Final Project: The Politics of Routing - Investigating the Link Between Interdomain Connectivity and Internet Freedom

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Part 1: Data collection and analysis

We have used the registered country code according to ISO3166-1. Currently 249 country codes are officially available. The CAIDA data contains 51, 501 AS numbers (ASN) all over the world.

In order to map each ASN to the country, we leverage the registration information provided by `cymru.com`. Out of all ASN, 50, 818 ASes can be identified and 683 ASes remained unidentified due to either missing or inaccurate information. For example, the country code EU belongs to Europe, but not a single country. Likewise, the code ZZ means the reserved ASN although the ASN was shown in CAIDA. However, in this project, those connections have been ignored which ended up with accounting for only 0.01%.

Along with ASN links from CAIDA, we combined the hidden edges using separate traceroute data, discovered by Rachee, with the existing links. As CAIDA data itself is incomplete because it might not see the local edges, the combination of two data set helps to get close to complete AS graphs. The number of connections among ASes in CAIDA is 199, 539 as of Aug. 2015, and the number from traceroute data is 15, 954, thus we eventually gained 50, 818 nodes (ASes) and 215, 493 edges (links) in total for the entire graph. In the graph, blue nodes represents domestic ASes and red ones depicts international ASes.

Part 2: Sub-graphs of the topology per each country

The 231 countries turn out to possess at least one or more ASes. First, we produce the sub-graphs of the Internet topology for each country. The graph illustrates what the topology of 192 countries looks like at a glance. Again, due to the incompleteness of data set some edges are clearly missing, or some countries have no outgoing connection. Figure 1 illustrates the example of the topology for two countries that is known to censor Internet traffic and not.

Part 3: Exploring the metrics

The goal of this project is to see how interdomain connectivity relates to Internet freedom or economic/political characteristics of the countries based on their interdomain connectivity. Therefore it is essential to choose appropriate metrics and check how well they could explain the relationship bewteen AS connectivity and Internet freedom. We have taken advantage of three official indexes to measure economic/political characteristics: Freedom House Index (FHI), Democracy Index (DI), and Reporters Without Borders Index (RWBI). However, not all countries are available to get the indexes. We could obtain 192, 167, and 178 indexes (FHI

Table 1: Correlationship Coefficient between each metric and public indexes

Explored Metrics	**FHI**	**DI**	**RWBI**
Number of nodes	0.148157	0.153996	0.072192
Number of edges	0.137037	0.142764	0.06467
Number of foreign ASes *	0.319965	0.320038	0.237468
Number of domestic ASes connected to foreign ASes *	0.280964	0.296195	0.193413
Average clustering coefficient	0.155442	0.22917	-0.0155
Average degree connectivity	0.208344	0.290089	0.11854
Average neighbor degree	0.24887	0.335812	0.13519
Average node connectivity	0.13002	0.172013	-0.0176
Surveillance index	0.085757	0.062251	0.112105
Average shortest path length *	0.384775	0.45908	0.255431
Center	-0.12796	-0.19907	-0.00313
Diameter *	0.419671	0.479558	0.284273
Eccentricity	0.400835	0.461213	0.271562
Periphery	-0.07819	-0.04564	-0.04058
Radius *	0.31978	0.365964	0.227006
Density *	-0.32574	-0.42206	-0.16544
Components	0.426518	0.450295	0.350895
Average Degree *	0.303342	0.377229	0.161176
Average Path Length *	0.378565	0.45397	0.237122
Modularity *	0.305919	0.419153	0.217303
Community Number *	0.416936	0.492711	0.285289
Total Triangles	0.060901	0.106298	0.031786

in 2012, DI in 2014, and RWBI in 2015 in order) for different country set respectively. The intersection of three indexes filters the final 131 countries to evaluate the metrics.

Each index represents different scale and meaning, thus we normalized and tweaked it for consistency. For example, the lower index of both FHI and RWBI, the better, which means the country with the low index has more freedom and less censored country. Meanwhile, the higher DI represents the more developed country in terms of democracy. Therefore, we normalized them from 0 to 1 that always indicates 0 is the worst and 1 is the opposite. After adjusting the indexes, the correlationship coefficients among them are 0.916, 0.797, and 0.877 respectively. (FH and DI, DI and RWBI, and FH and RWBI) This means these indexes can be good indicator candidates to achieve the objective of this project. Figure 2 shows two cumulative distribution function (CDF) graphs. The first one is the distribution of ASes (nodes) and their links (edges), and the number of ASes that have connection to foreign countries. The other one shows the distribution of three publicly available indexes to explain the degree of freedom and democracy.

