sciendo

Article | DOI: 10.21307/connections-2019.031

CONNECTIONS

Issue 1 | Vol. 44 | 2024

Intelligencers, Cliques, and Stars in the Spread of 17th -Century Cartesianism

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Abstract

This paper examines the dissemination of Cartesianism in the 17th century by studying the networks of authors in the field of natural philosophy. Key figures who spread knowledge and innovated the field are identified and contextualized. Furthermore, the network analysis shows how different ways of thinking coexisted within the social networks of early modern natural philosophers. To achieve this methodologically, originally bipartite networks were projected into author-to-author networks that were divided into time slices. Measurements of centrality and assortativity were used to determine prominence and diversity, which were complemented and refined with close reading. The findings reveal not only cliques of geographically connected authors, but also an overall highly connected field. Additionally, assortativity indicates a moderate tendency toward homophily in the authors' connections to others within the same philosophical tradition. The study furthermore identifies that central authors were predominantly eclectic or Cartesian, suggesting that Cartesianism was driven by such individuals in structurally well-connected positions.

Keywords

Historical social networks, Early modern science, Complex networks, Digital humanities, Projected networks, Multiplex evolving networks

Introduction

René Descartes (1596–1650) is regarded as one of the leading figures, if not *the* founder, of early modern Western philosophy (Gaukroger, 1995; Russell, 1947). The relevance of the context in which his work was disseminated cannot be overstated, and it is reasonable to attribute his success to both his exceptional talent and the network in which he operated. Descartes may be seen as a rather strategic philosopher; he left France for the more liberal Dutch environment, actively spreading his ideas among leading universities while staying in close contact with important *literati* such as Marin Mersenne (1588–1648) in Paris. In time, he became one of the most discussed philosophers of the early modern period, and his position as a socially connected thinker has been partially studied either via case studies (e.g., Nadler et al., 2019; Schmaltz, 2016; Verbeek, 1992) or more recently by focusing on his correspondence (e.g., Rossini, 2022).

Descartes is a protagonist of the conventional narrative about early modern natural philosophy, which starts with a description of a field steeped in scholastic (or Aristotelian) traditions; this is then surpassed by a Cartesian approach around the mid-16th century, which in turn is overthrown by the Newtonian scientific doctrine. According to this narrative, the result was an entirely transformed field by the beginning of the 18th century, one in which experimental methods were the norm. This is the standard account of the Scientific Revolution; that is, through a radical break with what was previously considered "normal science," the field was completely altered by a new set of scientific principles (Hall, 1966; Koyré, 1957; Kuhn, 1962). In recent decades, this narrative has been challenged by a reappraisal of the importance of scholastic philosophy and an emphasis on the hybridization of different views (Garber, 2016; Gaukroger, 2006, 2010, 2016; Schmaltz, 2016). The idea of one tradition radically superseding another is now seen to be an oversimplification, and such scholarship encourages us to recognize the heterogeneity of early modern natural philosophy.

Despite their undeniable value, current studies usually focus on Descartes as the main driver of change in philosophical and scientific thought. Moreover, existing scholarship tends to work within narrow national or language boundaries in the appraisal of epistemic change in the history of science. Such premises overlook the larger social environment in which Descartes moved and lack an integrated view on the *wider* network in which he operated, which included a diverse cohort of thinkers. As a result, much remains to be clarified about the more integrated intellectual social environment in which Descartes moved and in which novel ideas were fostered and developed. My general aim and contribution to this debate are to provide an all-encompassing perspective on the dissemination and subsequent embedding of Cartesian philosophy into the wider field of natural philosophy. The starting point is not Descartes himself, but the field in its entirety, to allow authors who have previously not received any attention in scholarship to be considered in relation to this pivotal figure. Importantly, it will also enable the consideration of all these thinkers as significant figures within a larger, connected system.

While we can now move on from the idea of radical breaks in philosophical tradition, the narrative about the three "main traditions" should not be done away with too hastily, as it offers a construct from which we can move forward. In a previous study, for example, our data corroborated the hypothesis that these three "traditions" remain relevant in categorizing the different approaches developed during the period (Sangiacomo et al 2022a). The questions to be answered now are how the alternative hybrid view can be explored further and what methods are appropriate to do this. If used carefully, I suggest that a network approach can provide a suitable and effective methodology.

Historians are no strangers to using network terminology. We are often reconstructing social networks by referring to an individual's connections and environment and, as such, the "networked positions" of historical actors have often been described, albeit generally from a qualitative perspective. In the past decade, quantitative, data-driven historical network research has seen a rise in popularity (see, for instance, the edited volumes of Brughmans et al., 2016; Kerschbaumer et al., 2020; Raymond & Moxham, 2016), with specific attention being given to early modern networks, such as in Van den Heuvel (2015), and most notably correspondence networks (in the projects of *ePistolarium* (2009–2013), *Mapping the Republic of Letters* (2012–2017), *Reassembling the Republic of Letters* (2014–2019), and *SKILLNET* (2017–2022)). Since historical network analysis is a relatively novel discipline, many aspects of it remain unexplored. Various current studies investigate the networks surrounding particular individuals (ego-networks), and these projects take well-known, canonical figures, such as Descartes, as their starting point. This might not only have to do with a specific interest in them; there is simply more and more reliable data available on them. This does mean that entire-network studies—that is, studies in which all or nearly all of the individuals of an entire community are included—are scarce, and those that do exist often suffer from fragmentary or unreliable data.[1] Bipartite networks, however, offer rich methodological opportunities to address this problem.

Bipartite networks are networks with two types of nodes, allowing the researcher to use a shared attribute as an indicator of an underlying social connection, such as affiliation (Borgatti & Halgin, 2014). This indirect approach is highly useful, especially when faced with limitations in gathering data, such as is often the case with historical subjects. Additionally, human social interactions are often not limited to one specific environment or means of interaction. Multiplex or multilayer networks, that is, several networks of the same group of individuals with different connections in each layer can alleviate this problem by offering multiple layers of connectivity. One can think of a network with a layer for work connections and a layer for friendship connections, which will reveal different kinds of patterns individually, but together can deepen our insight into an actor's connectivity. Studying the

1 The article by Ryan and Tolonen (this issue) that deals with publishers in the Scottish Enlightenment is a rare example, as they point out: traditional scholarship teaches us a lot about a few individual publishers, but systematic studies of publishing diversity are virtually nonexistent.

spread of Cartesianism can therefore benefit from a multiplex, bipartite approach. For historical research, network studies that include multiple layers remain underrepresented (De Valeriola et al., 2022; Valleriani et al., 2019) and examples of historical bipartite networks and their projections are even rarer (Riva, 2019; Vozár, 2018). Networks that capture temporal changes are especially underdeveloped in the historical context, though examples can be found (Petz et al., 2020; Vugt, 2017).

In this study, I will explore the intersection of bipartite, multiplex, and diachronic networks to comprehensively investigate the spread of Cartesianism in 17th-century natural philosophy. Specifically, I will address two research questions. Firstly, what can be said about the social profile and network embedding of the authors who were prominent in the field, and were they instrumental in spreading or popularizing Cartesian approaches? Secondly, within these networks, do "the old" (scholastics) and "the new" (particularly Cartesians, and to some extent eclectics) coexist in diverse environments, or do most authors belong to subcommunities where a single tradition prevails? For both these questions, I am interested in the development of the field over time to see whether, at several time-intervals, a change in the status of certain authors and the diversity of the environment can be observed. My analysis will help to determine whether and to what extent novel approaches were integrated and adopted among a broad range of intellectuals in the 17th century.

Through a selection of network-based approaches, I will investigate these questions by focusing specifically on two matters: (1) node prominence and (2) network diversity. With regard to the former, the networks are used to analyze the authors' situation in relation to others in the network and to investigate who held potentially important or influential positions. The idea is to look for individuals who, by their positions in the network, could have had access to relevant information or been able to fulfill pivotal roles in distributing new ideas. Likewise, when such central authors were "old school," that is, "scholastic," they could potentially have been powerful agents for the preservation of the traditional ways. Regarding the second matter, network diversity will be examined by looking at the occurrence and spread of different types of authors across networks to see if any homophilous tendencies emerge. Network homophily refers to the idea that people often associate with others who have similar properties. Such patterns have been studied within many types of social networks (e.g., racial and gender segregation (Shrum et al., 1988), music taste (Baym & Ledbetter, 2009), or political networks (Esteve Del Valle, 2022)). In this article, the "type" of an author is determined by an allegiance to one particular traditional approach, using categories of philosophical traditions (which will be explained in more detail below). Diversity, therefore, is understood here as a social environment in which authors typically did not belong to one specific scholarly tradition.[2]

My findings show that in all regards, Descartes' networked position was already very fortunate by the time he published his famous *Discours de la méthode* (1637). Additionally, there were a handful of authors who, while not necessarily canonical, held influential positions and had access to information that was crucial for the development of the field. These "intelligent influencers" were often part of fully connected cliques in scholarly environments, such as prominent universities and schools that served as hubs of knowledge resources, while at the same time they served as bridges between such cliques. Still, not all social environments are alike and in the least connected layer (that of co-publisher), we find Robert Boyle (1627–1696) in a remarkable position, at the center of an otherwise unconnected star-network. Regardless, the networks show that from the beginning to the end of the 17th century, the field of Western European natural philosophy was highly connected. While traditions mostly existed alongside each other, it is evident that from a network perspective, the fortunate positions were occupied by those who spread novel ideas.

This study covers the geographical range of the Netherlands (or Dutch Republic at the time), France, and Britain.[3] That is not to say that what happened beyond these borders (e.g., in what we now consider Germany or Italy) was insignificant. Still, it is well known that the Dutch Republic was a pivotal environment for the spread of Cartesianism, as was

2 Although I mention diversity, a certain homogeneity is also to be expected since the material used to build the corpus (the sources and details of which are explained in the next section) is meant to reflect the literature of one particular field, namely natural philosophy. Because of the field-boundaries, the authors in the corpus are rather similar in certain respects: upper-class men (and one woman, the British Margareth Cavendish (1623–1673)) with a formal education in natural philosophy. At the same time, given these boundaries, the network approach allows us to distinguish more subtle differences between authors and their social embeddedness and local discontinuities.

3 Geographical borders at the time were not the same as today's, but to a large degree, they do coincide for these three countries. Regardless, the demarcation of borders and the decision of who to include based on their nationality have been based on the selection as it appears in the corpus' source. More about this in section 2.

France, Descartes' original birthplace. Britain, despite the existence of more criticism and opposition, was also deeply influenced by the developments overseas (Gellera, 2016; Pacchi, 1973), and together these three countries formed the most important core of the intellectuals' network in the 17th century.[4]

Data and Method

The data corpus is based on the thorough scholarship contained in the voluminous *Dictionaries* of 17th-century Dutch, British, and French philosophers.[5] In these books, all authors who published works dealing with natural philosophy in a systematic way (e.g., university textbooks) or works devoted to the expansion, intensification, and elaboration of expositions linked with systematic works (e.g., dissertations) were gathered. The *Dictionaries'* bio-bibliographical information was used to list the author affiliations and first editions' publication data. I also made minor additions from online databases, such as *Scholasticon* or *OxfordDnB*, when the *Dictionaries* were insufficient. For the classification of authors by their philosophical allegiance, each author's "tradition" was included. "Tradition" refers loosely to the general system of ideas or theories to which an author adhered, based on their philosophical practice. These traditions are "scholastic," "Cartesian," "Newtonian," "eclectic," or "na" (in cases where no particular allegiance was mentioned). While these categories can be contested for their oversimplification of what, in reality, was more of a fluid negotiation between existing and emerging movements, they remain commonly used as basic divisions in literature and seem to be meaningful in a broad sense. The biographies in the *Dictionaries* were also used to classify the authors, as they often indicate their philosophical allegiances.

