# 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 seperate 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. (http://dandylife.net/test/topologies) 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 Iran that is known to censor Internet traffic.

## 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: Free 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.

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.

Table 2: Number of ASes and the normalized indexes: Free 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 |

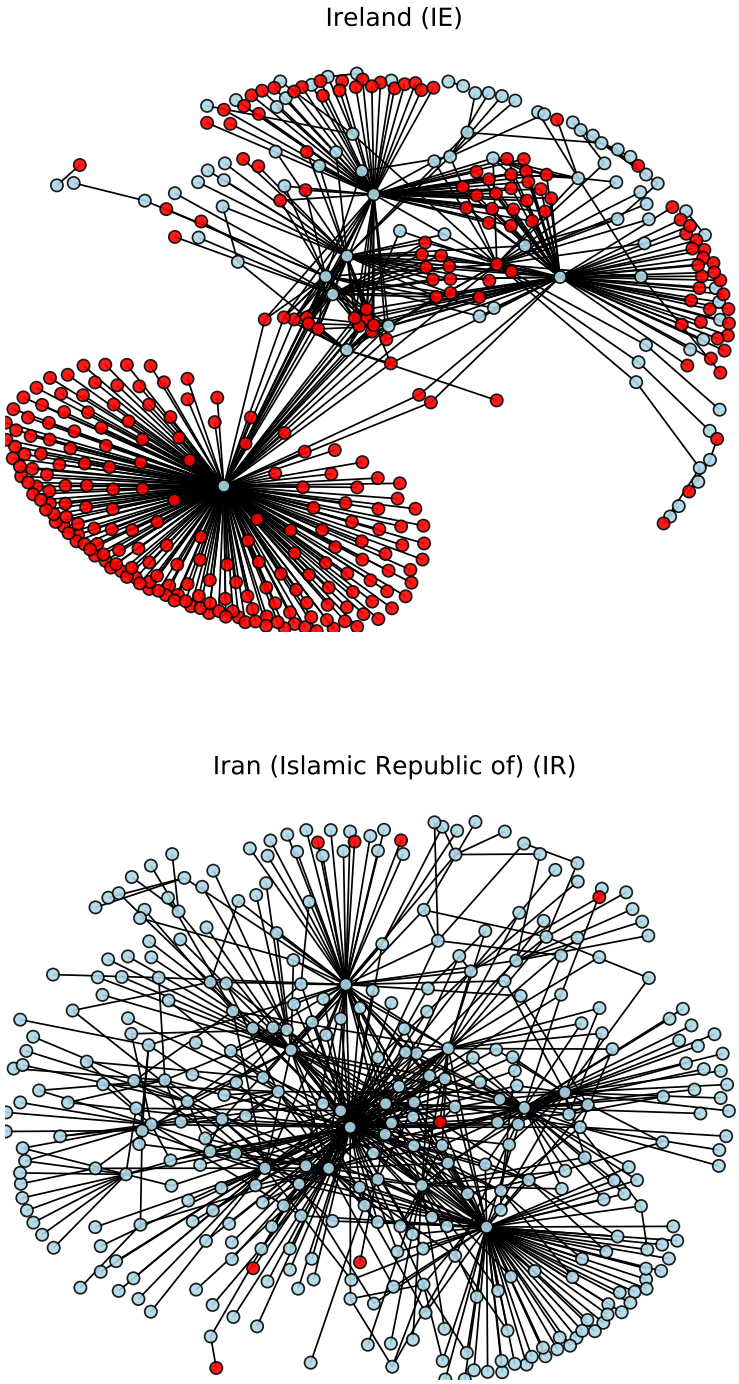
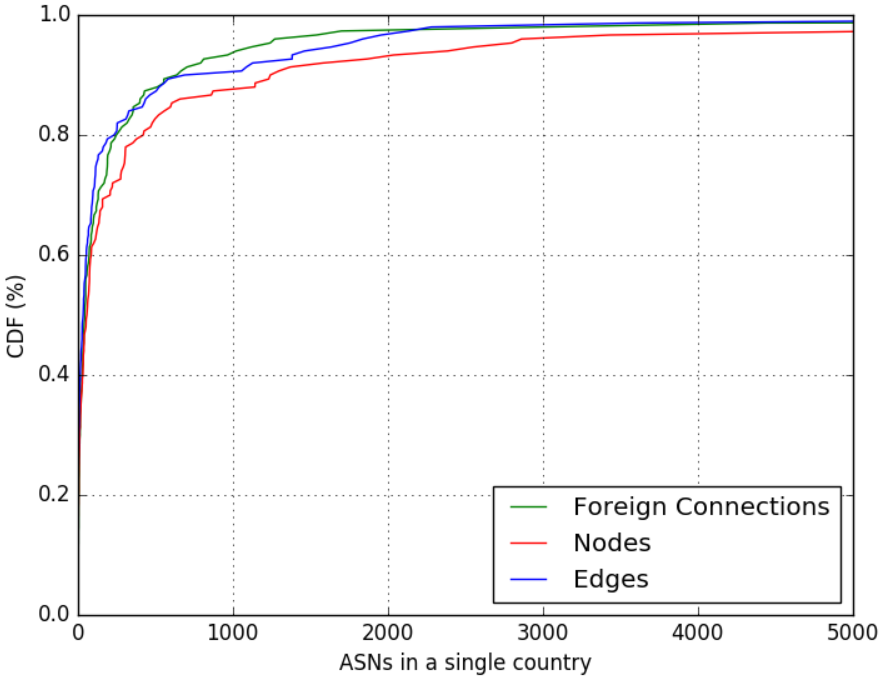