Table 2 is the part of the indexes and the number of ASes for a country. After getting the sub-graphs of each country, in Table 1, we have explored 22 different metrics with the help of both `networkX` and `gephi` libraries.

Note that correlationship coefficient is the coefficient that measures statistical relationships quantitatively, such as correlation and dependence, between two or more random variables or observed data values. It ranges from -1 to 1 that indicates two variables have either positive or negative relationship. Once getting all values of the metrics for all countries, we compute the correlationship coefficient between individual metric and the index. Here we only care the case that the absolute value of the coefficient is larger than 0.25.

We selected 10 metrics as the features for clustering. In Figure 3, the upper half consists of three rows and ten columns. Each scattering plot implies the positive or negative relationship between the metric and the index. Similarly, the lower half shows the CDF of each scattering that represents the relationship according to the correlationship coefficients we discovered. Figure 4 is the final outcome of clustering with setting up 4 clusters as a parameter. We have evaluated 8 different clustering algorithm and each has different result. This is very expecting consequence because different clustering algorithms have their own strengths and weaknesses. It is worth noting the there are several algorithms that automatically decide the number of possible clusters. Different colors represent different clusters, and each dot means a single country. If the algorithm needs the parameter, we separately marked it on the bottom of each clustering. In particular, K-means algorithm found the centroid of each cluster that has been marked as large circle in the figure.

We have not combined all features together when performing clustering, because we were not able to discover the feature that strongly supports the relationship between ASN and the freedom of Internet or the degree of democracy for a country. It is still an open problem, but this project sheds light on the possibility of the relationship. For future work, we can apply other indexes such as Good Country Index. Also, it would be worthy to investigate the combined metric by feature reduction or linear regression for clustering.

References

[1] Team Cymru, IP to ASN Mapping,
`https://www.team-cymru.org/IP-ASN-mapping.html`

[2] Scikit-learn, Clustering,
`http://scikit-learn.org/stable/modules/clustering.html`

[3] Wikipedia: Censorship by country,
`https://en.wikipedia.org/wiki/Censorship_by_country`

[4] CAIDA, AS Relationships Dataset,
`http://www.caida.org/data/as-relationships`

[5] Gephi, The Open Graph Viz Platform,
`https://gephi.org/`

[6] NetworkX, High-productivity software for complex networks,
`https://networkx.github.io/`

[7] Matplotlib, a python 2D plotting library with MATLAB-like interface,
`http://matplotlib.org`

[8] Danai Koutra, Ankur Parikh, Algorithms for Graph Similarity and Subgraph Matching,
`https://www.cs.cmu.edu/~jingx/docs/DBreport.pdf`

[9] Freedom House Index,
`https://freedomhouse.org/report/freedom-net-2015/table-country-scores`

