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Comparative Trajectories in the Royal Society Network

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KEYWORDS *History of science, information design, information visualization, network visualization, Royal Society.*

DATE *Spring–Summer 2013*

URL http://dataminding.org/Network8/index.html#

ABSTRACT Our notion of science brings together elements of theory, experimentation, application, as well as a narrative of history, relevancy, and progress. While it strives to be objective, it can't help but to be biographical as well, because all these ostensibly external elements are contained within the life of the scientist. This project casts the biographical unit of the scientist as a fundamental unit of scientific history through visualizing the Royal Society as a network.

Established in 1660, The Royal Society of London for Improving Natural Knowledge is the oldest scientific academy in continuous existence. At its founding the society was structured around the seven chairs of astronomy, divinity, geometry, law, music, physics, and rhetoric. Today, the organizational structure of the society includes mathematics/computer science, astronomy/physics, chemistry, engineering, earth sciences, biology, developmental biology, anatomy, and health/human sciences. These collections of disciplines define scientific pursuit quite differently, yet they are directly connected by the society's long history through the election of its 7,000 fellows. This is because existing members, forming direct links between each recommender and inductee, elect each member into the society.

The visualization models provided center on this internal election system. They depict how the Royal Society's use of scientists' recommendations are a fundamental unit of force for a node-and-link model, and can be seen as an historical as well as a professional network. The historical trends can be seen through the rise and fall of individual disciplines, as well as modifications to disciplinary boundaries within the scientific network.

INTRODUCTION

Established in 1660, The Royal Society of London for Improving Natural Knowledge is the oldest scientific academy in continuous existence. Its history, and the many significant contributions that its members have made, provide it with a central place in the scientific community.[1] The Royal Society claims many prominent scientists as its members, scientists who have also been recognized by international scientific awards. Since the Nobel Prize's establishment in 1901, Royal Society members have accounted for roughly a third of its 863 winners. The significance of the Royal Society's membership records as a prominent historical dataset lies in its ability to convey narratives of historical trends such as the rise and decline of academic disciplines in the sciences. Because of the significance and longevity of the society, narratives of the development of disciplines in larger

1660	2013

Astronomy
Divinity
Geometry
Law
Music
Physics
Rhetoric
	Mathematics, Computer Science
	    Pure and applied
	Astronomy and Physics
	    including theoretical physics ans applied physics
	Chemistry
	    applied chemistry, theoretial chemistry
	Engineering
	    technology, instrumentation, materials, science, experimental fluid dynamics
	Earth Sciences
	    and physical environmental sciences
	Biology
	    Biochemistry, structural, biology and molecular cell biology
	Developmental biology
	    genetics (excluding population genetics), immunology and microbiology
	    (except medical microbiology)
	Anatomy, physiology and neurosciences
	Organismal, evolutionary and ecological science
	    including soils and agriculture
	Health and human sciences

FIGURE 1: *Two different organizations of the Royal Society can be found at its founding to today.* Source: *The Record of the Royal Society of London for the Promotion of Natural Knowledge, 1940; royalsociety.org, 2013.*