The resulting database lists the authors, their publications, and publishers, together with several attributes of these entities. The data was processed to create four author-to-attribute edge lists for the bipartite multiplex network.[6] The same set of authors appear in each layer, but in each, a different relation is represented. Each layer captures a knowledge environment[7] that indirectly connects authors, allowing the construction of *shared knowledge environments* that served as potential paths for the dissemination of information, facilitated the production and distribution of knowledge, and stimulated interaction between authors. The four environments are the author's academic affiliation (Layer 1), their affiliation place (Layer 2), their publishers (Layer 3), and their publication place (Layer 4). The affiliations of Layer 1 form perhaps the most obvious knowledge sphere and are often scholarly, academic environments such as universities, schools, and learned societies. In Layer 3, the link to publishers is made explicit. The printing press has long been recognized as a radical transformer of intellectual life; for instance, it allowed natural philosophers to redirect their mental talents to science instead of manual tasks like copying tables and theories (Eisenstein, 1979) and enabled their role in the curation and dissemination of printed works (Pettegree & Der Weduwen, 2019). With this in mind, publishers and their printing locations are key factors of the field's development. Layers 2 and 4 take a more high-level view of the environments of Layers 1 and 3, by linking to locations (cities) of the affiliations and publishers. Proximity is an important factor in social relations, and the inclusion of cities as a dimension will allow us to discern geographical mobility; it can reveal city-hubs and groups of authors who resided in the same geographical locations for work or publishing purposes. It must be pointed out here that while the amalgamation of all these layers to create a combined view of the authors' connections sounds appealing, this approach does not make much sense with these particular layers. Connections to an affiliation, publisher, or city all hold qualitatively different values and, as such, combining them would conflate relations that actually need to be approached differently. For this reason, the creation of one all-encompassing layer has not been pursued.

While they can serve as a rich source of information, in their bipartite form, these networks are problematic for two reasons. One is that the two-mode nature of the networks (including two different node types, the authors and a particular circle) is difficult to analyze using the most common network analysis tools. This problem can be overcome by creating "projected networks," in which only one node-type remains and analysis can, for the most part, be carried out using regular network analysis measures. The second problem is that the networks as a whole cover an

4 From existing scholarship, we know that after 1700, Cartesianism had certainly not disappeared, but by then Newtonian science had started to emerge. This brought about entirely new dynamics, mostly in the area of the Dutch Republic and Britain (Hutton, 2004; Schmaltz, 2017). The developments of the field toward Newtonianism will be dealt with in a separate study, because they constitute a further transformation of the field of natural philosophy in the 18th century, with different focal points.

5 Bunge et al. (2003), Pyle (2000), Yolton et al. (1999), and Foisneau et al. (2008).

6 Network node and edge date can be found at https://doi.org/10.5281/zenodo.10798160.

7 I refer to them interchangeably as knowledge 'environments', 'circles' or 'spheres'.

entire century, which makes it difficult to make detailed inferences about the data. Thus, to fully grasp the field's development, I have divided the networks into a few specific timeframes, allowing for progressive and chronological assessment of the networks.

Projected Networks

In a network projection, the network data containing the ties between two different node sets is compressed to show the connections within one of the node sets, tying the nodes based on a shared neighbor node. This approach considers the shared spaces as potential environments where social ties could develop, with subsequent opportunities for the exchange of ideas between the nodes. In fact, even though one-mode (nonprojected) networks are most common, many real-world social networks may be modeled quite naturally using bipartite structures, representing members and the groups to which they belong (Latapy et al., 2008). Some scholars even suggest that *all* one-mode social networks can be regarded as projected networks, based on the particular structural features found in empirical network data, such as high clustering and degree assortativity (Vasques Filho & O'Neal, 2020). Either way, my subject deals with historical agents whom we are unable to interview or examine in person, and in such cases of unobservable direct social relations, bipartite projections are useful proxy indicators to infer the connections between these subjects, in the sense that close proximity functions as a strong potential indicator of familiarity with each other's work (Düring, 2016). For the current study, the indirect social connectors are the four environments to which the authors in the corpus can be considered to belong; that is, their professional affiliations and associated cities, their publishers and the cities where they were located.

Since the authors are the constant factor in the multiplex network, and my current analytical interest relates to them, it is their projections that are considered here.[8,9] With a projection, the original bipartite networks containing two node-types are transformed into unipartite networks consisting of only the authors. As a result, any pair of authors sharing a common circle in the original network are connected in the projected network. For example, two authors working at the same university (Layer 1) or publishing with the same publisher (Layer 3) would be directly connected in the network projection.

In the projections, each tie receives a weight value attribute, representing the number of common environments the authors have, such as a university. By using weighted projections, information about the number of different connections that exist between two unique authors is maintained (Vasques Filho & O'Neal, 2018). Nevertheless, with the creation of a projection, some information from the bipartite structure is lost, such as the specific environment shared by a pair of authors and how prominent that particular node was in the network. Applying weighted edges can alleviate some of this information loss, although in principle, some information still becomes inaccessible in the projections. However, for analytical purposes, the original networks can always still be used as a reference, as I show in the following analysis.

Time Slices

The study of temporal dimensions in networks is currently at an underdeveloped stage, and there is no consensus of how such studies should be done (Graham et al., 2022, p. 227).

Time-slicing, or creating chunks of time at particular intervals, is a frequently used approach for analyzing networks over time. There is no "right" way to temporally divide a corpus, and it could even be argued that any chronological split of the corpus is altogether arbitrary. There are no comparable examples of the approach I have taken to slicing the multiplex network here.

Ultimately, the approach adopted depends on the goals of a study, the data that is available, and how it can offer historians "novel ways to think about the multiple dimensions of change" (Lemercier, 2015). In this case, the data corpus covers over 100 years, and there are three "time-stamps" collected based on the information from the *Dictionaries.* These are birth and death dates of the authors, the period during which they were active at a particular institute, and the dates of their publications. Unfortunately, the first two data points are not very useful since they are largely incomplete or uncertain and they exclude any authors without an affiliation.[10] For current purposes,

8 Alternatively, a projection of the environments could be made, where for instance two universities would be linked if they employed the same author. This is less justified, especially for Layers 1, 2, and 4, since these are institute and city-nodes without (human) agency and, thus, less suitable for social network analysis. Furthermore, the authors are the initial source for the networks, making their information more complete, as opposed to projections of the circles that are only gathered through this particular set of authors.

9 Building and measuring the networks was done with the Python library NetworkX.

10 For author-affiliation, 34% is unknown or none. Of the life-span information, one-fifth is unknown.

Table 1. Description of the time slices for each network layer.

Slice	Name	Time frame	Years covered	Number of authors	Geographical range
1	Pre-Cartesian	1586–1637	51	36	Netherlands, Britain, France
2	Cartesian	1586–1687	101	160	Netherlands, Britain, France
3	Newtonian	1586–1700	114	175	Netherlands, Britain, France

the publication date is the most effective variable to group authors. Not only are the publication dates largely complete,[11] these dates also pinpoint an exact moment in time when an author shared relevant information within their field, indicating their activity in the scholarly community.

Subsequently, the slicing is determined by the publication dates of the seminal works that typify the intellectual turning points of the century. These seminal works are Descartes' *Discours de la méthode* (Leiden, 1637) and Newton's *Philosophiae naturalis principia mathematica* (London, 1687) and their publication dates mark the periods. Thus, the "pre-Cartesian" slice is generally determined from the first publication in the corpus, Abraham de la Framboisière's *Methodicae institutiones philosophiae* (1586) to Descartes' *Discours* (1637), and then the "Cartesian slice" includes the period up to Newton's *Principia* (1687). The next period is the "Newtonian slice," extending to the end of the century.[12] This is only a slight extension of the second slice and, with regard to Newton, it only allows an investigation of his influence at a very early stage.

The final multiplex network consists of four layers with three slices each: dividing the multiplex into these time frames results in a total of 12 sublayers for analysis. The networks are accumulative; that is, for every new slice, publishing authors in that time range are added, but previous ones do not disappear. While the odds of two authors being alive at the same time decrease, accumulative networks can be made intelligible by realizing that an author at the end of the century would have had access to the information published by authors they are tied to. Even when the latter author was no longer alive, the influence of their work would have extended forward in time as their publications were still part of the field. We can envisage how this works by imagining, for instance, the University of La Flèche educating and then employing Pierre Gautruche (1602–1681) during most of the years between 1624 and 1653, increasing the odds that he was familiar with authors like Etiènne Noël (1581–1659) and Marin Mersenne (1588–1648), who some years (or decades) before his arrival were active in the same city, studying the same field and writing on related subjects. It seems highly probable that Gautruche would have been acquainted with the work of Noël and Mersenne and thus they are linked in the network.

Measurements: Centrality and Assortativity

Formal quantitative analysis of social networks commonly uses measurements of centrality. High centrality values are associated with occupying positions of some kind of importance or visibility and are therefore important measures for revealing important individuals or groups in a network. Three centrality measures are taken into account when analyzing the slices in the multiplex. These are degree, betweenness, and eigenvector. Degree is the number of direct ties an author has. High degree authors would have had a high potential *communication activity* (cf. Freeman, 1978) by having been close to many (works of) other authors. This would have given them an advantage in the sense that they would have had easy access to information. Having many ties can make a person influential as well, since an author's many direct relations to other authors makes the passing on of ideas (their own and other's) relatively uncomplicated.

Betweenness gives a value based on the frequency with which a node (an author) falls in between a pair of other nodes (authors) on the shortest path connecting them in the network. As such, it is more closely related to potential *control of communication* (ibid). Lastly, eigenvector centrality is the extent to which a node has connections to other nodes that

11 Only two titles, dissertations by the French Paul Bacuet (1626–1670), have unknown publication dates. These can be estimated at 1634, the year he published another *Disputatio*.

12 Note that this is not to indicate that Newtonian science from this point onward was widespread; the cut-off point indicates the date from which we can consider the appearance of the well-known major competitor for Descartes.

have many ties, and it is calculated proportionally to the sum of the degrees of its neighboring nodes (Newman, 2010, p. 186). It ascribes importance to an individual based on their ties to other individuals of importance. It also provides a relative view on status and might be a better indicator of potential influential positions than degree centrality.[13]

Higher scoring authors are most likely to have been involved in the development of the field. They would have had particular advantages that enabled them to fulfill positions of importance, where they were either influential themselves or influenced by others, based on their structurally central position in a particular network. At the network level, "being central" is determined quantitatively, explicitly omitting a predetermined idea of who should be considered central or prominent.

In the assessment of the results, I focus mostly on the authors who score the highest on several of the centrality measures. Their position and relevance are further determined by assessing biographical information in secondary literature. Finally, by taking a close look at the particular works written by these central authors, a more comprehensive understanding of them as potentially important authors emerges.

Since I work with projected networks primarily, proximity can easily be misunderstood as social similarity; that is, two authors tied to one university become directly tied in the projection. In a sense, this does indeed denote similarity, because they had the same professional environment, but they may have taught competing views on a topic, and this is invisible through this bird's eye view. To create a more nuanced picture, assortativity can be measured.

Assortativity is a measurement of *similarity of connections* in the network, and it measures whether the authors in the network connect preferably with other authors who are in some way the same. Assortative mixing is a pervasive phenomenon found in many networks (Newman, 2002) and is captured in the concept of homophily. Network homophily can be calculated with the assortativity coefficient for a specific node attribute; the outcome indicates whether there are more dyadic ties of a particular type than can be expected randomly. The assortativity coefficient values range between –1 (no shared properties) and 1 (perfect assortativity). Positive scores can be considered as *assortative*, negative as *disassortative*, and 0 as *neutral* (Newman, 2003).

In the time slices, I measure assortativity of the "tradition" attribute, to consider whether authors tend to be linked to authors within the same philosophical tradition. For instance, are Cartesians found in environments that are filled with other Cartesians (indicating assortative mixing), or are they found among other types of thinkers, such as Newtonians, scholastics, or eclectics (indicating disassortative mixing)? The measurement can indicate how mixed these author communities were with regard to their scientific practice and therefore can help with answering the main question about the diversity of the environments, in terms of traditional allegiance. It is to be expected that the networks overall become more diverse over time, based on the introduction of new categories in each time slice such as "Cartesian" and "Newtonian," and the question is how these traditions existed alongside each other. An earlier assessment of the projected networks of the overall corpus has already shown a neutral to slightly positive score on assortative mixing of the traditional categories, but this study included only "primary authors" (the authors of explicitly systematic works dealing with natural philosophy) (Sangiacomo et al., 2022b). Now, the network has become more complete and the introduction of time slices has made the results more comprehensive.

Limitations to the application of centrality measures to historical networks must be taken into account. Results for high degree and eigenvector will show typical projection-cliques (see Figure 1), causing the main clusters to have the highest degree authors, with these authors appearing at the top.[14] This leads to seemingly uninformative top-scoring, because it inevitably points to authors connected to the largest cluster.

For example, in the affiliation layers, top degree and eigenvector positions are occupied by the Dutch authors because many of them were at Leiden University, the most popular university overall, and they shared one or two other university affiliations. Regardless, this still shows us which environment was the most tightly knit, namely that of the Dutch universities. In addition, the well-connectedness would have allowed for a more frictionless transmission of knowledge in the Dutch university circles. The kind of interconnectedness we see

13 Network measurements are done on the weighted projections using NetworkX, a Python package for creation and analysis of networks. Details and equations can be found on (*NetworkX documentation*. (n.d.). https://networkx.org/).