Figure 1: The topology of Internet connectivity in Iran shows that only a few domestic ASes are connected to foreign ASes. This allows the country to control the incoming and outgoing traffic flow easily. In contrast, the connectivity in Ireland looks different, it is not known to have censorship operation.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



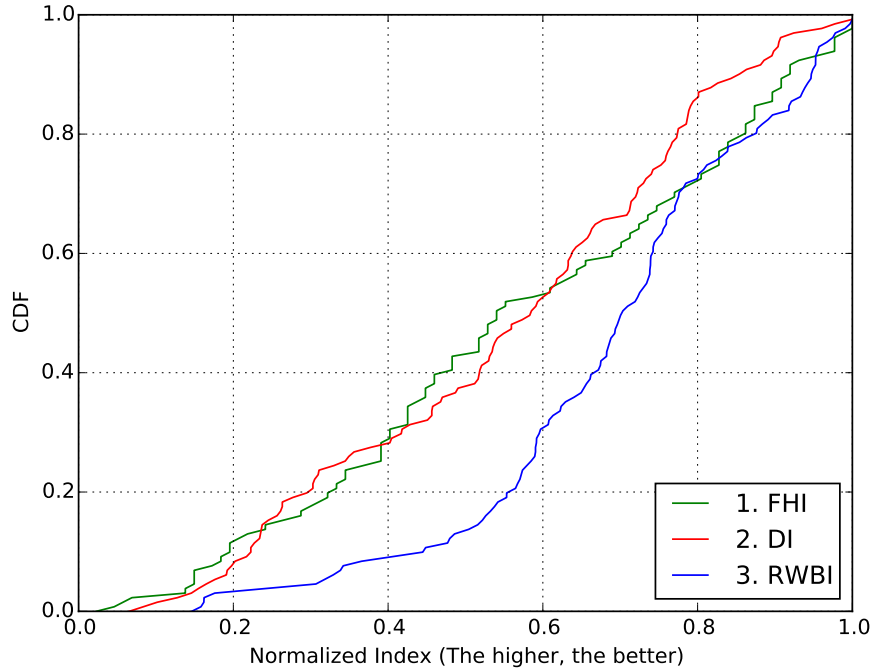




Figure 2: The CDF of the Indexes - FHI, DI and RWBI