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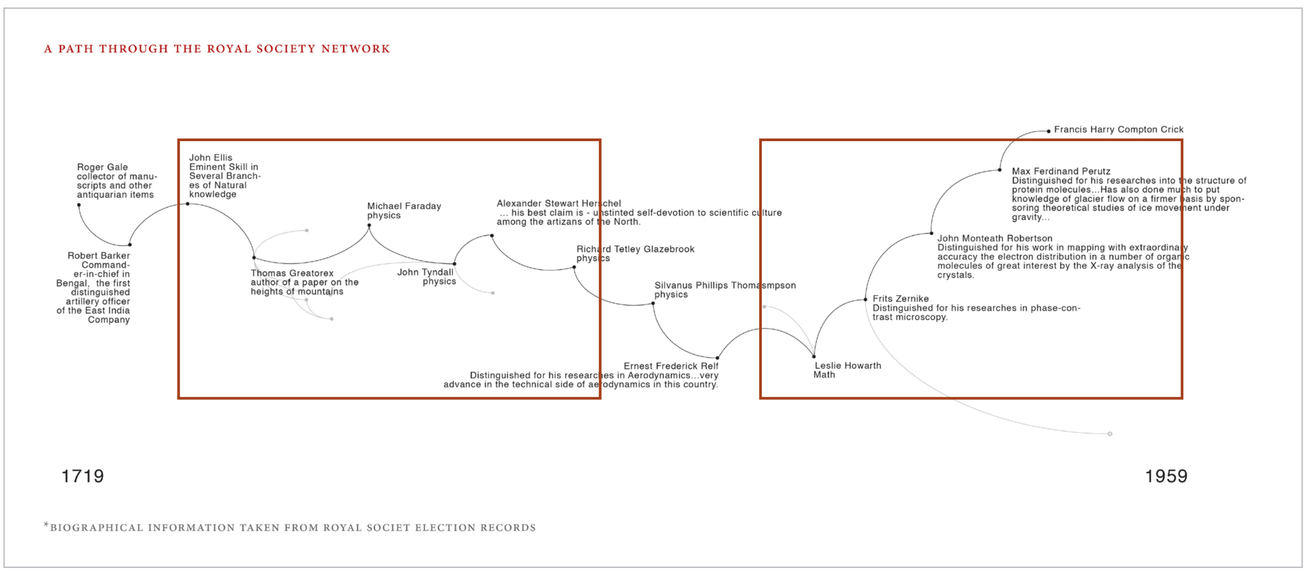
scientific communities can perhaps also be captured through the lens of the Royal Society's membership.

The most striking image of the network is a comparison between the disciplinary structure of the society at itsfounding and its structure today (FIGURE 1, previous page). The two very different organizations reveal not only how the Royal Society has evaluated scientific merit at these two moments in history, but also implies the disciplinary compositions of scientific communities at large. The current society has eleven sections, or committees, of specialization from mathematics to health and human sciences (right column). However, in 1660 at the society's foundation, the disciplinary distinctions within the society were very different. The earliest organization is documented at the time of the society's founding in 1660 (left column).

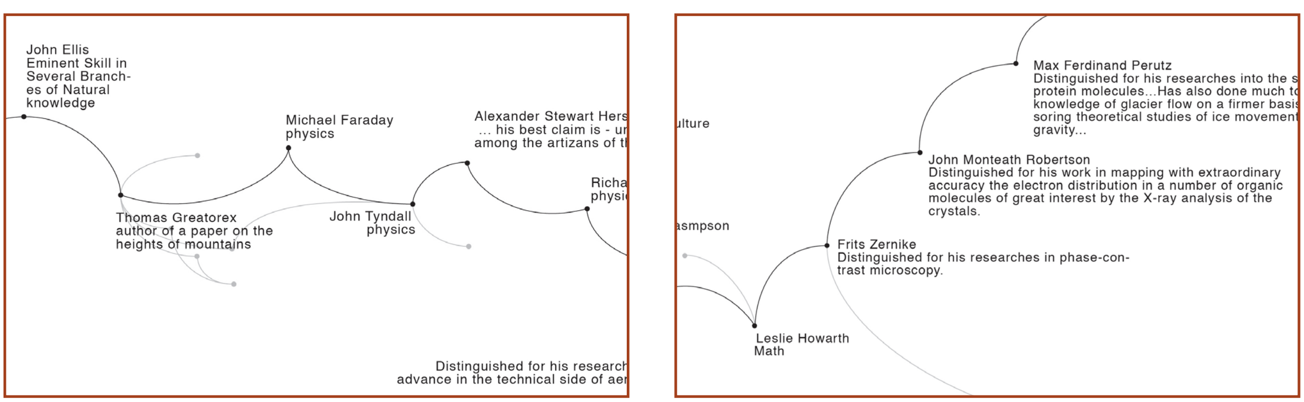
DISCIPLINARY ORGANIZATIONS OF THE ROYAL SOCIETY IN 1660 AND IN 2013

Tracing the changes between these two organizational structures provides us with insight into the disciplinary origins of particular modern day scientific specializations, and also documents the demise of particular pursuits within the scientific community. This tracing is made possible by the election system of the Royal Society. The elections of new members are possible only through the recommendation and endorsement of existing fellows. This internal system effectively links the present members of the society with its founders, and thus their modern day professions with historical ones (FIGURE 2). In this way, the scientists' recommendations of others for membership are historically traceable links that, in aggregate, also reflect the emergences

