lambda2
lambda3
Hub Longitude (Degrees)
Distance 1
Total Distance
Distance 2
phi1
phi2
phi3
Hub Latitude (Degrees)
Joint Probability: 100.00%
Log-Loss: 0
Cases: 625
Total Value: 2,546.527
Mean Value: 254.653
phi1
Mean: 0.684 Dev: 0.089
Value: 0.681
0.02% <=0.45
0.02% <=0.5
4.01% <=0.55
15.99% <=0.6
27.97% <=0.65
15.99% <=0.7
8.00% <=0.75
8.00% <=0.8
19.98% <=0.85
0.02% >0.85
phi3
Mean: 0.684 Dev: 0.068
Value: 0.689
0.02% <=0.45
4.01% <=0.5
0.02% <=0.55
8.00% <=0.6
8.00% <=0.65
27.97% <=0.7
35.96% <=0.75
15.99% <=0.8
0.02% <=0.85
0.02% >0.85
lambda1
Mean: -1.839 Dev: 0.217
Value: -1.838
23.98% <=-2.09
12.00% <=-1.98
8.00% <=-1.87
4.01% <=-1.76
23.98% <=-1.65
27.97% <=-1.54
0.02% <=-1.43
0.02% <=-1.32
0.02% <=-1.21
0.02% >-1.21
lambda2
Mean: -1.649 Dev: 0.318
Value: -1.650
10.00% <=-2.09
10.00% <=-1.98
10.00% <=-1.87
10.00% <=-1.76
10.00% <=-1.65
10.00% <=-1.54
10.00% <=-1.43
10.00% <=-1.32
10.00% <=-1.21
10.00% >-1.21
lambda3
Mean: -1.385 Dev: 0.092
Value: -1.394
0.01% <=-2.1
0.01% <=-2
0.01% <=-1.9
0.01% <=-1.8
0.01% <=-1.7
0.01% <=-1.6
15.99% <=-1.5
31.96% <=-1.4
31.96% <=-1.3
19.98% <=-1.2
0.01% >-1.2
phi2
Mean: 0.649 Dev: 0.143
Value: 0.650
10.00% <=0.45
10.00% <=0.5
10.00% <=0.55
10.00% <=0.6
10.00% <=0.65
10.00% <=0.7
10.00% <=0.75
10.00% <=0.8
10.00% <=0.85
10.00% >0.85
2:0
Hub Ra...