14 For instance, we see high clustering reflected in a very high level of "triadic closure" (in layman's terms, this is captured in the phrase "a friend of my friend is also my friend"). This is measured with the transitivity clustering coefficient, indicating the level of situations where, if a relation "∘" is transitive, and a ∘ b, and b ∘ c, then a ∘ c is implied (Newman, 2010, p. 198). Values for transitivity were found to be very high, ranging from 0.7 to 0.9 (1 being perfectly transitive).

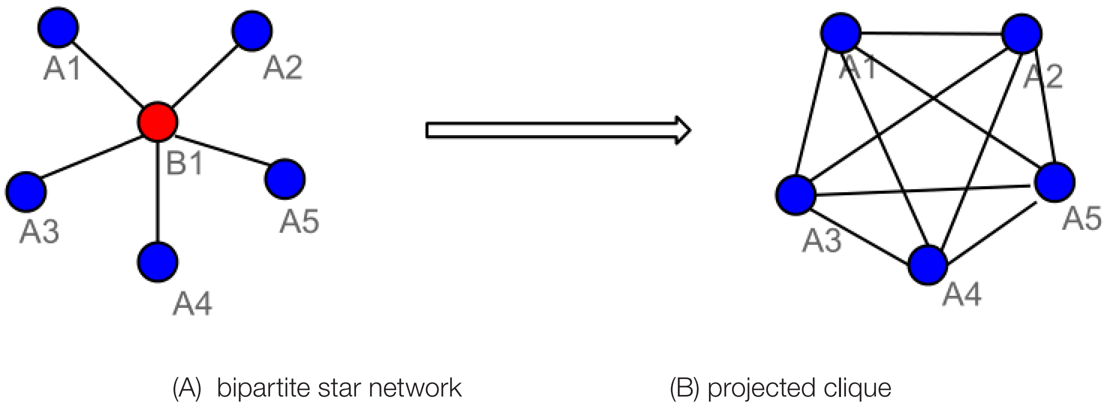

Figure 1: Illustration showing how a star-shaped network in bipartite configuration (A) becomes a clique (B) in the projection where one shared circle (B1) becomes a connection between all authors.

among these authors is not nearly as prevalent in the French and British spheres. By using weighted graphs, the cliques are more refined as some of the original information is maintained and presented. The inclusion of betweenness centrality can also further nuance this analysis.

On a general level, careful consideration is necessary in regard to the interpretation of the results, since the quantitative methods are not specifically attuned to historical contexts (De Valeriola, 2021; Düring, 2016). This means we can expect difficulties using these measures as simple indicators for social centrality as it is commonly understood. It is more intelligible to view these measures not as proof, but as *potential for centrality* (Düring, 2016, p. 99). Since the layers represent accumulative knowledge with nodes added, but not removed from the networks, centrality measurements become complex to interpret in the subsequent layers, particularly in cases where the high scoring authors are deceased but the authors they are connected to are not (this becomes especially relevant in the third slice, where more authors have passed away). We can, however, evaluate the networks in terms of "knowledge spheres." For high betweenness, for example, we can evaluate an author as being "in between" such spheres. In the case that they were alive, they had access to these otherwise quite separate environments, giving them structural advantages and influential positions (as we will see with Descartes and Mersenne). As such, they can be considered proper social network bridges or brokers. When deceased, these authors can no longer be considered genuine bridges because for authors to *literally* function as bridges or brokers, they needed to have been alive at the same time as the bridges they were connected to. While this can be established through close reading, it is obscured at the general network level. Nevertheless, the position of such central authors is still significant because they are represented *through their publications*. The connected (and still living) authors would still have had direct access to their predecessors' work, simply by being connected to the same knowledge sphere.

Results

In terms of capturing the spread of Cartesianism, Slice 1 is the most limited, with only 36 authors. Measurements are less likely to be significant or even legitimate because of the small sample size and are not, therefore, taken into account for the Slice 1 subsample. The slices for this period do, however, provide a starting point of sorts, allowing us to see how natural philosophers were already connected in several spheres. The network graph visualizations[15] are especially helpful here since, on account of their size, they are legible at the node-level. Descartes stands out in every layer for having a central position in one way or another (as I will explain in more detail below), indicating that his position with regard to social embeddedness in knowledge environments

15 All visualizations are made in Gephi version 0.10.0 (Bastian et al., 2009), using the *ForceAtlas2* algorithm (Jacomy et al., 2014). Unless stated otherwise, clusters are determined by the community detection algorithm also known as the "Louvain method" (Blondel et al., 2008). This is used as a visual aid to color the graph and guide the discussion, less so to explicitly demarcate or identify communities.

was very advantageous at the time he published the *Discours*.

In my treatment of the results, Layers 1 and 2 are taken together as "affiliation layers," and Layers 3 and 4 as "publisher layers." Dividing them in this manner enables a consolidated discussion of the results, as Layer 1 relates to Layer 2, with both covering a dimension of an author's social embeddedness through their affiliations. The same applies to Layers 3 and 4 via their links with publishers. See Appendix A and B for detailed tables with network descriptions and measurements, including, *inter alia*, the numbers of nodes and ties, centrality and assortativity measures.

Layers 1 and 2: Co-Affiliation and Co-Affiliation Place

In the first slices of Layers 1 and 2, there are distinctive clusters of authors coming from circles in Paris and Leiden. Since this is the "starting slice," there are not yet any Cartesians (except Descartes himself). About half of the authors in the first slices are considered Aristotelian, the other half either eclectic or not specified. Within these categories, eclectic authors are mostly found among the French.

Compared to the first slice, Slice 2 represents a great expansion of authors in the field, with the network now including 160 authors, spanning the years 1586–1687. As expected, there are some high-density clusters, making it possible to discern groups that were active in similar environments, be they universities or cities. In Slice 2, there are 31 Cartesians and only 3 authors who are labeled "Newtonian" (apart from Newton, these are John Wallis (1616–1703) and Robert Hooke (1635–1703)). Newton himself is central in Layer 2, Slice 2 (high betweenness), but the other two Newtonians are not. Here, Newton is positioned well in these knowledge circles due to his ties to other authors with diverse backgrounds, including those of the Royal Society and the University of Cambridge, such as Pierre Du Moulin (1568–1658, scholastic) and Kenelm Digby (1603–1665, scholastic), who is in turn associated with the Mersenne Circle (more about Mersenne below). Zooming in to the center of Layer 2, slice 2, Figure 3 shows clearly that there are groups of authors with stronger ties between them (thicker lines) within the clusters. We see these stronger connections especially in the Dutch (orange) and British (green) clusters, but less in the French (blue), suggesting that French authors had fewer locations in common with each other. This could mean that the French were either less mobile (e.g., gravitating toward Paris) or more diverse (e.g., visiting entirely different cities to their colleagues).

The third slice is slightly larger, now including all the authors up to the turn of the century. It includes 175 authors from 1586 to 1700 and thus can be said to capture the entire field of natural philosophy in the 17th century in the Netherlands, Britain, and France. The small number of additional authors introduces a shift in both central authors and their diversity. There are now 36 Cartesians but no additional Newtonians. The Dutch become more prominent, now with Herman Boerhaave (1668–1738, eclectic), Nicolaus Hartsoeker (1656–1725, Cartesian), and Christiaan Huygens (1629–1695, eclectic) high on the lists. Bernard Connor (1666–1698, tradition n.a.) is the only central British (or rather Irish) author, a position resulting from his education in central locations in France (the universities of Paris, Montpellier and Reims) and subsequent affiliations with the universities of Oxford and Cambridge, as well as the Royal Society and Royal College of Physicians. While Connor's position, stemming from his noble birth and connections to prominent affiliations, was excellent, his contributions were less in the field of natural philosophy and more related to historical and medical research (Stone, 2004). For instance, he published a work explaining miracles using the principles of medical knowledge (*Evangelium medici* (1697)). While this signals a controversial stance that can be related to the contemporary changes in natural science, his relevance for natural philosophy seems minimal based on his professional involvements.

Homophily scores for "tradition" are positive overall, although they are just above 0 (between 0.02 and 0.04), and strongest in the first layer, indicating that the networks tend to be *somewhat* homophilous within the authors' relations through their affiliations. In other words, within affiliations and affiliation cities, we see some similarity in the philosophical traditions of connected authors, and there is a more than random chance that authors who share an affiliation also share the same "tradition." Interestingly, the layers become slightly more homophilous in the third slice. This can be traced back to a growing number of Cartesians, mainly in the Dutch environment. The scores are close to neutral though, so we can still consider the field to be rather diverse. Figure 4 shows the network graph for co-affiliation (Layer 1), for the entire 17th century (Slice 3), with node color according to the tradition-attribute.

The topology is similar to Slice 3 in Layer 2 (co-affiliation city), only with denser (more populous) clusters. The visualization reflects the numbers; that is, clusters are not entirely dominated by authors of

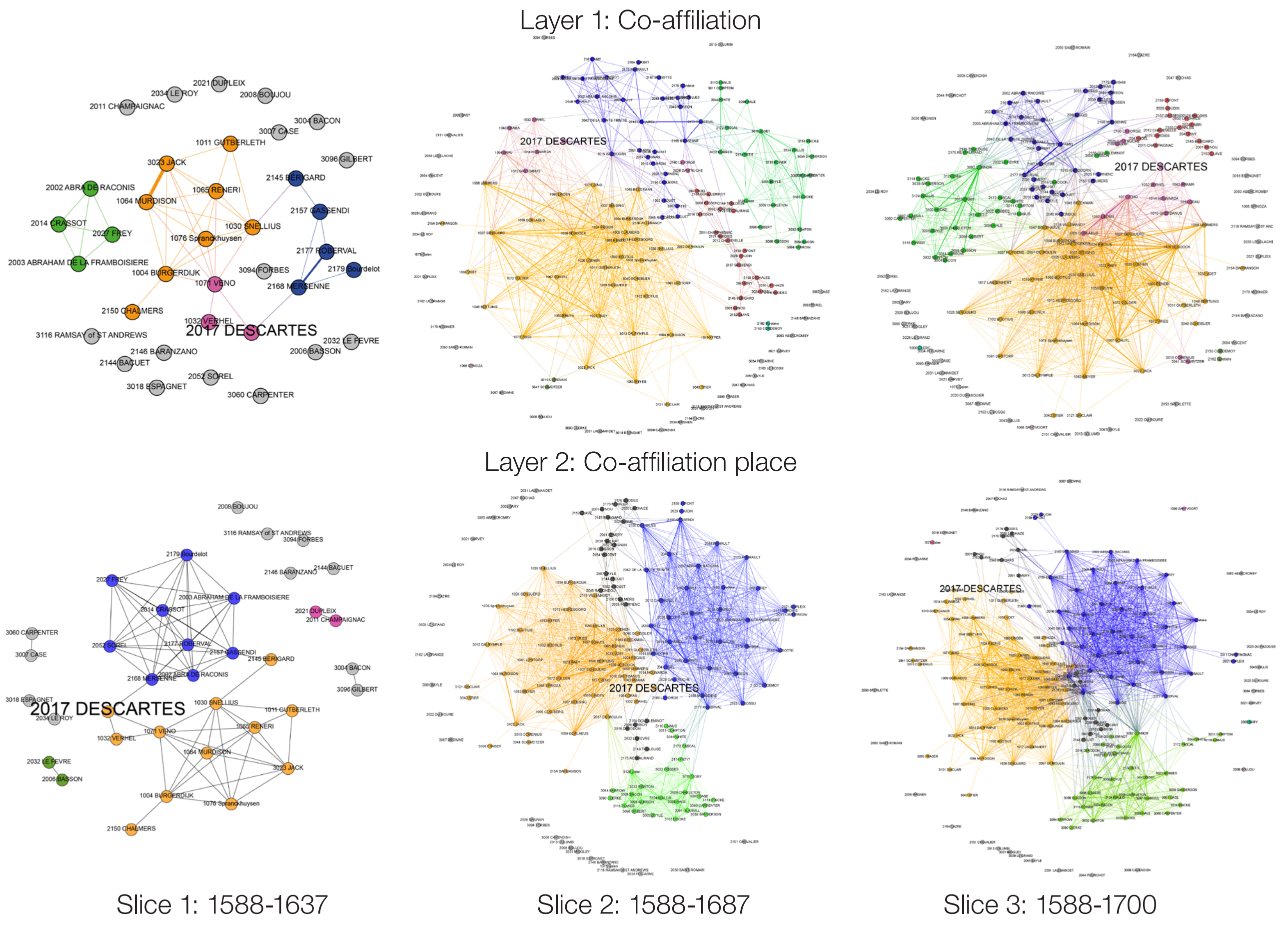

Figure 2: Network graphs of the slices of Layers 1 and 2. The colors correspond to clusters, where roughly the orange clusters are authors tied within Dutch environments, green within British, and blue within French.