FIGURE 2: *By tracing a single path through time across the network, we can see the diversity of professions that can originate at different points in history from a single source.*



(DETAILS)



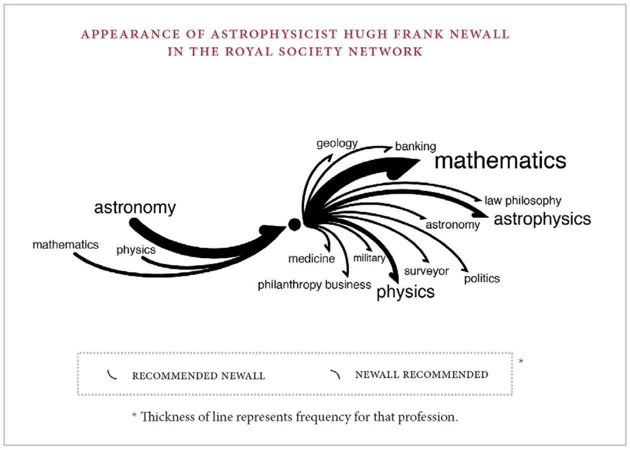


FIGURE 3:
Hugh Frank Newall's immediate network within the Royal Society demonstrates the emergence of particular fields and subfields. His nomination is among the first introduction of Astrophysicists into the society. He is recommended by existing fellows working in astronomy, mathematics, and physics.

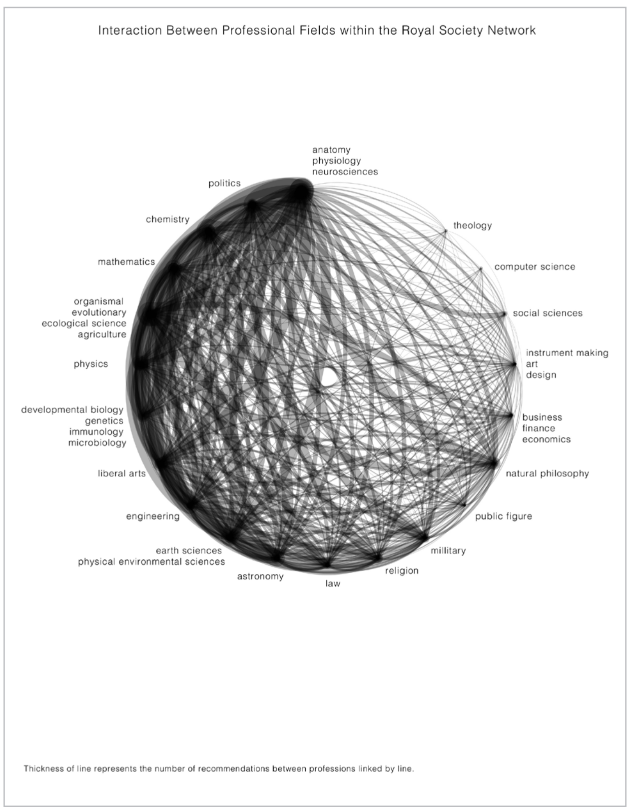


FIGURE 4:
This graph shows both the distribution of fellows within and the interactions between fields of the Royal Society.

of scientific fields and subfields over time (FIGURE 3 and FIGURE 4). This aggregation necessarily includes relationships of both personal and professional nature. The resulting visualization includes a biographical perspective on scientific communities, and how science is practiced in history. It is productive to treat disciplinary boundaries found within the network not only as lines of division, but also cast separations and divergences of disciplines as points of interest. The evolutionary relationship within—and the biographical nature of—scientific communities are the two central themes of the story told by the Comparative Trajectory visualizations (FIGURE 5, next page).