[10] Wikipedia: Democracy Index,
`https://en.wikipedia.org/wiki/Democracy_Index`

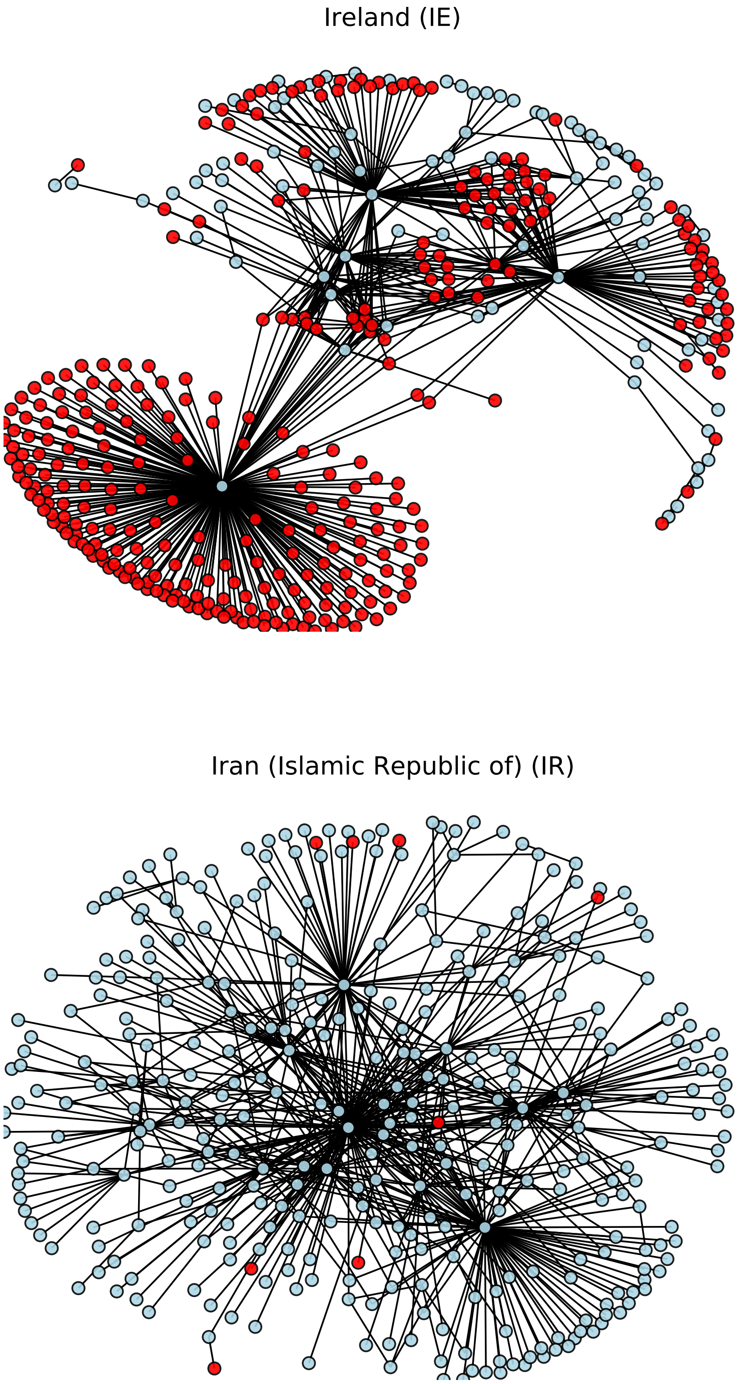
[11] Reporters Without Borders Index,
`https://rsf.org/index2014/en-index2014.php`

[12] ASN topologies per each country at a glance,
`http://dandylife.net/test/topologies`

[13] Correlationship Coefficient for Indexes VS Metrics,
`http://bit.ly/1m7IMji`

Table 2: Number of ASes and the normalized indexes: Freedom House Index, Democracy Index and Reporters Without Borders Index)

