Advances in Complex Systems
Vol. 25, No. 4 (2022) 2240010 (20 pages)

DOI: 10.1142/S0219525922400100

World Scientific
www.worldscientific.com

# MAPPING THE NETWORKED CONTEXT OF COPERNICUS, MICHELANGELO, AND DELLA MIRANDOLA IN WIKIPEDIA

LUIS A. MICCIO[*,†], CARLOS GÁMEZ-PÉREZ[‡,§], JUAN LUIS SUÁREZ[¶,**] and GUSTAVO A. SCHWARTZ[*,‖]

[*]*Donostia International Physics Center, P. M. de Lardizábal 4, 20018 San Sebastián, Spain*

[†]*Institute of Materials Science and Technology (INTEMA), National Research Council (CONICET), Colón 10850, 7600 Mar del Plata, Buenos Aires, Argentina*

[‡]*Departament d'Educació Lingüística i Literària, i Didàctica de les Ciències Experimentals i de la Matemàtica, Universitat de Barcelona, 08035 Barcelona, Spain*

[§]*Càtedra Dr. Bofill de Ciències i Humanitats, Universitat de Girona, 17002 Girona, Spain*

[¶]*CulturePlex Lab, Western University, London, Ontario N6A 3K7, Canada*

[‖]*Centro de Física de Materiales (CSIC-UPV/EHU) — Materials Physics Center (MPC), P. M. de Lardizábal 5 20018 San Sebastián, Spain*

[**]*jsuarez@uwo.ca*

Received 11 March 2022
Revised 1 September 2022
Accepted 30 September 2022
Published

To discern the role social and cultural networks play in the emergence of preeminent historical figures and ideas in History, we use a method based on complex networks analysis to reveal emergent interactions in Wikipedia. We built a network constituted by derivative links, where nodes are connected if they are co-linked by other papers or co-link other papers within Wikipedia. We apply this method, focused on the structural distance, to three significant individuals associated with the Italian Renaissance: Copernicus, Michelangelo, and Pico della Mirandola. The results point to the effectiveness of this approach for discovering new knowledge about the interdisciplinary transactions between people and ideas coming from artistic, scientific and philosophical domains during this period. The emergent network reflects the apparently strong network-level interactions between Michelangelo and Mirandola's clusters; the importance of Hermeticism across the three clusters; and how the so-called "knowledge dealers" related to Neoplatonism contribute to the depiction of the period by future historians.

[**] Corresponding author.

Finally, we advance the notion of "focus reading", in which complex networks analysis allows us to build bridges between close and distant forms of reading historical evidence.

*Keywords*: Cultural analytics; Michelangelo; Copernicus; Mirandola; renaissance; art-science-philosophy; complex networks.

## 1. Introduction

For a long time, the study of preeminent historical figures, especially in art, science, and other highly creative occupations, was performed in the Western tradition through an individualistic lens, mostly based on the idea of singular "geniuses" [28]. However, this approach lacked the tools and concepts to take advantage of the relevance of the networks of relationships that range from child development to social dynamics and include personality, humor, interpersonal relationships, the social environment, chance, and the collective imaginary. As Sal Restivo remarks [24], around any "genius" there is always a network (composed of people, objects, and ideas) in which his/her work is born and develops. Understanding this network and its characteristics is crucial for a better comprehension of the big paradigm shifts through History. This knowledge is particularly relevant when analyzing transcendent moments like the Renaissance or the Enlightenment, which show simultaneous and sudden paradigm shifts in art, science, music, philosophy, and other disciplines [39]. The emergent processes driving these cultural transformations arise from interactions among a large number of elements (either people, objects, or ideas). To unveil and characterize these processes, the tools of complex networks theory have shown to be a suitable and powerful option addressing different cultural problems [1, 7, 10, 29, 30].