The dataset used for this visualization project is derived from the election document for fellows entering the society, and originates from the Royal Society's archives. They have been made public by the society and are kept in a searchable chronological digital archive.[2] Each record represents the election of a fellow into the society, and is comprised of three parts: basic biographical information of the candidate for fellowship such as full name and date of birth, the reasons for which the candidate is nominated, and the signatures of the existing fellows in support of the election. The collection of nomination records includes approximately seven thousand entries (nominated fellows) and covers the years between 1731 and 1962.

The Comparative Trajectories experiment I present here uses the scientist fellow as the basic unit for visualization in the form of a node, and their recommendation of and by other fellows as a directional link. As a result, the society's evolving structure is visualized by its internal recommendation and election system as a network graph. By representing the scientists' recommendations of each other as a fundamental unit of force, a snapshot of the state of different disciplines within the sciences is made to interact in the context of a network. The resulting graph is intended to aid our understanding of the evolution within and between different disciplines of science historically while also utilizing the biographical nature of both professional and personal relationships.

Nodes carry the information of fellows such as their occupation, reason for election (contributions cited in the record of election), texts they are mentioned in, prizes, and dates of birth, death, and election. The node qualities are expandable with additional data and displayed according to the filters used in particular interactive views. In addition, nodes also carry information of measurement within the network such as their degree, centrality, and membership of subgroups.

Links between two nodes carry the recommendation relationship between two scientists. Links are additionally encoded with the order in which the recommendation signature appears in the record. The relationships between recommenders and nominated fellows are the primary structure of the network.

When the records are put together, they form the base graph using approximately seven thousand nodes and fifty-five thousand links. The question of how to connect two different types of organizations through a recommendation system is best answered by network graphs. Gephi is the most robust tool for this data because of its ability to accommodate for the size of the data, and the numerous network measurements that are built into the software.[3] The graph is constructed in Gephi using the force atlas layout. The graph is chronological from left to right. This layout algorithm uses attraction and repulsion as proportional to the distance between nodes. In this network graph, as time progresses, the graph gets both bigger and more dispersed.

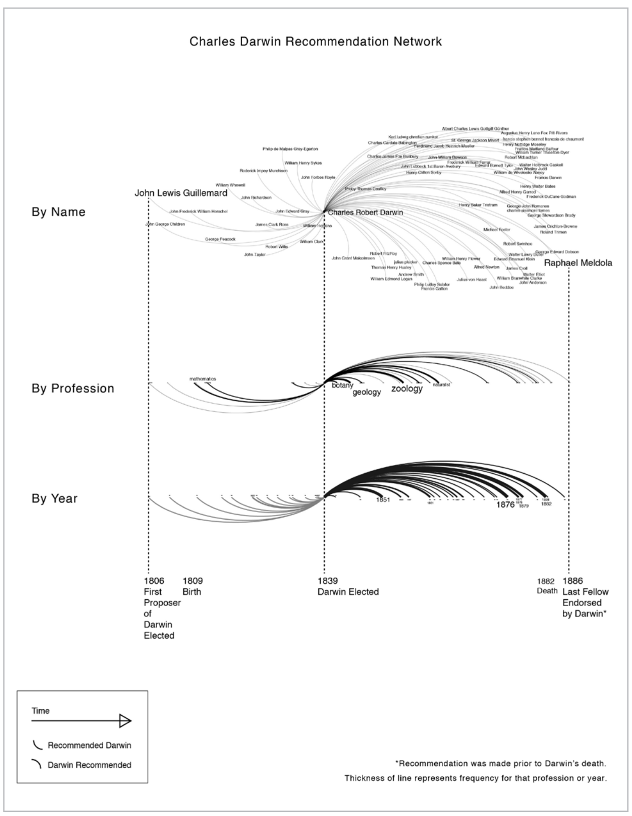


FIGURE 5:
The biographical power of the network graph can be seen in detail through the example of Charles Darwin's connections. By viewing by name, profession, and year, we can get a sense of the communities of expertise that Darwin surrounded himself in, as well as how active he is as a scientific advocate at different periods of his life.