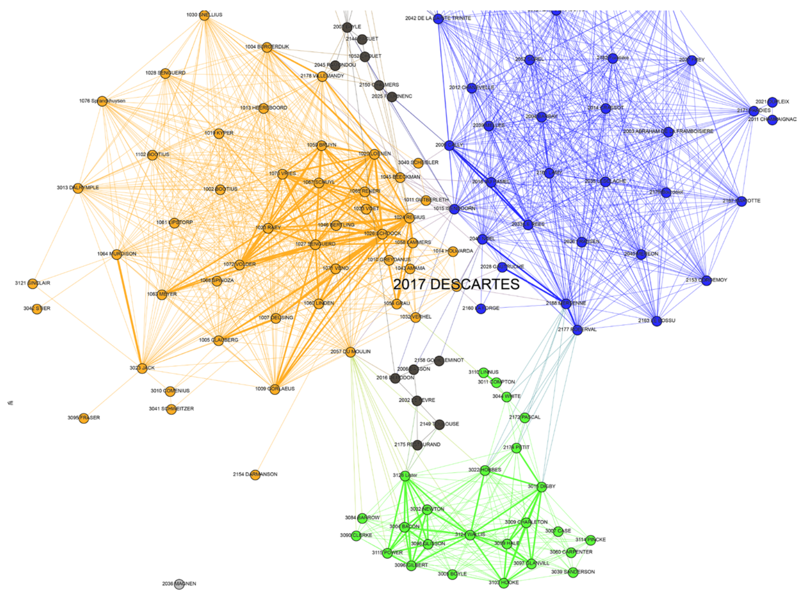

Figure 3: Layer 2, Slice 2 (1586–1700) More high-weighted edges exist among knowledge circles in the Netherlands (orange) and Britain (green) than in France (blue).

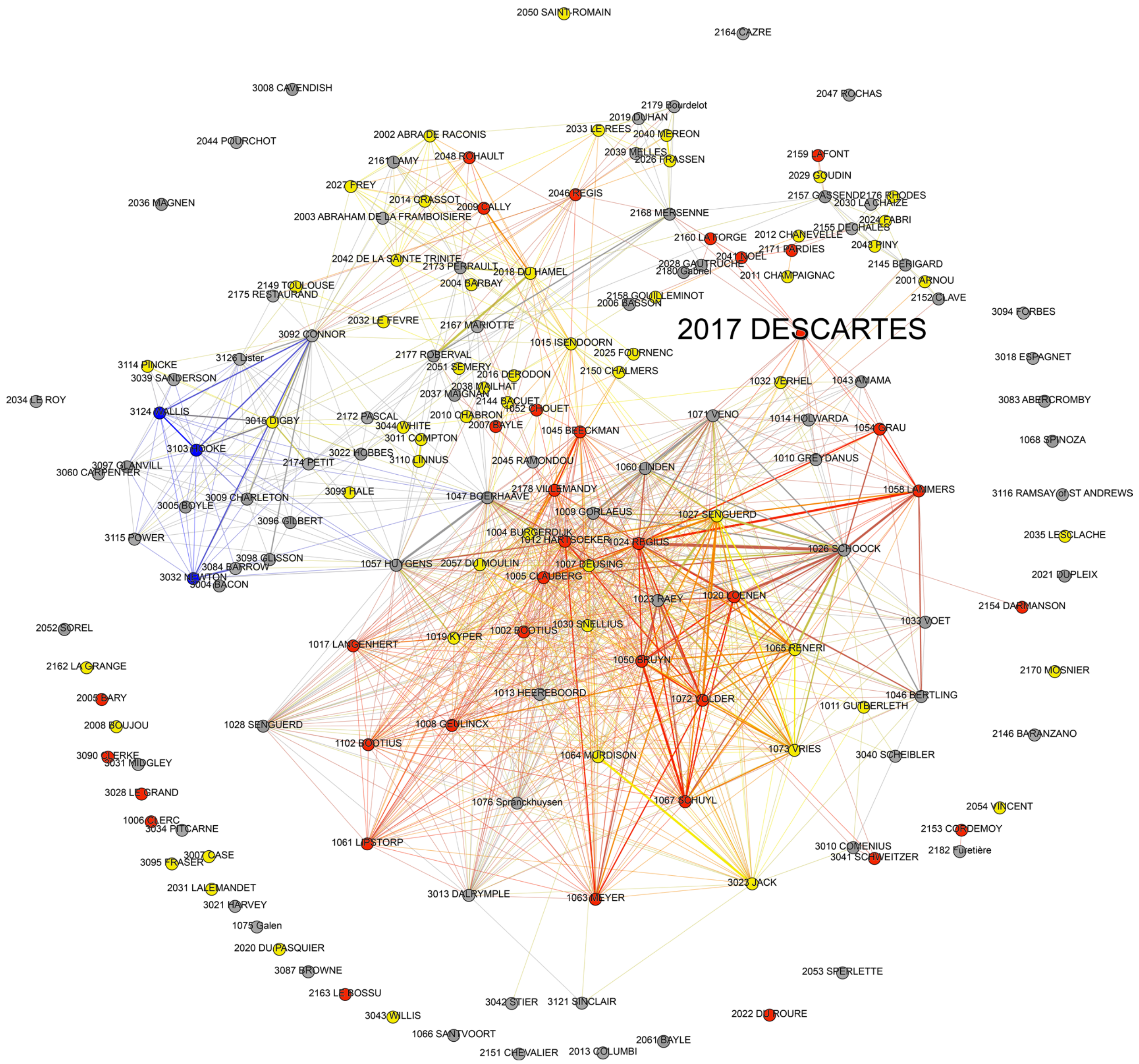

Figure 4: Network graph for Layer 1, Slice 3: co-affiliation for authors between 1586 and 1700. Nodes colored by "tradition" attribute. Blue: Newtonian, red: Cartesian, yellow: scholastic, grey:eclectic or not specified.

a particular tradition, but there is some particular grouping. What the visualization adds is insight into how they are spread throughout the network. Some traditions are more prevalent in certain groups than others. For example, Cartesians (red) are mostly found in the prominent Dutch and the French environments, and the three Newtonians (blue) are found in the one cluster of authors mostly connected by their co-affiliation with the University of Oxford and the Royal Society. Scholastic (yellow) authors pervade the entire network, as do eclectic authors or those with no specific allegiance (both gray).

As the graph shows, the Newtonians are certainly not isolated, but their clique does not include any Cartesians. The eclectic Huygens and Boerhaave, who score highest betweenness values in Layers 1 and 2, bridge the Newtonians to the Dutch knowledge spheres with their membership to the Royal Society and to one or more Dutch universities, while also having ties to authors affiliated with the Parisian Académie des Sciences. The ties that the Newtonians share with authors whose reach extends beyond their clique (such as Huygens and Boerhaave) are commonly based on the affiliation of an "outsider" author to British institutions, often the Royal Society. In this sense it seems that, at least in the late 17th century, the few Newtonians "kept to themselves" and were in contact with outside thinkers only insofar as the others were coming to them. As for Cartesians, they found themselves in a scholastic environment, where they would have been competing for hegemony—a situation in which eclectic authors might have played a key role as mediators between the two more divided views. The religious backdrop was Protestant Reformation in the Dutch Republic and Catholicism in France, which makes it understandable that the main playground for Descartes and his views was first in the Netherlands. Teaching at all universities was traditionally based on the authority of Aristotelian philosophy, but it would have been more natural for the French than the Dutch to insist on Catholic philosopher-theologists such as Thomas Aquinas and Duns Scotus.[16] In this light, we could hypothesize that Dutch Protestants more generously embraced Descartes in their efforts to discard previously dominant Aristotelian–Catholic authorities and to do away with Aristotle, "the blind pagan teacher," as Martin Luther called him (Luther, 1545, 6:457, cited in Stern, 2020).

Already involved in religious reformation, the Dutch would also have been more welcoming and their universities being friendlier environments for scientific reformations. An example of this is the success of the work of Franck Pieterszoon Burgersdijk (1590–1635, scholastic), who is said to have "contributed with the rapid acceptance of Cartesianism in the Dutch Republic" with his comprehensive manuals on philosophy for universities that covered the entire field, but treated it independently from theology and philology. His pupil, Adriaan Heereboord (1613–1661, Eclectic) further developed along those lines and was an avowed sympathizer of Descartes (Van Bunge et al., 2014, pp. 61–72). Burgersdijk and Heereboord are both well connected in the Dutch cluster, but not beyond. The high density of the Dutch-networked environment (as opposed to the more diffused French and British ones) could have greatly accelerated, or at least facilitated, any momentum in knowledge development.

High betweenness points to authors who were in a better position to synthesize ideas from several, otherwise less well-connected, environments. Looking at authors who are both high in betweenness *and* degree or eigenvector values (those with many, or multiple important, connections), some in particular stand out: these are predominantly Dutch or French. Pierre du Moulin, Marin Mersenne, Henricus Regius (1598–1679, Cartesian), and Jean-Baptiste du Hamel (1623–1706, scholastic) are found in such positions throughout the slices, in both Layers 1 and 2.

Du Moulin is conspicuous in the network for being the only French author with high degree centrality. He also has a high betweenness score as he is a bridge between the Dutch and French and British authors (being schooled first in Sedan, then Leiden and Cambridge, and at the end of his life serving as a church minister in Paris). Leslie Gordon Tait mentions in a 1955 thesis that "[i]t is surprising that there is no complete account of the life of Pierre Du Moulin," and it is remarkable that there has been little more than passing attention given to this "important French Huguenot" (Tait, 1955, p. i). Tait recognized Du Moulin's central position in the mid-20th century, and since then it seems to have been acknowledged more widely. Armstrong and Larminie (2008) mention how his noble ancestry helped him to develop contacts and friendships with high-placed officials, and they praise his "astonishing literary output" which was not devoid of controversy, making him a well-known person among the British social and clerical élite. These factors would have placed him in an advantageous position, both as an initiator of new ideas and as a conduit for the spread of knowledge. Based on the biographies and his position in the network of natural philosophers, it is clear that Du Moulin was at the center of a spider's web, tying together important knowledge spheres in his time. Examining his personal profile as a case study, it would seem that his philosophical endeavors were primarily aimed at, and relevant to, the field of theology and the development of French Protestantism rather than natural philosophy. Still, if we think of religious backgrounds as fostering a certain direction in the field, as I highlighted earlier, we may contend that religious and scientific change stimulated each other. Thus, the fact that Du Moulin was spreading Protestant ideas in France could have paved the way for philosophers to be more open to the novel ideas of Cartesian physics as well.

Du Moulin also offers an example of how network centrality must be evaluated closely; while he was highly central in Layers 1 and 2, he died in 1648, when Newton was 6. He was thus not in a position to discuss ideas with Newton, despite their shared Cambridge environment. However, their connection can still be considered relevant because of this social proximity. The fact that they were active in the same

16 All the while, Descartes insisted on being Catholic, even though his work was condemned by the Catholic church, with his works being placed on the *Index Librorum Prohibitorum* in 1663 (Hatfield, 2018).

environments increases the chance that the later Newton was familiar with the work of Du Moulin.[17]

The other three highly central authors were more directly involved in the development of Cartesianism. The French Marin Mersenne, to start with, is a well-known figure and already widely acknowledged for his "bridging" position. His socially rich activities are well documented and preserved in his prolific correspondence with many intellectuals of his time, notably Descartes (for whom he managed all French correspondence and maintained a lifelong friendship [Hotson and Lewis, s.d.]). In the networks of Layers 1 and 2, Mersenne has high centrality scores in all slices, although more so in betweenness than in degree or eigenvector.

This results from his affiliation with eight different institutions, including some collèges and convents, as well as his own Mersenne Circle, also known as the "Academia Parisiensis"—an informal place for philosophers to get together and discuss ideas freely. Members of Mersenne's circle included more than just university scholars, as it was a hybrid association that also included participation through letters (De la Croix & Duchêne, 2021). Justin Grosslight paints an interesting picture of Mersenne, explicitly in network terms (although not through network analysis), as a person "promoting novel claims" and "encouraging discussion on new mathematical concepts" in his connections to other philosophers (Grosslight, 2013, p. 338). He refers to Mersenne as an *intelligencer*. The term "intelligencer" is interesting and although it is rarely used today, historically it referred to someone who was a bringer or carrier of information, sometimes in the role of a spy (OED Online, 2022). While this definition is suitable, I also think it rather apt to read the term as a portmanteau of "intelligence" and "influencer," the latter fitting our contemporary conceptions of individuals in online social networks who have the ability to affect behavior and opinions by their large following. "Intelligencer" then takes on the meaning of an intellectual who, due to their reputation and well-connected central position among their peers, is able to leverage their power to spread knowledge and access to it. This is exactly what Mersenne did, even "manipulating his correspondents into sharing claims and forcing dependency upon him to circulate information" according to Grosslight (360). As a translator of Galileo's work and an enabler of scientific communication he made his mark in the network, but in his own work too, Mersenne was concerned with the spread of the "new mechanical science." He used his writing to further develop what he learned on his travels; in his *Cogitate physico-mathematica* (1644), for instance, he compiled the latest work of his contemporaries, such as Thomas Hobbes and Gilles de Robertval, alongside his own experiments to verify Galileo's numerical data on free fall and velocity (Harmou, 2022).