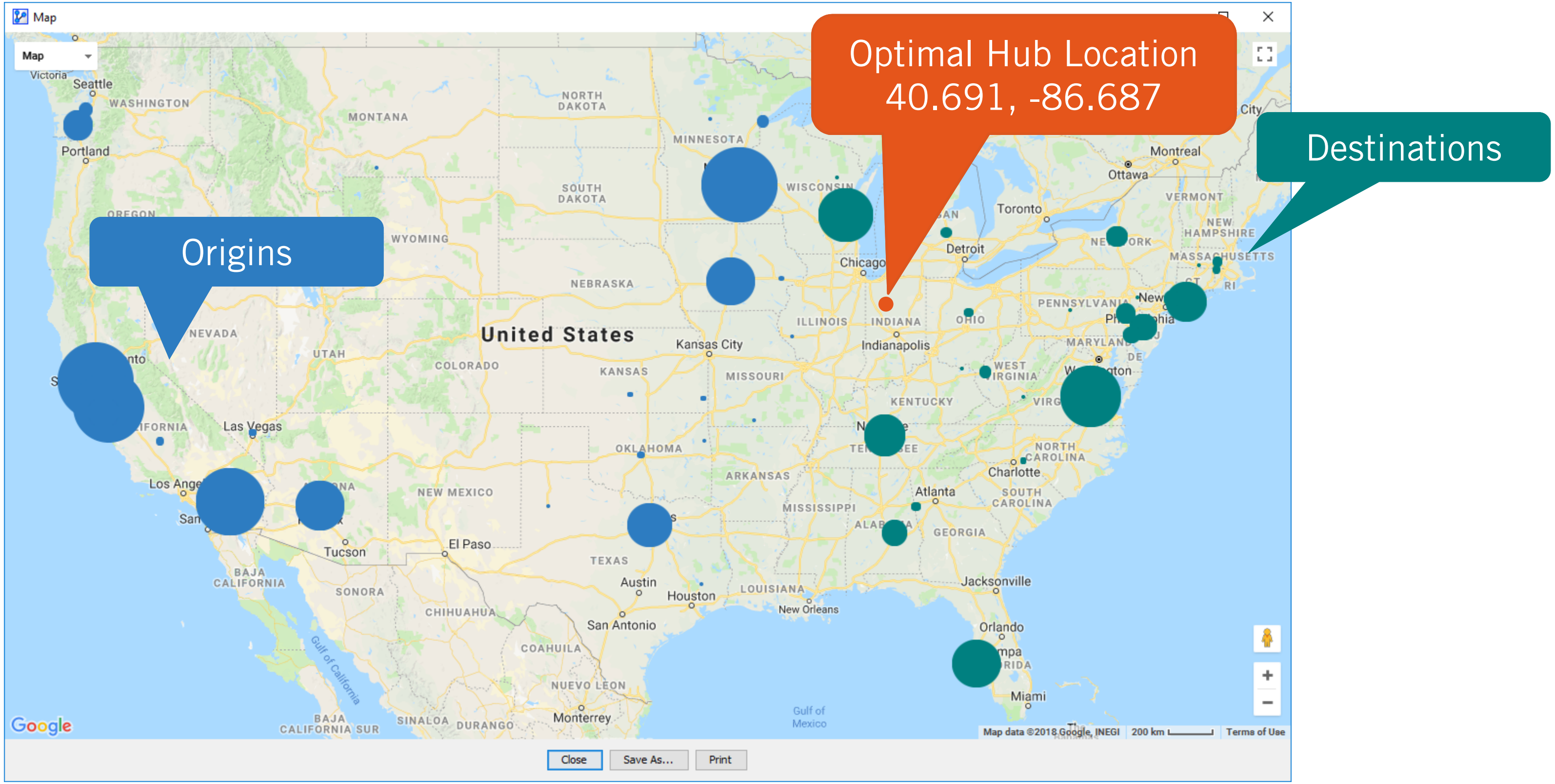


BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\3 Hub Location\Hub Radians Reference 2.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Hub Radians Reference 2.xbl
lambda1
lambda2
Hub Longitude (Degrees)
Distance 1
Total Distance
phi1
phi2
Hub Latitude (Degrees)
Genetic Optimization of Functions
Function
Target Total Distance
Value 0
Options
Restrict Search to the Selected Nodes
Search Method
Hard Evidence
Value/Mean Variations in % of
Mean Domain Progression Margins Edit Variations
MinXEnt Binary Value Shift
Intermediate Points 10
Direct Effects
Genetic Settings
Number of Kingdoms 5
Population Size 10
Crossover Rate (%) 10
Gene Mutation Rate (%) 25
Selection Rate (%) 50
Fixed Seed: 31
Genetic Stop Criterion
Consecutive Number of Generations Without Improvement 5
For Each Kingdom
Across all Kingdoms
Output
Store the n Best Solutions in Evidence Scenarios 10
Store All the Solutions in Evidence Scenarios
Replace Evidence Scenarios
Append to Evidence Scenarios
Save All Generated Solutions
Browse
OK
Cancel
Joint Probability: 100.00%



BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Studies\GIS\3 Hub Location\Hub Radians Reference 2.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Hub Radians Reference 2.xbl
Optimization Report of Total Distance (Hub Radians Reference 2)
Analysis Context
No Observation
Initial State
Value
2,606.7017
Search Method: Value/Mean Variations in % of Mean Probabilities (Binary)
Synthesis
Nodes | lambda2 | phi2
Initial State | -1.6492 | 0.6493
Best Solution | -1.5154 (0.1338) | 0.7089 (0.0596)
Min | -1.5154 (0.1338) | 0.7089 (0.0596)
Max | -1.5154 (0.1338) | 0.7089 (0.0596)
Best Solutions
lambda2 | phi2 | Score | Value
-1.5154 | 0.7089 | 1,633.5583 | 1,633.5583 (-973.1433)
Close
Save As...
Print
lambda3
phi3
Hub Latitude (Degrees)
Joint Probability: 1.95%
Log-Loss: 5.68
Cases: 12.22
Total Value: 1,584.895
Mean Value: 158.489
lambda2
Mean: -1.515 Dev: 0.057
Value: -1.515 (+0.135)
0.00% <=-2.09
0.00% <=-1.98
0.00% <=-1.87
0.00% <=-1.76
0.00% <=-1.65
27.50% <=-1.54
72.50% <=-1.43
0.00% <=-1.32
0.00% <=-1.21
0.00% >-1.21
Hub Longitude (Degrees)
Mean: -86.553 Dev: 4.206
Value: -86.687
0.00% <=-118.3
0.00% <=-112.6
0.00% <=-106.9
0.00% <=-101.2
0.00% <=-95.5
21.12% <=-89.8
53.14% <=-84.1
25.74% <=-78.4
0.00% <=-72.7
0.00% >-72.7
phi2
Mean: 0.709 Dev: 0.026
Value: 0.710 (+0.060)
0.00% <=0.45
0.00% <=0.5
0.00% <=0.55
0.00% <=0.6
0.00% <=0.65
29.43% <=0.7
70.57% <=0.75
0.00% <=0.8
0.00% <=0.85
0.00% >0.85
Hub Latitude (Degrees)
Mean: 40.637 Dev: 1.929
Value: 40.691
0.00% <=26.5
0.00% <=29
0.00% <=31.5
0.00% <=34
0.00% <=36.5
18.37% <=39
45.64% <=41.5
35.99% <=44
0.00% <=46.5
0.00% >46.5
Total Distance
1633.5583362889
GA Score: 1633.5583363
Hub Ra...