Using the same distribution, when only nodes are visible, we can see that the nodes are close together earlier in the graph (FIGURE 6). The higher density of recommendations accounts for this in the earlier stage of the society.

The higher level of interconnectedness in the earlier parts of the society is more visible in this weighted node view where the node sizes are determined by their degrees (FIGURE 7). The more links or recommendations a fellow gives or receives, the larger the node they are represented by. Larger nodes mostly occur in the chronologically earlier parts of the graph.

The links are curved based on the original distribution in order to make the shape and inner components of the network more clearly visible without distorting the original shape of the network. (FIGURE 8)

FIGURE 6-8 illustrate a pattern emerging from the network's chronology. As seen in the combination of weighted nodes and overall shape of the links making up the network, in FIGURE 9, the number of connections is higher in the earlier part of the network, while the lack of connections contributes to the dispersion of the shape to the later part. This phenomenon can be explained as the lesser occurrence of inter-recommendations in the later part of the network.

Based on these visualizations, we can now ask if discipline is a contributing factor by looking at the disciplinary trajectories that travel across the length of the network. This is done by color-coding increasingly smaller subsets of disciplines in order to define different types of trends. The length of individual colors visible horizontally across the network illustrates the longevity of particular disciplines. This series of graphs starts with the larger distinction between liberal arts and sciences (FIGURE 10), and then develops a more refined separation of color for subgroups within these two larger groups. For liberal arts, two disciplines—law and politics (FIGURE 11)—are highlighted because they are found in the original charter of the Royal Society and accounted for a significant segment of early members' professions. For further distinctions within the sciences, basic color-coding according to the modern organizational structure of the Royal Society is used.

Using the disciplinary information in the dataset, the data are put into two categories of liberal arts and sciences (FIGURE 10). The black areas indicate cases where a profession or discipline could not be determined.