Another French philosopher of interest is J.-B. Du Hamel. He does not have a high degree score, but he is found between knowledge spheres, with high betweenness centrality in the first layer. He is well embedded in the French environment with six different affiliations, including schools in Caen and Paris, and he was a founding member of the Académie des Sciences in Paris. This "highly cultivated priest" functioned as a bridge between the scientific and theological communities: "Du Hamel enlarged the circle of his Parisian acquaintances, acquiring powerful associates and protectors capable of advancing somebody whose intellectual gifts they greatly admired" (Sturdy, 1995, p. 84). While Sturdy mostly emphasizes Du Hamel's relations with powerful patrons and acquaintances, he played the same role for others as well. From Augustin Vialard's 1884 thesis on Du Hamel, we learn how the philosopher's respect for Descartes, which he shared with his two friends Picard and Malebranche, did not prevent him from acknowledging the value of Pierre Gassendi (1592–1655), an eclectic but anti-Cartesian *and* anti-Aristotelian thinker. Du Hamel invited Gassendi over when he (then 61) was in Paris, and the former proved himself "l'interprète inspiré de la pensée de tous" (Vialard, 1884, p. 56). It is Gassendi to whom he owes his high eigenvector position since he links the Parisians to Claude Guillermet de Bérigard (1592–1663, eclectic) and his Italian knowledge spheres. Alternatively, in The Hague, Du Hamel made friends with Constantin Huygens and met his son, Christiaan, who he subsequently introduced to important circles in Paris (Vialard, 1884, p. 57). One might say that with Du Hamel, we find another typical "intelligencer."

In his work, Du Hamel notably integrated Cartesian mechanical principles within an Aristotelico-scholastic framework instead of the opposite, which was usual for the time. In his aptly titled book, *Philosophia vetus et nova* (*Old and new philosophy*, 1678), he admits the superiority of Cartesian principles over the ancients despite their limited explanatory powers ultimately concluding that Aristotelian principles are necessary to disclose all natural effects. Du Hamel was not directly acquainted with Descartes, or with those close to him, but he was otherwise uniquely

17 In fact, we have insight into Newton's library as it has been catalogued, although not exhaustively (Iliffe and Mandelbrote, s.d.). Pierre Du Moulin's work does not appear on this list, but there is a work by his son, Peter Du Moulin (*The history of the English & Scotch Presbytery* (1659)) in the collection.

placed in between central figures and locations. His "sincere commitment to the need to found the new mechanistic philosophy on Aristotelian principles" (Schmaltz, 2016, p. 113–115) provided excellent material for the transition from an "old" to a "new" science.

Gassendi, on the other hand, was a member of the Mersenne Circle, and through Mersenne connected to Descartes. It is known that they corresponded and Gassendi provided a set of objections to Descartes' *Meditations*, but Descartes had not yet published when Gassendi started working on the epicureanism for which he is most associated (Lolordo, 2006; Wilson, 2008). Gassendi scores high on betweenness centralities in the networks, his knowledge spheres being diverse and international. He can be seen as offering an alternative to Descartes' views, and while he was unsuccessful in that regard, his role was not marginal. It has been highlighted that his core ideas can be found in the works of members of the Royal Society of London, including those of Boyle and Newton (Fisher, 2014; Wilson, 2008). Although his opposition to Cartesianism was unsuccessful, his central position ensured that his work had an extended reach and an influence on future authors.

In the Dutch environment, Martinus Schoock (1614–1669, eclectic) and Henricus Regius (or Hendrik de Roy) are the highest in eigenvector centrality and they are deeply embedded in the Dutch cluster, often with strong ties (weighting 2 or 3 due to their co-affiliation with two or three Dutch universities). Both of their roles in the history of philosophy are usually framed as associated with the heated discussions on Cartesianism in Utrecht, notably involving Descartes and the scholastic theologian Gisbertus Voetius (1589–1676). Upon the request of Voetius, Schoock, then professor at the University of Groningen, wrote "a fierce treatise" with the mocking title *Admiranda methodus novae philosophiae Renati des Cartes* (The Admirable Method of the New Philosophy of René Descartes, 1643) (Van Berkel, 1984). The disputes eventually led to a ban of Cartesianism at the University of Utrecht (Verbeek, 1988). The academic controversy aside, Regius was an interesting early Cartesian. In the first two network layers, he scores highly for his manifold co-affiliations: five different schools and universities in the Netherlands, plus one each in Montpellier and Padua. His multiple institutional allegiances would have given him access to a diverse network of scholars and libraries. Regius is usually discussed because of his relation to Descartes, who publicly disapproved of his views (Antoine-Kolesnik, 2010; Schmaltz, 2019, 2022). Still, through his teachings and writings, he spread Cartesian ideas to other scholars who later became associated with Cartesianism, such as De Raey, Craanen, and Broen. While he had his own views on particular matters as well—deviating from Descartes especially in metaphysical matters[18]—he was perceived as a Cartesian and described as "faithful, if also innovative" (Schmaltz, 2022, pp. 1792–1793) and a "more prominent representative of Cartesianism in the medical community than Descartes himself." (Dobre, 2022, p. 260). All this becomes apparent in his work *Fundamenta Physices* (1646), in which he followed Cartesian philosophy, albeit developing his own views about the idea of God being innate in us. With Descartes, this idea was central, but Regius denied it (Clarke & Bos, 2020), explicitly stating: "*Imo ipsa idea Dei, quae scilicet non est ex revelatione vel inspiratione divinâ, non videtur nonis innata, sed vel ex rerum observatione in nobis primùm producta, vel ab aliis tradita*." (The very idea of God, which of course comes not from revelation or divine inspiration, does not seem to be innate to us, but either first produced in us from the observation of things, or handed down by others., Regius, 1646, p. 252). The rejection of this concept of innateness was a harbinger of the empirical natural science yet to come.

To recapitulate, we can gather that Descartes was well connected to important figures such as Mersenne in France, but his ideas still encountered more resistance there than in the Netherlands. Because of the religious–political backdrop, the French do not seem to have needed an alternative to the traditional scholastic approach in the way that the Dutch did, but the Cartesian developments were still closely followed and engaged with by influential authors in France, even when they did not subscribe to them—as we have seen with Du Hamel and Gassendi. Philosophers who were deemed "eclectic" were often authors who did not mind combining the new mechanical practices with the old Aristotelian systems of knowledge. In this sense, they would not have been too averse to Descartes, even if they disagreed on key issues.

Such leniency would already have had an impact on their approach to science, placing scholastic philosophy under increasing pressure to make way for *libertas philosophandi*,[19] as it was practiced in the new *Académie des Sciences* in Paris (founded 1666).

18 cf. Descartes in his conversations to Burman (Descartes 1976 [1648], 38).

19 The phrase *Libertas philosophandi,* meaning "freedom of philosophising," or "freedom of thought," is often associated with the first disputes over Cartesianism. It was a slogan of sorts popular among learned men in the middle of the seventeenth century, especially in Holland (Sutton, 1953).

Layer 1 shows us that the supporters of Descartes or Cartesianism in France are not as tightly connected by shared institutions as in the Netherlands, and they are mostly centered in the city of Paris (as we can see from Layer 2). At the beginning of the 18th century, when Cartesianism was widely accepted in French universities, the same absence of strong co-affiliations may have impeded the acceptance of Newtonian science, which was picked up more readily in Britain and the Netherlands (Ariew, 2014).

Layers 3 and 4: Co-Publisher and Co-Publication Place

In the network of the first slice of Layer 3, only five authors have a connection. There is a triad of authors who co-published with Elzevier (Amsterdam) and a dyad that published with Patij (Leiden). In the subsequent slices, the most prominent authors are those who co-published with Elzevier, the well-known and celebrated printing and publishing family business tied to the University of Leiden (Goldsmid & Willems, 1885).

There are no specific publishers in the book trade other than Elzevier that stand out for working with natural philosophers at the beginning of the century (see Slice 1). In Slice 2 of Layer 3, we see a handful of unconnected network components.[20] The result is there being no significant betweenness authors, since there are no authors bridging the various components. The same applies to the third slice, which is largely the same, with a few more dyads. The co-publisher layer is incredibly sparse overall, demonstrating that there were few authors who published with the same publisher or publishing house.[21] Multiple publications are included for many authors, each of which could possibly link to another author through a co-publisher. For most authors, however, this was not the case, and their nodes stand unconnected in the network.

If any authors could be considered central here, it would be Descartes and Robert Boyle (eclectic), who have the highest degree and betweenness values. Descartes also has a high eigenvector score. In Layer 3, Slice 3, Descartes' position (central in the orange cluster) shows that he co-published with some Dutch and French authors of heterogeneous traditional allegiance. There are no other authors in the corpus who published with Jan Maire of Leiden, the publisher of the first edition of the *Discours*. Still, Descartes' other works were published with relatively popular publishers in an environment that fostered material on natural philosophy. This is reflected in his high eigenvector, which shows that "many" authors also worked with the same publishers: Elzevier, Moyaert (Leiden), and Le Gras (Paris). While also central, Boyle's position (central in the green cluster) is quite different. The authors he is tied to are rarely connected to each other, showing a more incidental publishing pattern. His pattern shows that he was not loyal to any one publisher, but the publishers he did work with also worked with other natural philosophers. This gives Boyle a center-in-star network position—a type of structure that is not found in any other layer of the networks, because most of the projections have clustered cliques. Perhaps his position can be understood from the notion that, while Boyle was an esteemed natural philosopher and, as co-founder of the Royal Society of London, a prominent figure, he was less of an academic figure because he did not actively pursue a career in schools and universities. His legacy lies rather with his more independent contributions to experimental and empirical science (Sargent, 1995). His scattered publishing activities reflect this intellectual independence, while also showing that his choice of publisher was not random. Through their engagement with natural philosophers, these publishers seemed relevant to the field, and Boyle's use of them could have been strategic publishing decisions.

The Newtonian authors co-published with several printers that worked exclusively for London's Royal Society (Rivington, 1984), such as William Godbid and Moses Pitt (tying Boyle to Wallis), Samuel Smith (tying Newton to Boyle), the Crooke family (tying Boyle, White, and Hobbes) or John Martyn (publisher of authors in the blue clique seen in Figure 5, Layer 3). Apart from the Newtonians, these knowledge spheres are dominantly eclectic, with the exception of Antoine le Grand (1629–1699), who played an important role in propagating Cartesianism in Britain in the late 17th century (Easton, 2018).

Throughout the components of Layer 3, there are no homophilous patterns with regard to tradition in terms of assortativity measures. In fact, this layer is the only one with negative assortativity values, in Slices 2 and 3 (-0.2), although it should be noted that these are still close to neutral.

Layer 4 is completely different to the co-publisher layer. It is more similar to the affiliation layers; as with those layers, the slices of Layer 4 show a slight, but

20 The orange and purple cliques both include authors co-publishing with Elzevier, differentiated because they had branches in Amsterdam (orange, component size 14) and Leiden (purple, component size 6).

21 This, of course, tells us something about the publishers as well. No one seemed to be "specialised" in natural philosophy or directing their efforts toward works in this field.