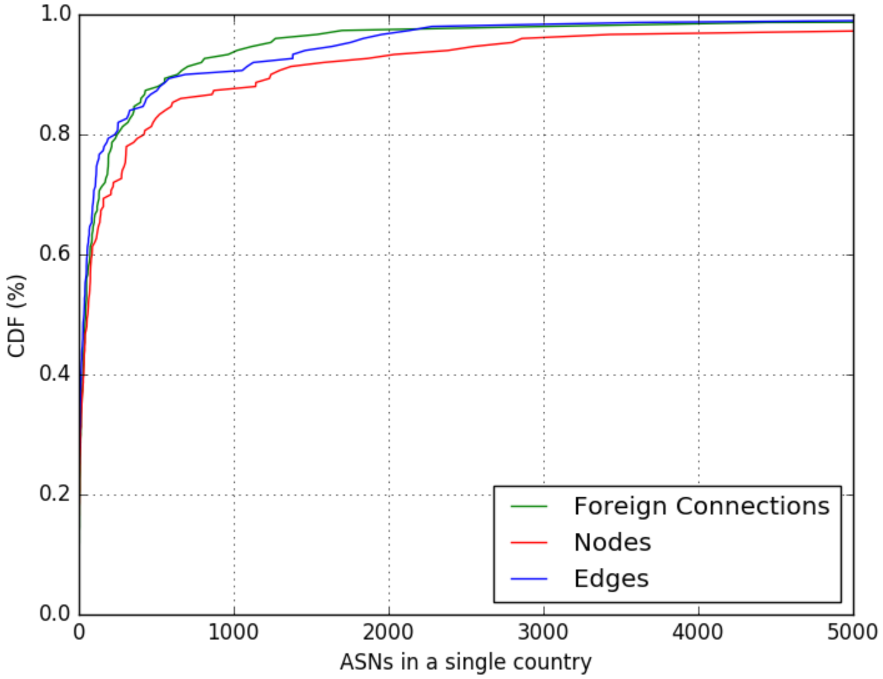
No	Country Code	Country Name	ASNs	FHI	DI	RWBI
1	AD	Andorra	1	0.9655	N/A	0.8403
2	AE	United Arab Emirates	55	0.2874	0.1763	0.6223
3	AF	Afghanistan	35	0.2644	0.1910	0.6131
4	AG	Antigua and Barbuda	3	0.6782	N/A	0.8254
5	AI	Anguilla	2	N/A	N/A	N/A
6	AL	Albania	39	0.5287	0.5186	0.7252
7	AM	Armenia	51	0.3678	0.3446	0.7296
8	AO	Angola	33	0.3448	0.2565	0.6080
9	AQ	Antarctica	0	N/A	N/A	N/A
10	AR	Argentina	376	0.5402	0.6508	0.7596
11	AS	American Samoa	2	N/A	N/A	N/A
12	AT	Austria	423	0.8736	0.8429	0.9569
13	AU	Australia	1169	0.8736	0.8960	0.8770
14	AW	Aruba	2	N/A	N/A	N/A
15	AX	land Islands	1	N/A	N/A	N/A
16	AZ	Azerbaijan	36	0.1954	0.1977	0.3420
17	BA	Bosnia and Herzegovina	31	0.5632	N/A	0.7415
18	BB	Barbados	6	0.8966	0.4181	N/A
19	BD	Bangladesh	227	0.5172	0.5311	0.5419
20	BE	Belgium	198	0.9885	0.7740	0.9423
21	BF	Burkina Faso	6	0.6322	0.3401	0.7896
22	BG	Bulgaria	526	0.7011	0.6384	0.6717
23	BH	Bahrain	19	0.1494	0.2023	0.3384
24	BI	Burundi	11	0.2874	0.2542	0.5422
25	BJ	Benin	7	0.7241	0.5164	0.7192
26	BL	Saint Barthlemy	0	N/A	N/A	N/A
27	BM	Bermuda	10	N/A	N/A	N/A
28	BN	Brunei Darussalam	6	0.2529	N/A	0.6219
29	BO	Bolivia, Plurinational State of	15	0.5747	0.5322	0.6927
30	BQ	Bonaire, Sint Eustatius and Saba	0	N/A	N/A	N/A
31	BR	Brazil	3052	0.6092	0.7119	0.6844
32	BS	Bahamas	4	0.8851	N/A	N/A
33	BT	Bhutan	5	0.4483	0.4282	0.6751
34	BV	Bouvet Island	0	N/A	N/A	N/A
35	BW	Botswana	14	0.6552	0.7672	0.8010
36	BY	Belarus	87	0.0460	0.2949	0.4769
37	BZ	Belize	9	0.8736	N/A	0.8575
38	CA	Canada	1084	0.8966	0.9040	0.9551
39	CC	Cocos (Keeling) Islands	0	N/A	N/A	N/A
40	CD	Congo, the Democratic Republic of the	14	0.1609	0.0757	0.5243
41	CF	Central African Republic	2	0.4023	0.0463	0.6597
42	CG	Congo	11	0.4828	0.2045	0.6705
43	CH	Switzerland	534	0.9770	0.9051	0.9182
44	CI	Cte d'Ivoire	7	0.3103	0.2768	0.7035
45	CK	Cook Islands	1	N/A	N/A	N/A
46	CL	Chile	145	0.7586	0.7593	0.7998
47	CM	Cameroon	12	0.3333	0.2633	0.5848



Ireland (IE)

Iran (Islamic Republic of) (IR)

Figure 1: The topology of Internet connectivity in Iran shows that only a few domestic ASes are connected to foreign ASes. This allows the country to control the incoming and outgoing traffic flow easily. In contrast, the connectivity in Ireland looks different, it is not known to have censorship operation. Ireland has many ASes that connect to foreign countries (red circles).