FIGURE 6: *Base Graph Nodes Only*

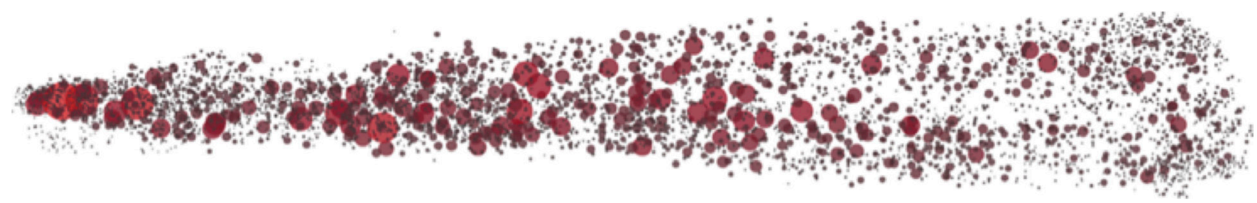


FIGURE 7: *Base Graph Weighted and Color-coded Nodes Only*

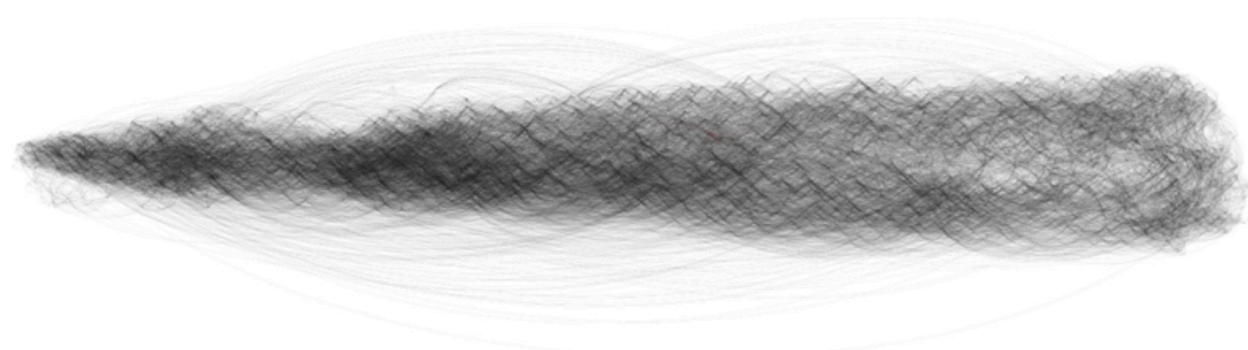


FIGURE 8: *Base Graph Links Only*

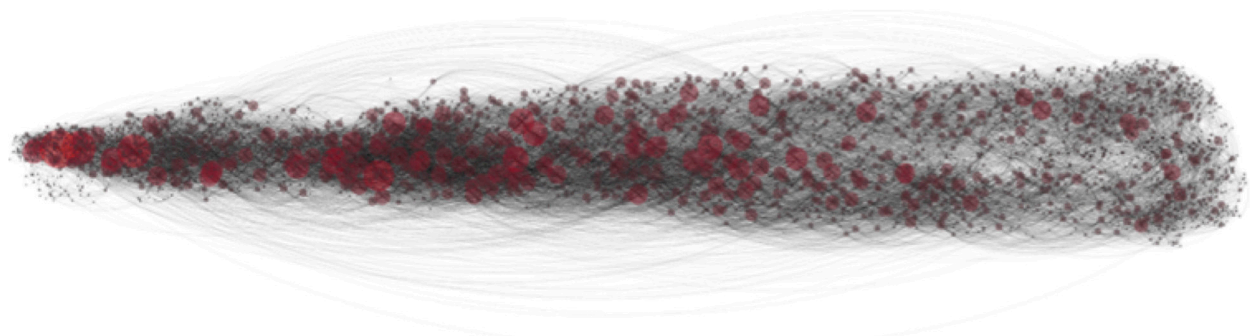


FIGURE 9: *Base Graph with Color-coded and Weighted Nodes*

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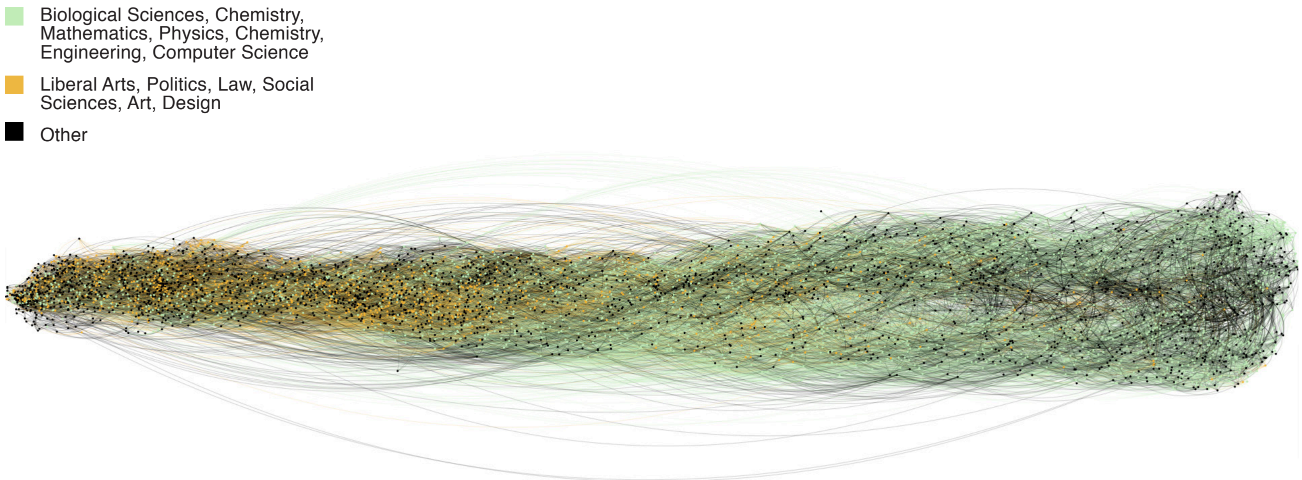