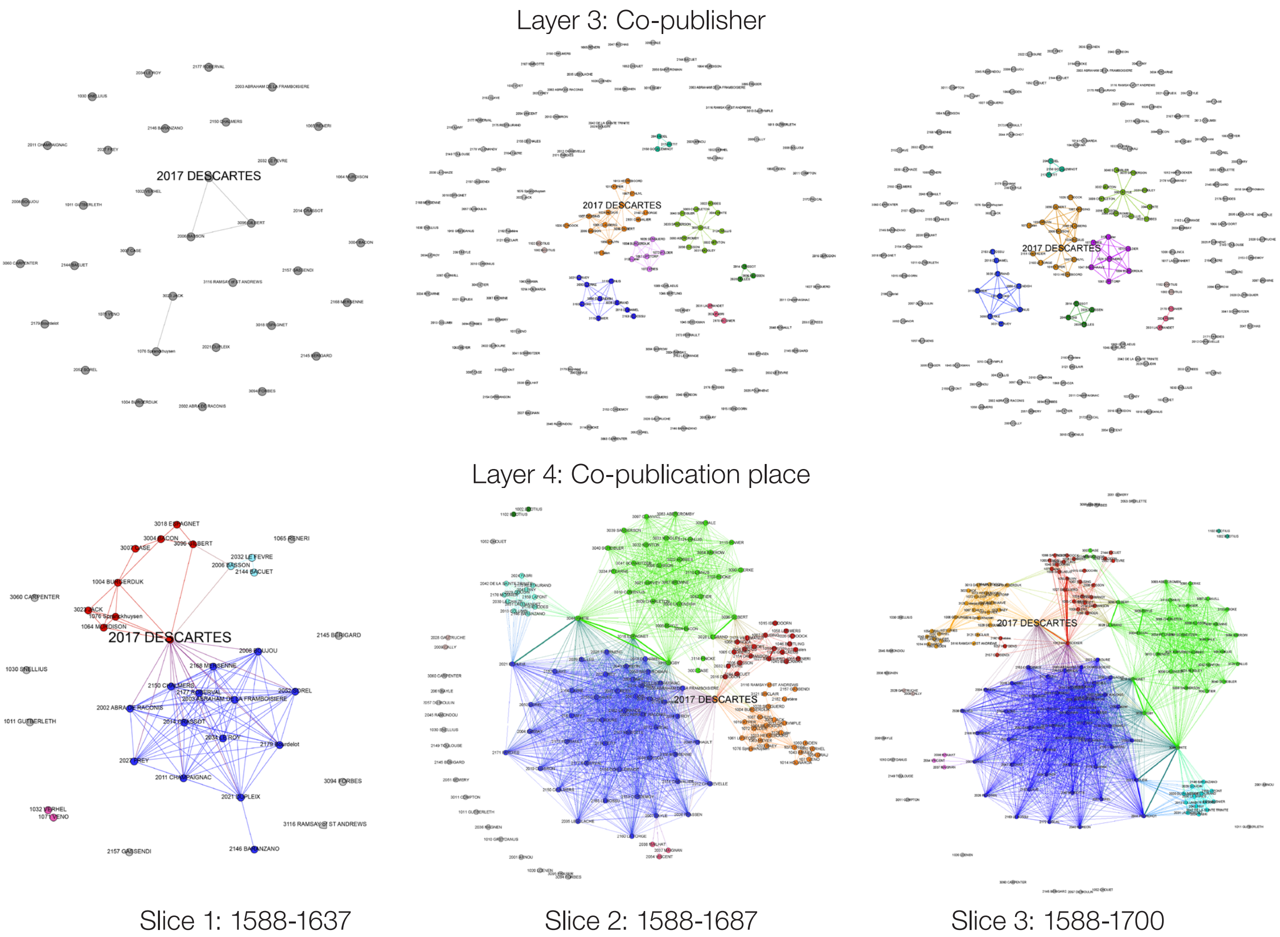

Figure 5: The network slices of Layers 3 and 4. Colors correspond to clusters, where roughly the orange clusters are authors tied within Dutch environments, green within British, and blue within French.

near-neutral similarity pattern for traditional allegiance, with scores at 0.02. Furthermore, the layer is highly connected as it is the densest overall and the authors have the highest degrees in the multiplex.

This is already visible in the first slice, where we find a large cluster of authors mostly co-publishing in Paris (Figure 5, blue cluster). The orange cluster groups authors with co-publishing places in Leiden, London, and Genève. Descartes fills a structural hole between the two, publishing in Leiden, Amsterdam, and Paris, and he is found at the top of all centrality lists in Layer 4. Authors by and large were co-publishing in France, particularly in Paris, with those publishing in Lyon being rather separate (light blue cluster). The clusters in Layer 4 are more sharply defined with some very obvious bridge-authors. Apart from Descartes, Thomas White (1593–1676, scholastic) is very central here. He bridges the French (Paris, Lyon) and British (London) spheres, by actively publishing on natural philosophy in the mid-17th century. In contrast to Layers 1 and 2, London is a common shared space for author activity (green cluster). The slices hereby reveal a specific dimension of the authors in the British knowledge environments, in that most of the structurally best connected authors are found publishing in London.

Because a few cities are so central in this last layer, it can be helpful to return to the bipartite network to look at both node sets in more detail. Figure 6 shows a piece of the bipartite network graph of Layer 4, Slice 3, zoomed in on the largest clusters. Paris and London are quite obviously the most popular places for natural philosophers to have published their work. The authors co-publishing in the Netherlands are less tightly connected, showing a more diverse landscape with regard to a shared publication place. Overall, this is surprising because Amsterdam is seen as the center f book production in the 17th century due to its relatively low level of censorship. On the other hand, publishing in France is known to have been heavily

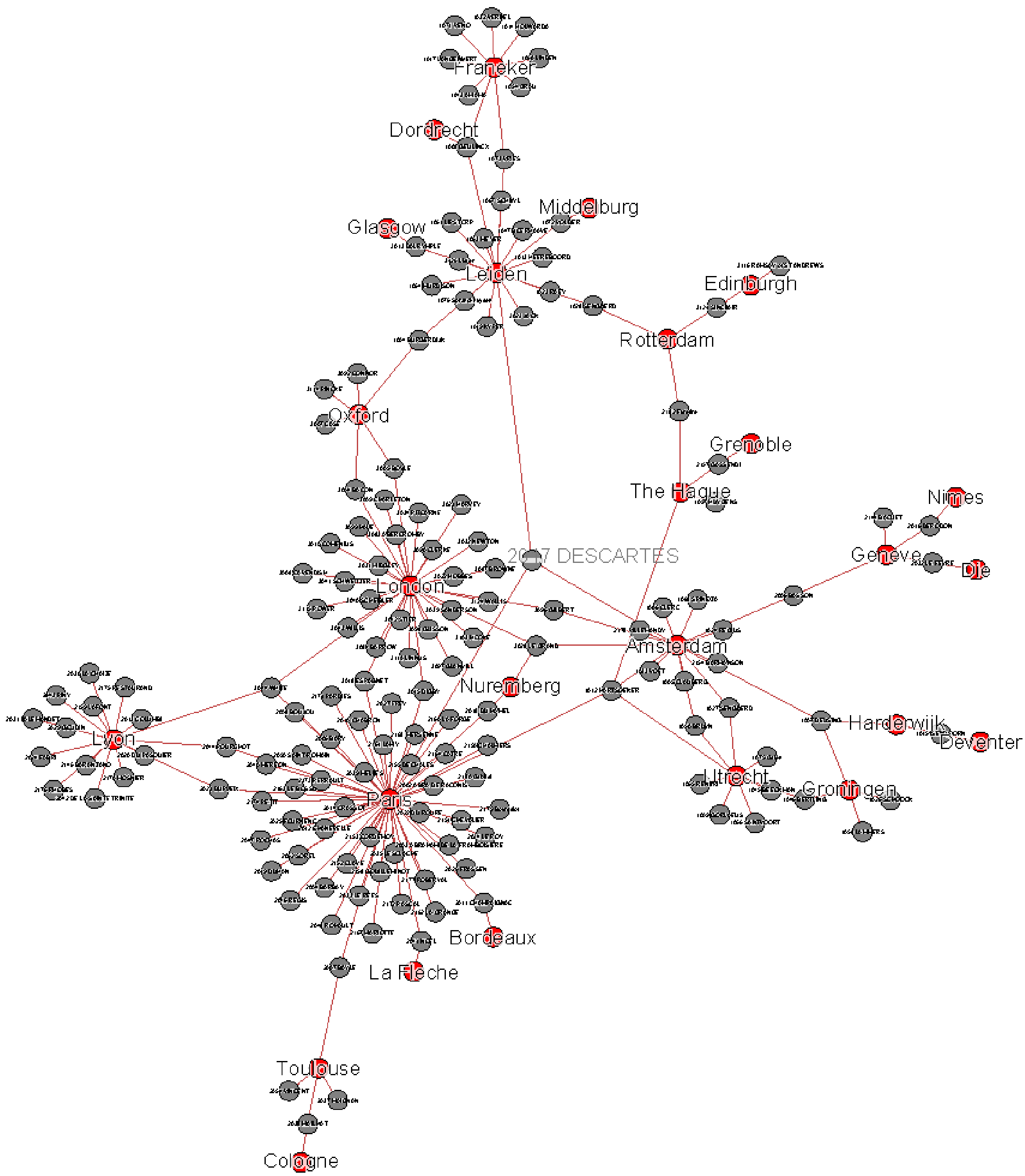

Figure 6: The biggest connected component of the bipartite network for Layer 4, Slice 3 (author-publication place, 1586–1700). The graph shows publication-place-hubs in Paris and London. The red nodes are the publication cities, the gray nodes are the authors. Size according to degree.

concentrated in Paris due to the authority exercised by the monarchy after the religious wars around 1600, with a private press and the 1618 establishment of the *Chambre des Syndicats*, which maintained absolute control over printing productions (Dijstelberge, 1994; Unwin et al., 2020). As such, while these networks reaffirm the image of the book trade in France, they suggest that a reevaluation of the trade in the Netherlands could be worthwhile.

The cities where many publishers were situated are those where the options for printing were omnipresent and, thus, where knowledge was easily copied and distributed. Descartes, and by extension his work, can be found in several such primary locations. These locations would have been stimulating and favorable environments for philosophical activities and, significantly, would also have provided philosophers with access to other works that were being printed there. Many of these hubs were cities with universities, but we do see a difference in cities that were popular from the university perspective as opposed to the publisher perspective. For instance, the Dutch environment was much more pronounced as a binding knowledge sphere in the affiliation layers than the publisher layers. There were several universities spread over the country, and many scholars taught or were educated at more than one of them. For the purposes of publishing their work on natural science, however, scholars were more inclined toward a single city, or maybe two. London is significantly more common as a co-publishing location than as a co-affiliation place, whereas France has a much more distributed pattern for author affiliations. Nevertheless, printing activity was predominantly centered in Paris.

In Figure 7, it is clear that the British clique (shown in the top right, with the Newtonian authors as blue nodes) is not as strikingly devoid of Cartesians as the co-affiliation place layer. There are no Cartesians in the British cluster around the three Newtonians in Layer 2, while here we find two: the aforementioned Antoine Le Grand who, here, is a bridge between the British and Dutch spheres and Gilbert Clerke (1626–1697), a mathematician who "apparently claimed credit for introducing the teaching of mathematics and of the new (Cartesian) philosophy at Cambridge" and was among the first to correspond with Newton about his *Principia* (Hutton, 2019). These "British Cartesians" are seen as important propagators of Cartesianism in Britain, all working around the same time and in the same place (London, but most notably Cambridge).[22] Despite this, they are not explicitly linked as acquaintances or contacts in the existing historiography.[23] Whether they knew each other or not, the knowledge environments they found themselves in proved less fertile for Cartesianism, as they consisted mostly of eclectic or nonspecified authors who were also beginning to be exposed to the emerging Newtonian innovations.

It can be concluded that while groups of authors with co-publishing patterns did exist, the publisher as an individual was not a relevant or prominent factor for linking authors in the field. It was expected that either more star-networks, such as that of Boyle, or more clusters would have appeared in these networks, based on traditional studies which emphasize the importance of particular publishers, or the symbolic status of publishers due to their printing of other notable authors' works (Pettegree & Der Weduwen, 2019, p. 180). However, the sparse and largely unconnected networks do not support the existing literature at all, which focuses on some printing houses—such as the Elzevier publishers who were "dominating the north"—as the most important and definitive for the trade (Unwin et al., 2020). While such publishers certainly stand out, they can hardly be said to dominate the field of natural philosophy. The results are different for *where* publishers operated; in Layer 4, for example, it is clear that although there were many publishers, they were grouped in the larger cities, resulting in the easy and numerous tying of authors by place of co-publication.

At the individual publisher level, the networks fail to capture any kind of determinant agency for the spread of Cartesianism. The significance of the publishers is likely to be found in their dynamics at other levels, such as their links to each other or their individual links to institutions and cities.[24] In the knowledge spheres of the book trade at a city level, Cartesianism is again (as with the affiliation layers) mostly embedded within a mixed environment of scholastic-eclectic authors.

22 Cambridge is also the place where we find Henry More (1614–1687), an early supporter and correspondent of Descartes, supposedly the one who coined the term "Cartesianism" (Hutton, 2015). While More worked with the Cartesian mechanical philosophy, he is not included in the corpus as he was an author of theological or literary works, rather than natural philosophy.