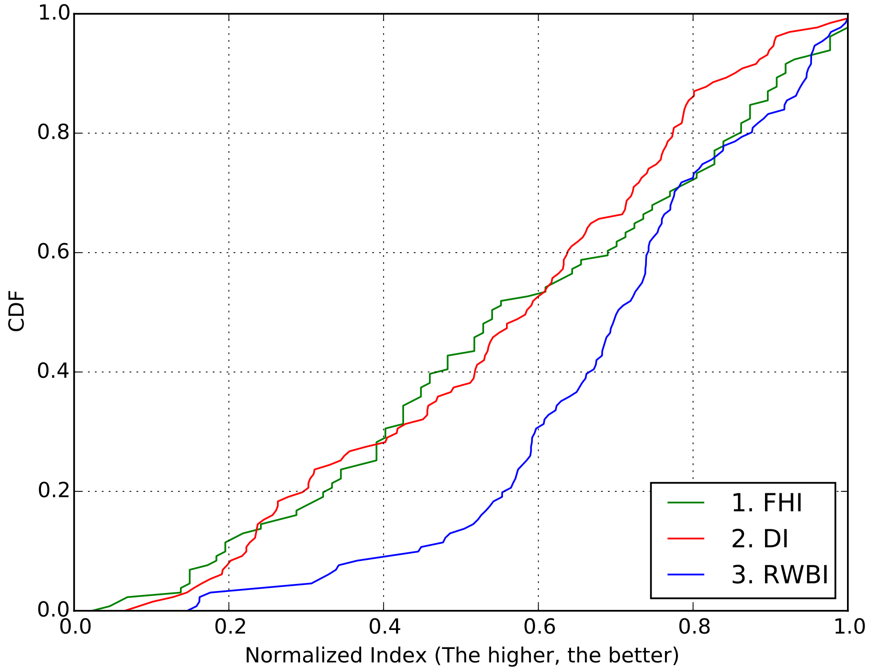


Figure 2: The CDF of the Indexes - FHI, DI and RWBI

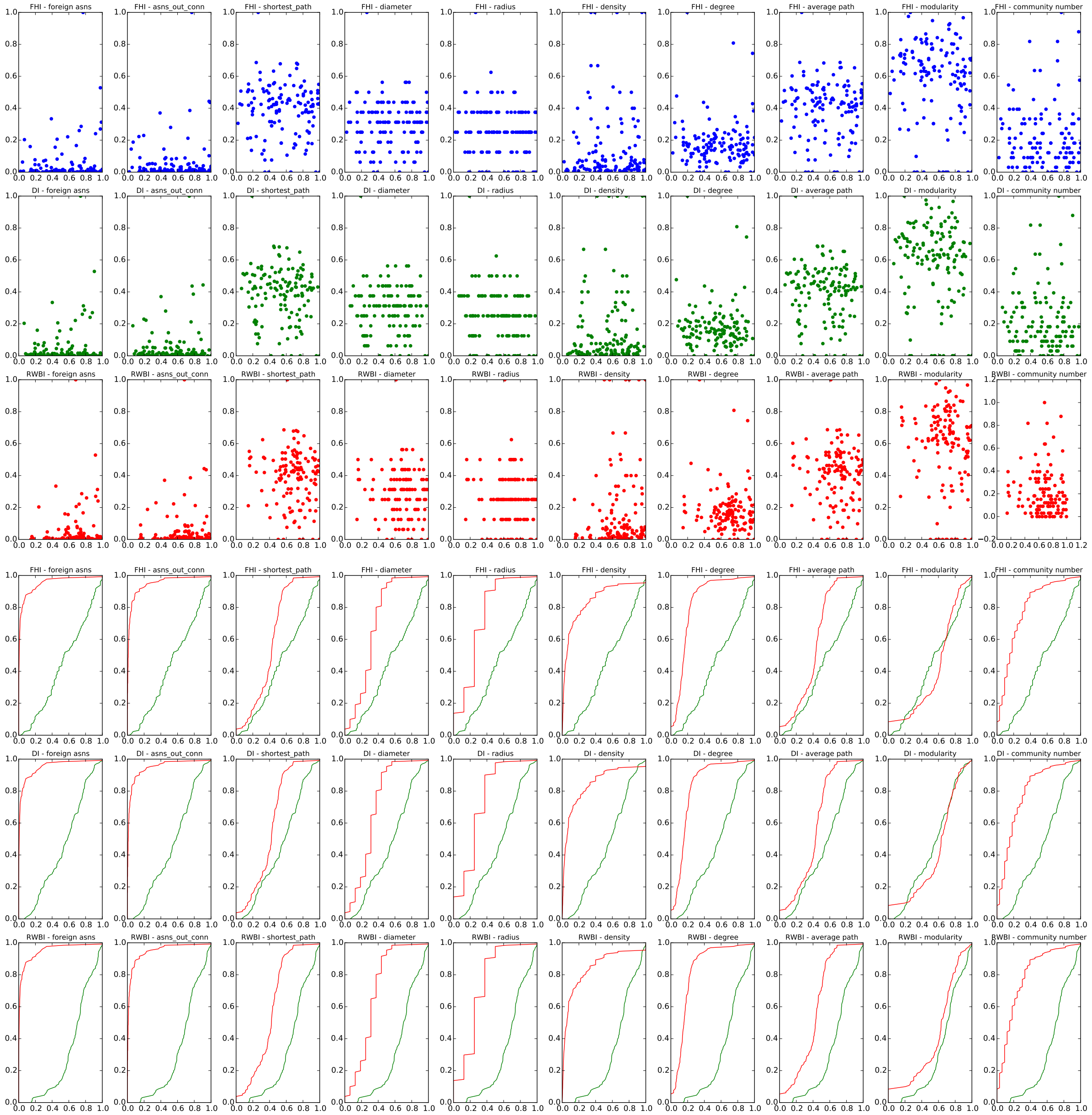