Hub Location Problem



In Conclusion…

Upcoming Events

Webinars & Seminars:

- June1 Webinar: Health Outcomes Research
- June 19 Seminar in Chicago: Knowledge Discovery in Financial Data

Register here: bayesia.com/events

BayesiaLab Courses Around the World in 2018

- June 26–28
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- August 29–31
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- October 29–31
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- December 4–6
  New York, NY

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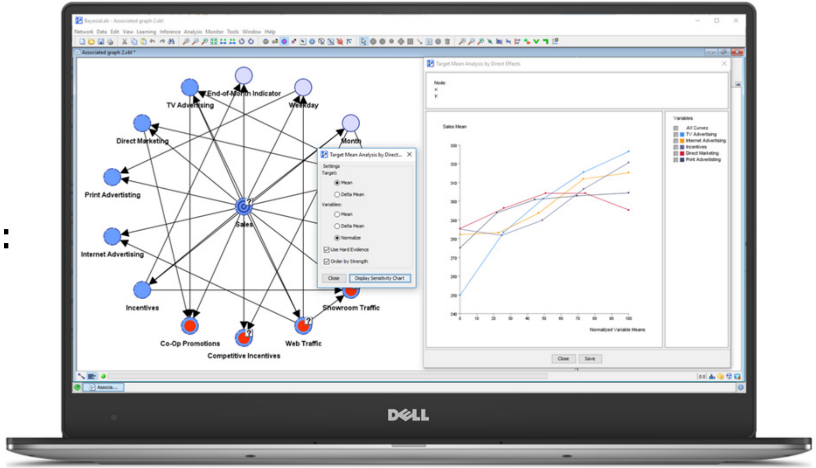
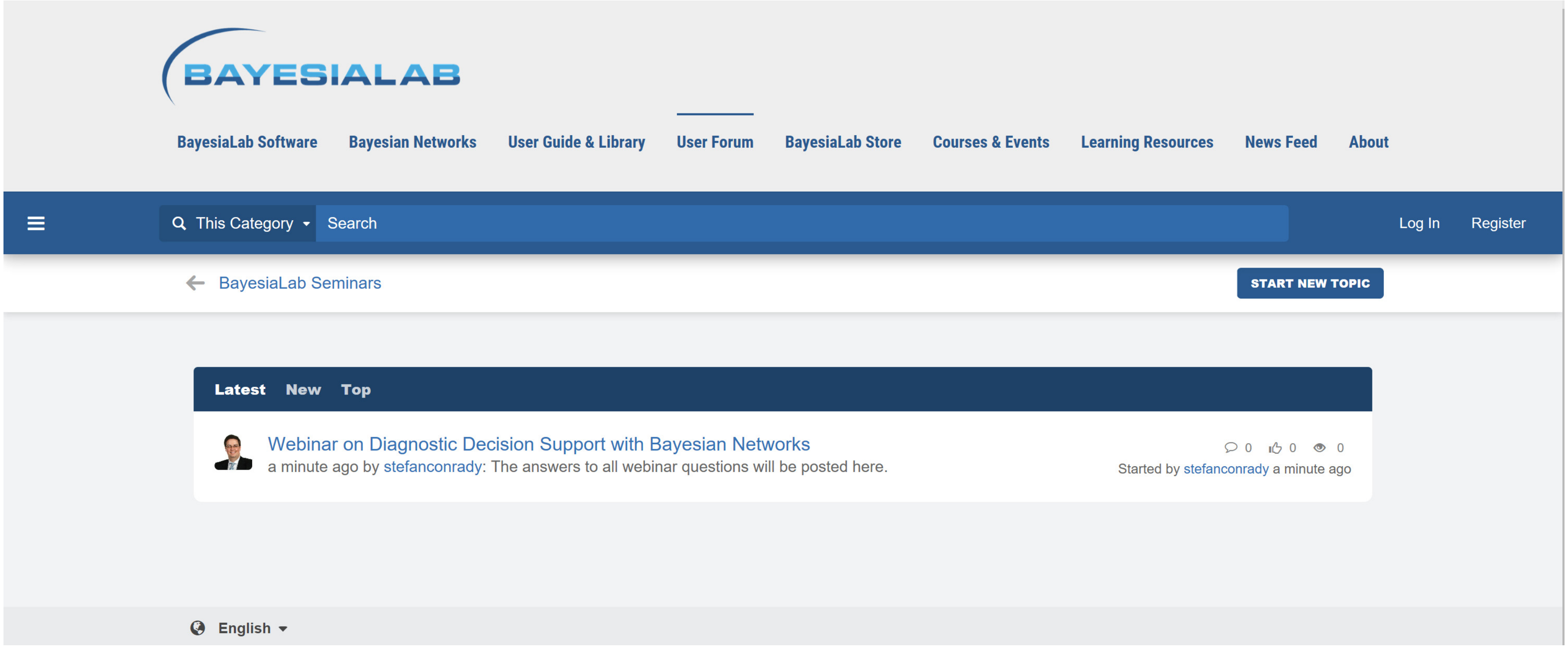
  www.bayesialab.com/evaluation



User Forum: bayesia.com/community




6th Annual BayesiaLab Conference in Chicago
November 1–2, 2018

Thank You!

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