23 In Hutton (2019), they are both mentioned, albeit separately, as Cartesians in Britain. Individual biographies, such as the ones in the *Dictionaries*, the Stanford Encyclopedia (Easton, 2018), and the Oxford DNB (Mandelbrote, 2004), do not mention any contact between the two philosophers.

24 For computational history, Valleriani et al. (2022) show an interesting example with their study on "awareness relationships" among printers and publishers.

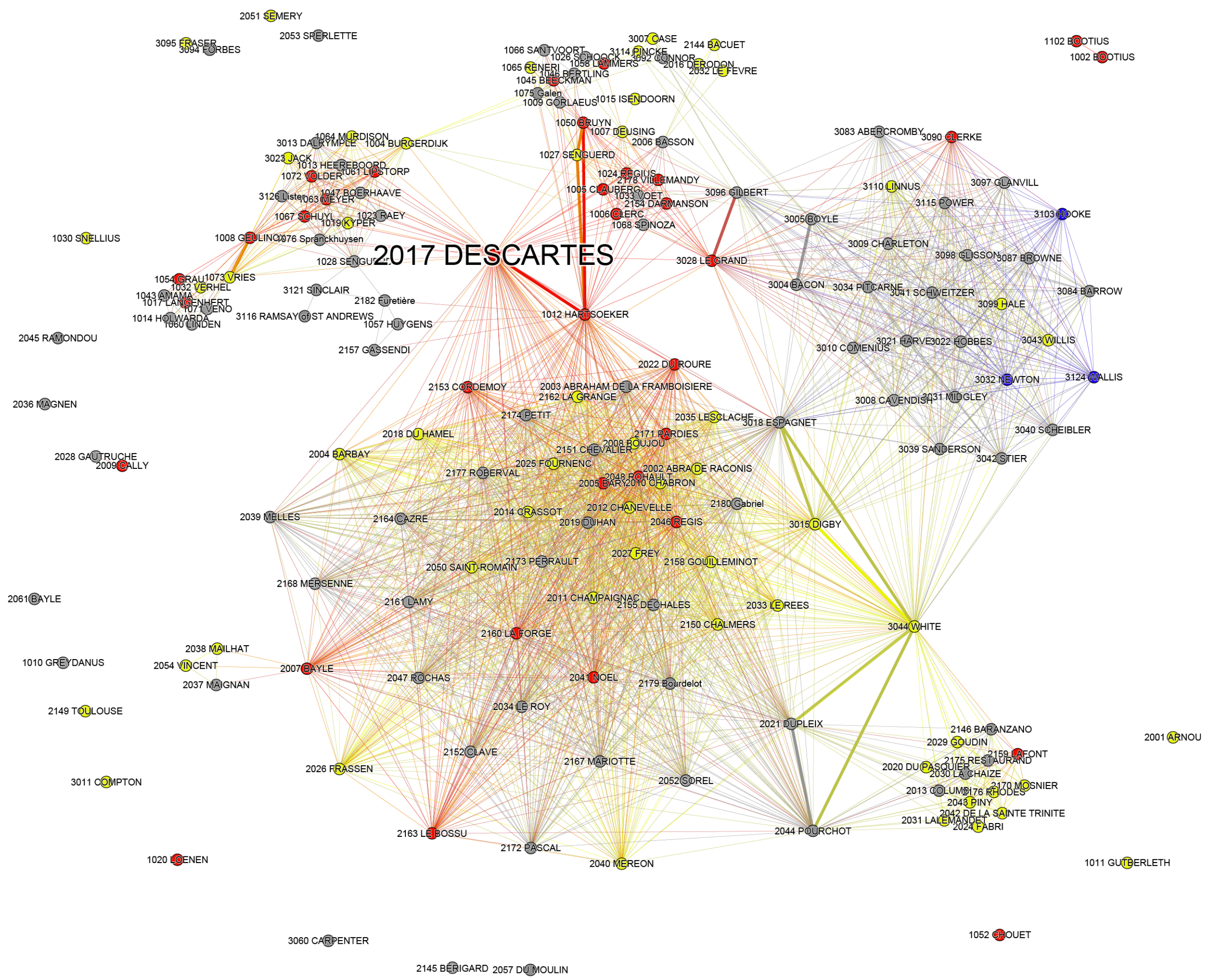

Figure 7: Network graph for Layer 4, Slice 3: co-publication place for authors between 1586 and 1700. Nodes colored by "tradition" attribute. Blue: Newtonian, red: Cartesian, yellow: scholastic, gray: eclectic or not specified.

Conclusion

The two main questions regarding the instrumentality of prominent authors in spreading and popularizing Cartesian ideas and the diversity of the network in terms of philosophical tradition have been answered using several network measures, complemented by a qualitative analysis of primary and secondary sources. On a general level, the results show that the overall field of natural philosophy as captured in these network layers has a striking similarity in clustering by geographical location, in the sense that authors are often grouped by one or two cities where they were actively working or publishing. While there remain some authors who do not connect on any level, the vast majority belong to a connected network, and we do not see any particular uncoupled subcommunities (based on tradition or other factors). These clusters and cliques within the projected networks were anticipated due to the transition from the original bipartite structures, but they additionally reveal the size and prominence of the actual, specific environments. Specifically, for the affiliation layers, France and the Netherlands have similar co-affiliation patterns among the authors, with Paris and Leiden as the main binding locations.

The Dutch environment is the most densely connected, with authors sharing several affiliations, while French affiliations are altogether more scattered with authors usually connecting in Parisian circles. For Britain, London is much more prominent as a co-publishing place than as a co-affiliation place.

Because many (if not most) natural philosophers were active at these locations, either working or publishing, cities like Paris, Leiden, and London provided fertile ground for scholarly communities to thrive. Considered as a whole, the field of natural philosophy in early modern Western Europe was a highly connected and diverse environment.

Although the religious–political situation was not categorically included in the networks, it inevitably played a part in the overall analysis due to the religious transformations of the times. The Netherlands was already undergoing its religious turn toward Protestantism and, thus, it may have been more susceptible to scientific change as well, with less attachment to the Catholic philosopher–theologists who were popular with the scholastics.

The two publisher layers reveal an overarching picture of the publishing activities of this scholarly field. Not mapped explicitly in this way before, the network layers show that publishers by themselves did not create significantly accommodating environments for natural philosophers. On a larger scale, the systematic relationships between publishers and institutions or among themselves remain largely unexamined here. Such a study could prove fruitful for wider fields in the future, but seems to have limited value for the narrowly defined field of natural philosophy.

To answer this article's first main question, the results corroborate the idea that the most central or prominent figures from a network point of view were key contributors to the spread and popularization of novel approaches. This is supported by the position and activity of authors such as Mersenne, Regius, Du Hamel, and Descartes himself. Their centrality would have made it easier for them, on the one hand, to be well acquainted with the latest research and, on the other hand, to readily spread their own. While they might not always have explicitly favored the Cartesian approach, their work and activities in the scientific community show engagement with a science that moved away from the traditional scholastic approach, in that they were mostly either Cartesian or eclectic in orientation. Du Hamel, one of the few central scholastics, was actually known for merging Cartesian thought with Aristotelian principles. Of course, the centrality scores of Descartes himself also prove that he was in an excellent position to reap the fruits of his own labor.

To answer the second main question, "the old" and "the new" certainly existed alongside each other, as indicated by the assortative mixing. This is true for both the affiliation and publication layers. Overall, assortativity measures indicate that there was *some* homophily in the network. This can be seen in the division of Cartesians of the Dutch circles and the Newtonians (at least those who were already publishing in the 17th century) in the British circles. Still, the assortativity values are not very strong, which indicates that the authors generally had diverse environments, meaning that they were generally exposed to a mixture of scholastic, eclectic, and Cartesian thinkers, although there were few Cartesians and mostly eclectics among the British. While contemporary philosophical discussions "on the ground" may have become quite heated or divided (as we saw with the Regius case), a diverse but connected environment is readily apparent from our more distant perspective. It is visible in the relatively dense networks of Layers 1, 2, and 4, where a relation to an author (or their work) with dissenting views was never far away.

There are, of course, limitations in terms of what the measurements can or cannot show for my data corpus. In regard to centrality measures, I have emphasized *potentiality* by leaving some space for uncertainty in the assessment of author prominence based on the measures themselves and highlighted the need to combine these measures with the author's actual work and biographical accounts. In Section "Layers 3 and 4: Co-Publisher and Co-Publication Place," the more comprehensive treatment of some of the most prominent authors demonstrates this. It also shows how these networks do not always capture all important relationships or individuals, as sometimes these can only be found outside of the field or the regions under study. I have mainly focused on authors with high scores for two or all three centrality measures, to avoid authors with high scores simply based on their presence in the main clique (i.e., to avoid the potential bias resulting from the projection technique). For assortativity, it is necessary to rely on tools for theoretical or contemporary contexts. In these networks, the authors' traditional mixing patterns show neutral or heterogeneous values. Still, through a closer assessment of the network graphs, certain patterns seem to emerge, such as the locations where certain types of philosophers were found: broadly speaking, Cartesians in the Netherlands and France, Newtonians in Britain, and scholastics and eclectics everywhere. There is potential for improvement of assortativity measurements, for instance by assessing the similarities on a narrower cluster-based level.

Another related reservation goes a little deeper into the epistemic limitations of network studies without the additional contextualization of the subjects and data. Uncertainty is something that is inherent to a historical data-driven project, but can be accounted for by contextualizing the data. In this regard, I approach the data as "situated knowledge"—a term from feminist theory (Haraway, 1988) that can help us acknowledge that "all data have important contexts of creation and organization, and situating them (or emphasising them as situated) includes critical examination of those contexts" (Lavin, 2021). The database and network design used here incorporate constraints through inclusion and exclusion criteria related to of the authors, their publications, and their relationships. When the criteria is determined differently, either more loosely or strictly, outcomes could be different. As a consequence, this means that treating these networks as all-encompassing, straightforward representations of social environments would be misleading. This stems from the way that the data was gathered using the *Dictionaries,* how it was processed (to fit network models and the division of the time slices), and the self-imposed limitation of strictly adhering to the field of natural philosophy. It highlights that our social environments are multilayered, and no single network can be considered a firm and finite structure, especially for complex and fragmented historical data. By treating the resulting relations as *potentials* and *situated knowledge* and supplementing the results with qualitative sources, these networks have certainly provided new insights.

Despite the uncertainties, if we understand the production of knowledge as a socially embedded process, it is relations such as the ones formalized in these four network layers that provide pathways of possibility for concepts to evolve. This complex network has brought to light how the ideas of Descartes, whom we know so much about on the individual level, functioned in the broader context of the debate that was going on in the field of natural philosophy at large.

Acknowledgements

This article is part of a project that has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement 801653). Additionally,I owe many thanks to the other project members, Andrea Sangiacomo, Raluca Tanasescu and Hugo Hogenbirk for the development of this paper.