Figure 3: The scattering and CDF plot between the index and the metric

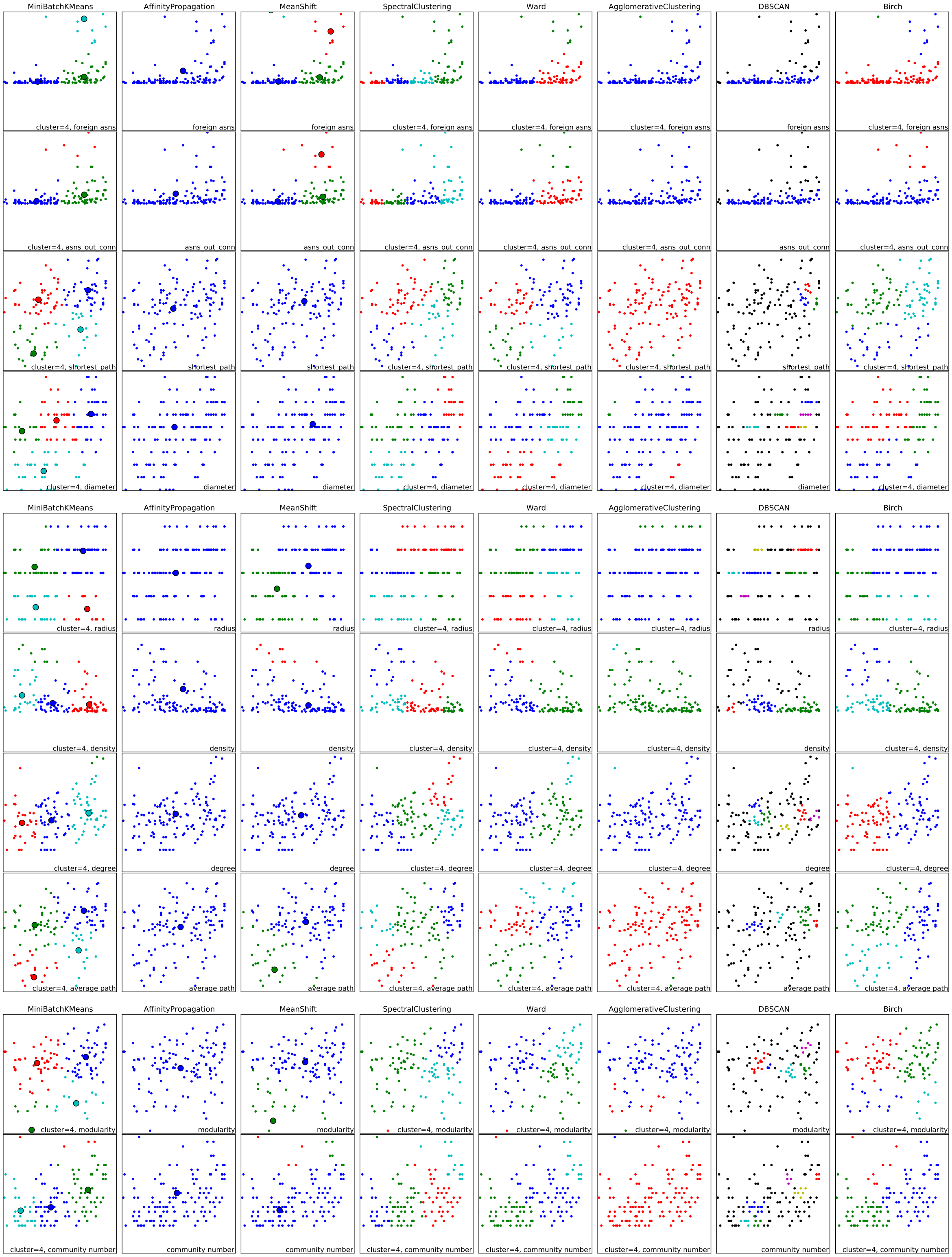


Figure 4: Clustering example with four clusters