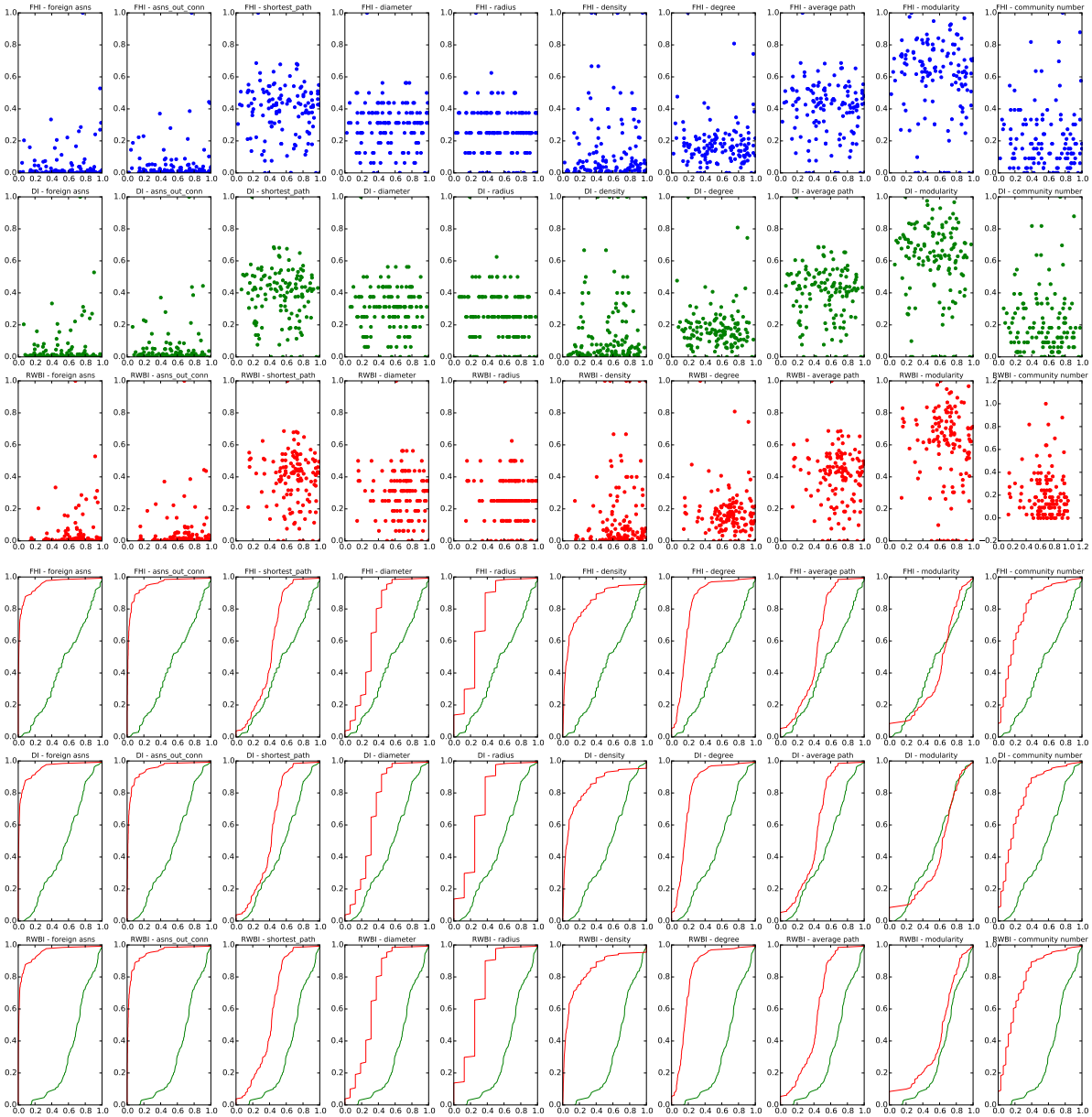



Figure 3: The scattering and CDF plot between the index and the metric

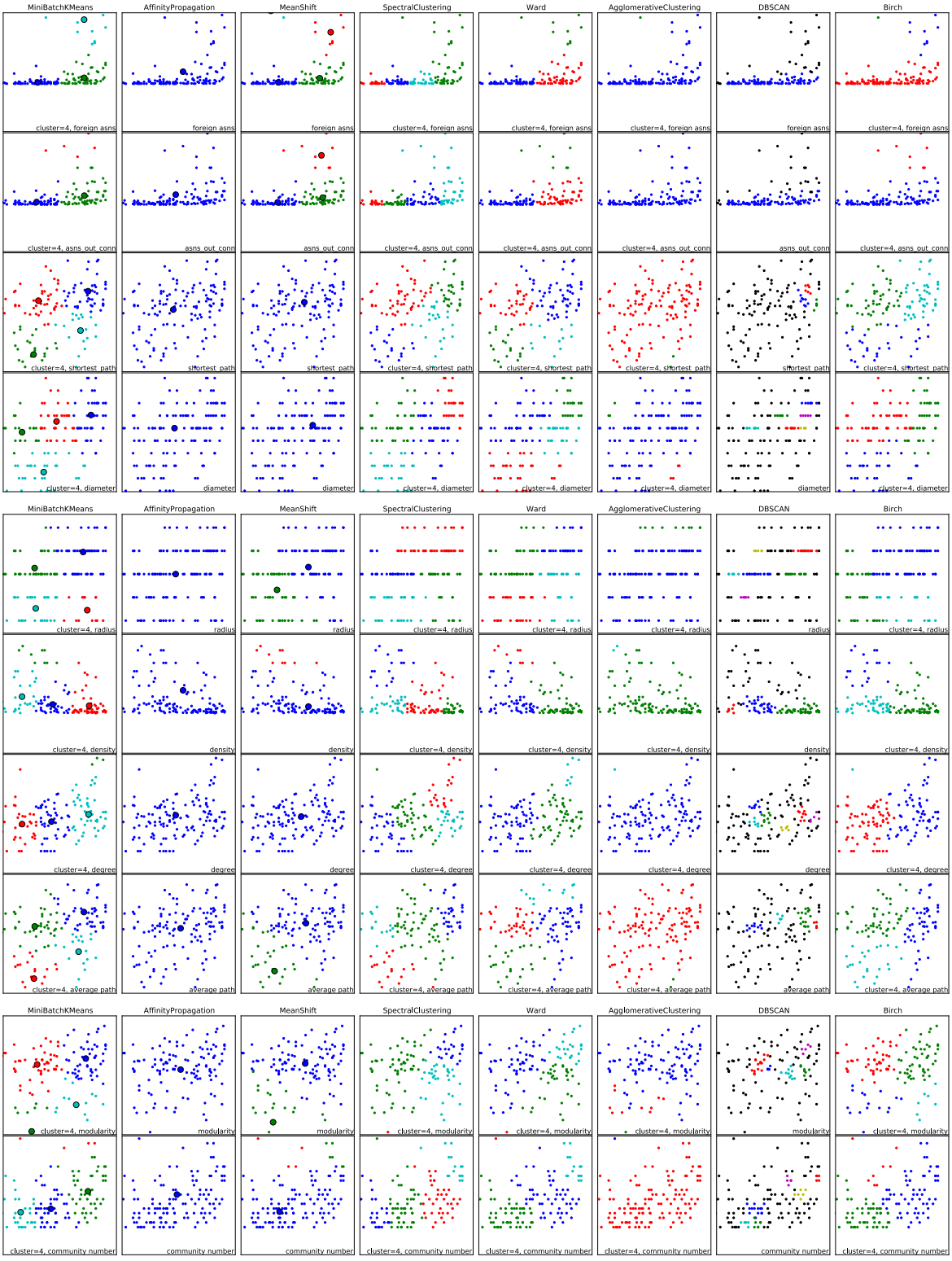



Figure 4: Clustering example with four clusters