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Appendix A

Table of projected networks’ top centrality scores

	Degree		Betweenness		Eigenvector	
	Author	Score	Author	Score	Author	Score
1. Co-affiliation						
	1030 SNELLIUS	8	1071 VENO	0.0541176	3023 JACK	0.452810
	1071 VENO	8	1030 SNELLIUS	0.0471148	1064 MURDISON	0.436308
	1004 BURGERDIJK	7	2017 DESCARTES	0.0364146	1030 SNELLIUS	0.349756
	1065 RENERI	7	2168 MERSENNE	0.0330532	1065 RENERI	0.343279
Slice 1	3023 JACK	7	2145 BÉRIGARD	0.0308123	1071 VENO	0.337054
	1064 MURDISON	6	2157 GASSENDI	0.0263305	1004 BURGERDIJK	0.328555
	1076 Spranckhuysen	6	1004 BURGERDIJK	0.0238655	1076 Spranckhuysen	0.322635
	2168 MERSENNE	4	1065 RENERI	0.0053782	1011 GUTBERLETH	0.164470
	1011 GUTBERLETH	3	3023 JACK	0.0042017	2017 DESCARTES	0.058146
	2002 ABRA DE RACONIS	3	1076 Spranckhuysen	0.0003361	1032 VERHEL	0.056726
	1024 REGIUS	42	2057 DU MOULIN	0.110625	1026 SCHOOCK	0.265475
	1026 SCHOOCK	42	2168 MERSENNE	0.074352	1024 REGIUS	0.254287
	1027 SENGUERD	39	1015 ISENDOORN	0.064694	1027 SENGUERD	0.245768
	1071 VENO	38	3032 NEWTON	0.057066	1023 RAEY	0.209960
Slice 2	1009 GORLAEUS	37	2018 DU HAMEL	0.048133	1072 VOLDER	0.209960
	1060 LINDEN	37	2157 GASSENDI	0.044051	1020 LOENEN	0.208370
	1045 BEECKMAN	36	1045 BEECKMAN	0.043824	1065 RENERI	0.208370
	2057 DU MOULIN	36	2017 DESCARTES	0.041256	1050 BRUYN	0.199737
	1007 DEUSING	35	2041 NOEL	0.036893	1067 SCHUYL	0.199737
	1020 LOENEN	35	1024 REGIUS	0.033459	1073 VRIES	0.194743
	1047 BOERHAAVE	53	1047 BOERHAAVE	0.060459	1026 SCHOOCK	0.239049
	1057 HUYGENS	51	1057 HUYGENS	0.054692	1024 REGIUS	0.229590
	1024 REGIUS	47	2168 MERSENNE	0.045200	1027 SENGUERD	0.227076
	1026 SCHOOCK	47	2018 DU HAMEL	0.043053	1072 VOLDER	0.198344
Slice 3	1027 SENGUERD	44	3092 CONNOR	0.040145	1023 RAEY	0.198344
	1071 VENO	43	2157 GASSENDI	0.037851	1065 RENERI	0.196032
	1009 GORLAEUS	42	1015 ISENDOORN	0.037372	1020 LOENEN	0.192994
	1012 HARTSOEKER	42	2057 DU MOULIN	0.036340	1050 BRUYN	0.185926
	1060 LINDEN	42	2041 NOEL	0.031390	1067 SCHUYL	0.185926
	2057 DU MOULIN	42	1024 REGIUS	0.031119	1073 VRIES	0.181739

Continued Table of projected networks' top centrality scores

	Degree		Betweenness		Eigenvector	
	Author	Score	Author	Score	Author	Score
2. Co-affiliation place						
	2157 GASSENDI	9	1030 SNELLIUS	0.081008	2168 MERSENNE	0.336375
	2168 MERSENNE	9	1071 VENO	0.077227	2157 GASSENDI	0.336266
	1030 SNELLIUS	8	2017 DESCARTES	0.076891	2177 ROBERVAL	0.331439
	1071 VENO	8	2168 MERSENNE	0.075630	2179 Bourdelot	0.331439
Slice 1	2002 ABRA DE RACONIS	8	2145 BÉRIGARD	0.074370	2002 ABRA DE RACONIS	0.331439
	2003 ABRAHAM DE LA FR.	8	2157 GASSENDI	0.074370	2003 ABRAHAM DE LA FR.	0.331439
	2014 CRASSOT	8	1004 BURGERDIJK	0.032269	2014 CRASSOT	0.331439
	2027 FREY	8	1065 RENERI	0.004958	2027 FREY	0.331439
	2052 SOREL	8	3023 JACK	0.003782	2052 SOREL	0.331439
	2177 ROBERVAL	8	1076 Spranckhuysen	0.000336	2017 DESCARTES	0.044564
	1015 ISENDOORN	44	2057 DU MOULIN	0.142795	1026 SCHOOCK	0.264853
	2057 DU MOULIN	43	1015 ISENDOORN	0.132943	1024 REGIUS	0.253570
	1024 REGIUS	42	2168 MERSENNE	0.055271	1027 SENGUERD	0.245631
	1026 SCHOOCK	42	3022 HOBBES	0.047200	1023 RAEY	0.209945
Slice 2	1027 SENGUERD	40	1045 BEECKMAN	0.046973	1072 VOLDER	0.209945
	1071 VENO	38	2177 ROBERVAL	0.044881	1020 LOENEN	0.207940
	2168 MERSENNE	38	2007 BAYLE	0.036053	1065 RENERI	0.207940
	1009 GORLAEUS	37	2155 DECHALES	0.030097	1050 BRUYN	0.199180
	1045 BEECKMAN	37	2041 NOEL	0.027780	1067 SCHUYL	0.199180
	1060 LINDEN	37	2178 VILLEMANDY	0.027690	1073 VRIES	0.194205
	1047 BOERHAAVE	85	1047 BOERHAAVE	0.097136	1047 BOERHAAVE	0.203733
	1057 HUYGENS	84	1057 HUYGENS	0.094769	1057 HUYGENS	0.199925
	1012 HARTSOEKER	74	1012 HARTSOEKER	0.065836	1026 SCHOOCK	0.198422
	3092 CONNOR	62	2057 DU MOULIN	0.040231	1012 HARTSOEKER	0.196985
Slice 3	1015 ISENDOORN	51	3092 CONNOR	0.036894	1027 SENGUERD	0.189696
	2057 DU MOULIN	49	2046 REGIS	0.035294	1024 REGIUS	0.189385
	1024 REGIUS	47	1015 ISENDOORN	0.032695	1023 RAEY	0.166912
	1026 SCHOOCK	47	2155 DECHALES	0.027896	1072 VOLDER	0.166912
	1027 SENGUERD	46	2157 GASSENDI	0.023704	1065 RENERI	0.164339
	2046 REGIS	46	2041 NOEL	0.023160	1020 LOENEN	0.161876

Continued Table of projected networks' top centrality scores

	Degree		Betweenness		Eigenvector	
	Author	Score	Author	Score	Author	Score
3. Co-publisher*						
	2006 BASSON	2				
	2017 DESCARTES	2				
Slice 1	3096 GILBERT	2	(Meaingless)		(Meaningless)	
	1076 Spranckhuysen	1				
	3023 JACK	1				
	2017 DESCARTES	11	2017 DESCARTES	0.003662	2017 DESCARTES	0.420029
	3005 BOYLE	10	3005 BOYLE	0.003423	1007 DEUSING	0.364578
	1007 DEUSING	7	1007 DEUSING	0.000955	1050 BRUYN	0.364578
	1050 BRUYN	7	1050 BRUYN	0.0009553	1005 CLAUBERG	0.356469
Slice 2	1005 CLAUBERG	6	3028 LE GRAND	0.000955	1024 REGIUS	0.356469
	1024 REGIUS	6	2018 DU HAMEL	0.000557	2006 BASSON	0.356469
	2006 BASSON	6	3090 CLERKE	0.000557	3096 GILBERT	0.356469
	3028 LE GRAND	6			1013 HEEREBOORD	0.099443
	3090 CLERKE	6			1019 KYPER	0.099443
	3096 GILBERT	6			1067 SCHUYL	0.099443
	2017 DESCARTES	11	2017 DESCARTES	0.003056	2017 DESCARTES	0.413808
	3005 BOYLE	10	3005 BOYLE	0.002857	1007 DEUSING	0.359179
	1007 DEUSING	7	1007 DEUSING	0.000797	1050 BRUYN	0.359179
	1050 BRUYN	7	1050 BRUYN	0.000797	1005 CLAUBERG	0.351190
Slice 3	1004 BURGERDIJK	6	3028 LE GRAND	0.000797	1024 REGIUS	0.351190
	1005 CLAUBERG	6	2018 DU HAMEL	0.000465	2006 BASSON	0.351190
	1024 REGIUS	6	3090 CLERKE	0.000465	3096 GILBERT	0.351190
	1028 SENGUERD	6			1013 HEEREBOORD	0.097971
	1047 BOERHAAVE	6			1019 KYPER	0.097971
	1061 LIPSTORP	6			1067 SCHUYL	0.097971
4. Co-publication place						
	2017 DESCARTES	19			2017 DESCARTES	0.276951
	2021 DUPLEIX	14			2021 DUPLEIX	0.267178
	2002 ABRA DE RACONIS	13	2017 DESCARTES	0.289916	2002 ABRA DE RACONIS	0.265720
	2003 ABRAHAM DE LA FR.	13	2006 BASSON	0.077311	2003 ABRAHAM DE LA FR.	0.265720

Continued **Table of projected networks' top centrality scores**

	Degree		Betweenness		Eigenvector	
	Author	Score	Author	Score	Author	Score
4. Co-publication place						
Slice 1	2008 BOUJOU	13	1004 BURGERDIJK	0.052941	2008 BOUJOU	0.265720
	2011 CHAMPAIGNAC	13	3096 GILBERT	0.052941	2011 CHAMPAIGNAC	0.265720
	2014 CRASSOT	13	2021 DUPLEIX	0.040336	2014 CRASSOT	0.265720
	2027 FREY	13	3004 BACON	0.010924	2027 FREY	0.265720
	2034 LE ROY	13			2034 LE ROY	0.265720
	2052 SOREL	13			2052 SOREL	0.265720
	3044 WHITE	87	2017 DESCARTES	0.296417	3044 WHITE	0.163875
	2017 DESCARTES	75	3044 WHITE	0.119346	3015 DIGBY	0.159032
	3015 DIGBY	75	1073 VRIES	0.063052	3018 ESPAGNET	0.159032
	3018 ESPAGNET	75	1028 SENGUERD	0.042672	2021 DUPLEIX	0.145555
Slice 2	2021 DUPLEIX	60	3015 DIGBY	0.042592	2017 DESCARTES	0.143690
	2007 BAYLE	51	3018 ESPAGNET	0.042592	2018 DU HAMEL	0.140837
	2018 DU HAMEL	49	2021 DUPLEIX	0.041558	2007 BAYLE	0.140428
	2002 ABRA DE RACONIS	48	3028 LE GRAND	0.036973	2002 ABRA DE RACONIS	0.140245
	2003 ABRAHAM DE LA FR.	48	3096 GILBERT	0.035604	2003 ABRAHAM DE LA FR.	0.140245
	2004 BARBAY	48	1007 DEUSING	0.034850	2004 BARBAY	0.140245
	3044 WHITE	94	2017 DESCARTES	0.224105	3044 WHITE	0.156231
	2017 DESCARTES	83	1012 HARTSOEKER	0.101351	3015 DIGBY	0.148668
	3015 DIGBY	81	3044 WHITE	0.101045	3018 ESPAGNET	0.148668
	3018 ESPAGNET	81	3015 DIGBY	0.043502	2021 DUPLEIX	0.141638
Slice 3	1012 HARTSOEKER	75	3018 ESPAGNET	0.043502	2044 POURCHOT	0.141638
	2021 DUPLEIX	66	1008 GEULINCX	0.033486	2017 DESCARTES	0.140054
	2044 POURCHOT	66	1073 VRIES	0.033486	1012 HARTSOEKER	0.139792
	2007 BAYLE	56	3028 LE GRAND	0.031206	2018 DU HAMEL	0.134171
	2018 DU HAMEL	54	3096 GILBERT	0.030342	2007 BAYLE	0.133811
	2002 ABRA DE RACONIS	53	2006 BASSON	0.029760	2022 DU ROURE	0.133669

*As Layer 3 in general has so few connections, not all the measurements in the slices have a (meaningful) top 10. In case scores could not be calculated (such as Betweenness in Slices 1) or when they were meaningless (such as some Betweenness scores in Slice 2 and 3), values were omitted.

Appendix B

Table of projected networks layer properties and additional measures*

	Nodes	Nodes BCC**	Ties	Ties BCC	Compo-nents	Diame-ter GC	Network density	Density BCC	"Tradition" Assrt.	"Tradition" Assrt. BCC	Degree Assrt.
1. Co-affiliation											
Slice 1	36	16	42	35	17	5	0.066667	0.291667	0.080139	0.121339	0.463926
Slice 2	160	123	862	861	37	7	0.067767	0.114754	0.028613	0.028709	0.646136
Slice 3	175	132	1123	1122	43	7	0.073760	0.129771	0.035031	0.035137	0.547374
2. Co-affiliation place											
Slice 1	36	21	71	67	12	5	0.112698	0.319048	-0.014128	-0.004708	0.529566
Slice 2	160	135	1351	1351	26	5	0.106211	0.149364	0.022183	0.022183	0.414559
Slice 3	175	145	1825	1825	31	5	0.119869	0.174808	0.026044	0.026044	0.170386
3. Co-publisher											
Slice 1	36	3	4	3	33	1	0.006349	1.000000	-0.142857	-0.500000	1.000000
Slice 2	160	14	95	32	108	3	0.007469	0.351648	0.015107	-0.174781	0.108104
Slice 3	175	14	107	32	118	3	0.007028	0.351648	0.009027	-0.174781	0.182325
4. Co-publication place											
Slice 1	36	26	115	114	10	4	0.182540	0.350769	-0.065461	-0.060822	0.510787
Slice 2	160	139	1973	1970	19	5	0.155110	0.205401	0.023061	0.022832	0.506951
Slice 3	175	153	2381	2378	20	5	0.156388	0.204506	0.020731	0.020569	0.504742

*Large numbers are rounded to six decimal places.
**BCC = Biggest connected component, referring to the largest connected component in the networks.