FIGURE 10: *Liberal Arts and Sciences Overview*

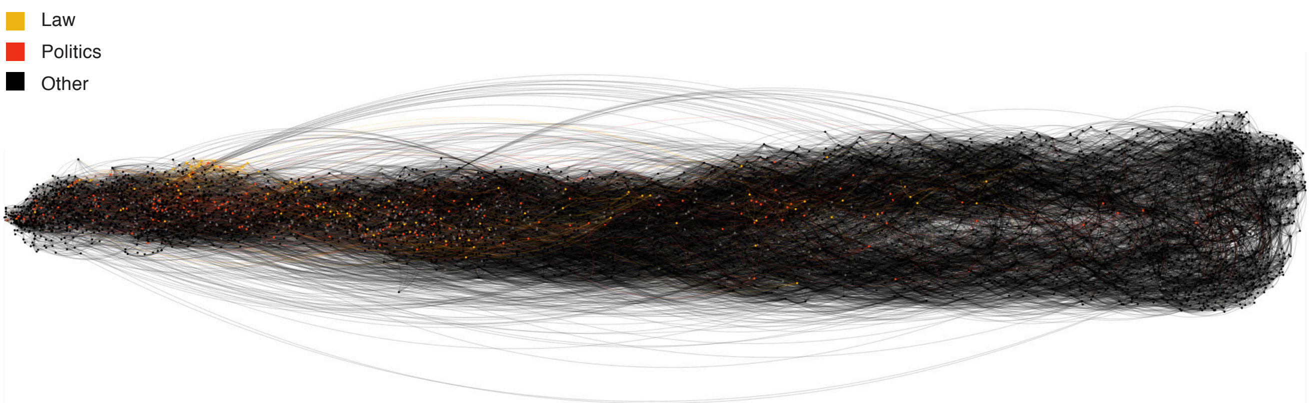

FIGURE 11: *Law and Politics Professions Color-coded*

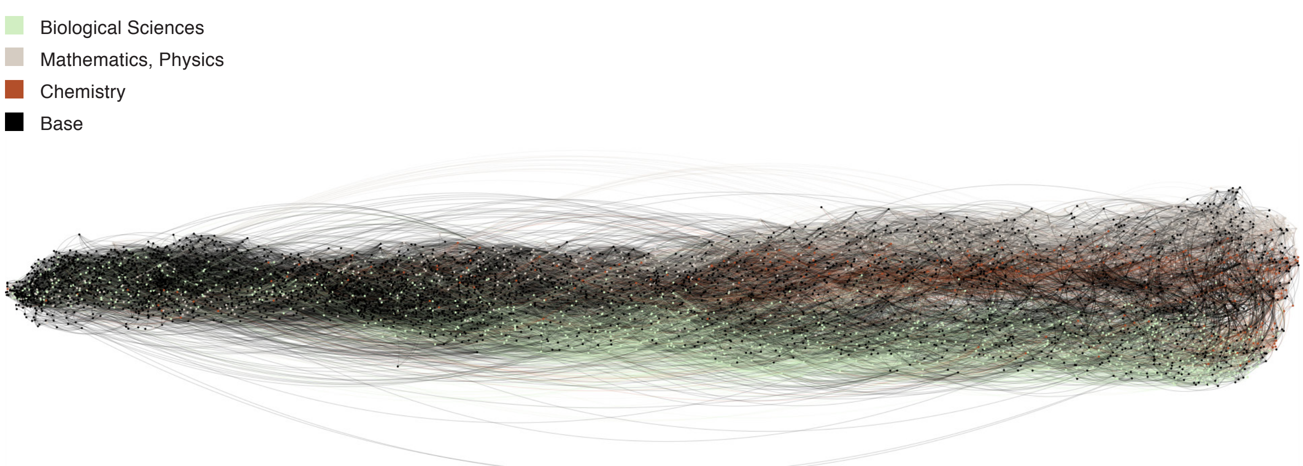

FIGURE 12: *Distinctions within the Sciences*

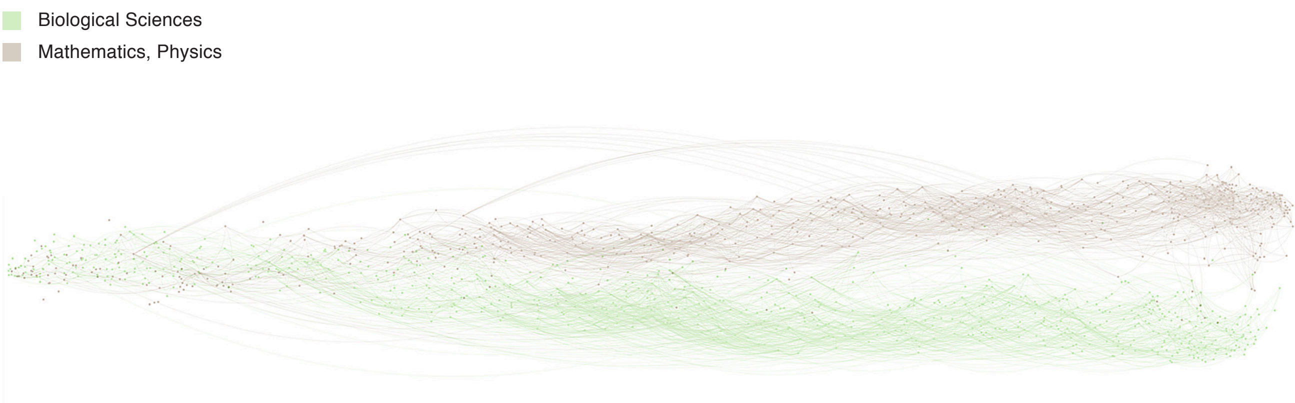

FIGURE 13: *Mathematics and Biological Sciences (Base map removed)*

As the graph shows, the majority of the fellows belong to the sciences. This should not be surprising considering the aims of the Royal Society. However, we can also see that there is an overwhelming amount of humanities scholars in yellow in the earlier section of the graph. This graph illustrates two points. First, the main component of makeup in the society's membership changes from liberal arts to sciences as time goes on. Second, the dispersion in the shape of the network is covered in green and therefore occurs within the sciences.

The Disciplines Within Sciences graph (FIGURE 12) is the more detailed color-coding of the green section in the previous image. The color-coding of disciplinary trajectories is very linear and lays horizontally across the network. This shows the separation between the disciplines. We can see that colors run linear and parallel to each other without many intersections. This describes disciplinary trajectories that are fairly separate from each other. This separation accounts for the shape of the network, as fewer interconnections will allow the force directed graph to spread out. This also illustrates the phenomenon of specialization and stronger disciplinary boundaries in the network of scientists.

The extremes of the previous graph are presented in the Math and Biology Graph (FIGURE 13). This image shows that the fellows in mathematics are the least likely to recommend those who are in the biological sciences.

In the non-science portion of the network, law and politics were particularly salient examples of disciplines in decline within this community (FIGURE 11). Although politicians still remain in the network today, very few fellows can be found whose primary profession is law. This presents a drastic shift from the original organization of the society, the original definition of "natural knowledge" included both law and politics as a crucial part of the society.

The visualizations above can be seen in greater detail in its interactive form on http://dataminding.org/Network8/index.html#

Technologies: Data acquisition: Python and Java
Visualization: Gephi and Javascript

BIOGRAPHY

Jia Zhang is a graduate student in the Media Arts and Sciences Program at MIT. She completed her undergraduate studies at RISD and received her MFA from the Design and Technology Department at Parsons in 2009. She currently works with the Social Computing group concentrating on visualizations of Cities.

NOTES

1 Information about the society are primarily from http://royalsociety.org/ the society's official website.

2 http://royalsociety.org/DServe/dserve.exe?dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=FastTree.tcl&dsqDb=Catalog&dsqItem=EC%2F1774&dsqField=RefNo#HERE

3 Gephi, an open source network visualization software can be found at: https://gephi.org/