In this work, we take advantage of a recently published method that uses complex networks analysis to reveal and analyze the interactions among people, works and ideas in Wikipedia [30]. Our main goal is to study these interconnections between three relevant individuals from the Italian Renaissance belonging to different disciplines (science, art, and philosophy). For this purpose, we have mined Wikipedia to generate a graph that represents the cultural universes of Copernicus (1473–1543), Michelangelo (1475–1564), and Giovanni Pico della Mirandola (1463–1494), as covered by Wikipedia. We have selected these three seeds for our exploration because they have been recognized as essential figures in their disciplines (historical relevance), their corresponding Wikipedia entries have enough links (statistical relevance) and they can help us to understand the background information available to them and their disciplines (purpose relevance). The result is a cultural network linking these three characters (and part of the corresponding disciplines) through the dense network of links connecting the Wikipedia papers related to the seeds. Hence, this emerging cultural network becomes the exploration object we analyze to explain and reconcile the existing Wikipedia knowledge about Copernicus, Michelangelo, and Pico della Mirandola and the connections between their respective disciplines.

The exploration of this emerging cultural network follows two steps. First, by looking into the resulting graph's structural, relational, and global properties, we can analyze the structure of the clusters surrounding each of our three personalities and determine how they are connected. This network analysis gives us a privileged position to explain the context that gave rise to each of these outstanding figures by identifying and examining the historical characters, places and doctrines alive at the moment of their irruption on the scene of the Italian Renaissance. Second, by identifying and analyzing the so-called "knowledge dealers" (nodes that are the most relevant contributors in connecting other nodes from *different* clusters), we can identify the important players in this cultural network. Since these knowledge dealers belong to different historical moments, we can peel away the layers of historical knowledge impressed upon Copernicus, Michelangelo, and Pico della Mirandola as a function of the lenses used by historians and researchers in later decades and centuries to explain the relevance and importance of these characters to their own contemporary scientific, artistic and philosophical debates.

We call "focus reading" to the combined use of these two exploratory tools within the framework provided by the transformation of Wikipedia information into a dataset to be analyzed as a network as described in the Methods section. Focus reading provides a mapping of the context in which knowledge has been constructed. This context would be understood as "the set of possible worlds, representing the background information available to the participants" [26] in a cultural dialogue, that is, to readers and writers of Wikipedia and, to a certain extent, to the sources Wikipedia employed.

## 2. Methods

### 2.1. *Dataset: Description, limitations, and validation*

We used the publicly available online access to Wikipedia to extract the network of internal links (those intentionally added in the main text) for selected papers (hereafter called *seeds*). For the present work, the seeds were "Michelangelo", "Nicolaus Copernicus" and "Giovanni Pico della Mirandola". Starting from these entries, we defined a directed graph from the internal links for the first and second nearest neighbors (papers) to each seed. Specifically, this work was performed with data extracted from Wikipedia between October and November 2021. From this obtained network, we iteratively removed poorly linked Wikipedia pages (poorly linked is defined as having zero in or outdegree that correspond to pages with no relevant information for this work). Thus, based on these seeds and procedures, we obtained a directed graph (hereafter called *universe*) containing 55,915 nodes (Wikipedia's papers) and 1,789,366 edges (links among them).

Wikipedia is the product of contemporary interests, goals, and biases. The historical distance between the period studied in this work and our own time implies that the network of relations we study is mediated in many ways, including: the

structure of the Wikipedia data; the sources used by Wikipedia authors and editors; and, their very human condition. It is important to note here that Wikipedia has many of the biases (genre, gender, race, etc.) we observe operating in other structures of our society [35, 36] and therefore the results could be shaped by this bias. Other possibilities and limitations about the use of Wikipedia for scientific purposes have been expressed by [4, 9, 41, 42] and might also have effects on the data we use. Thus, in order to minimize some of these limitations while maximizing the affordances of utilizing this crowd-sourced encyclopedia, we do not consider single links to be meaningful in the context of this study. Instead, we focus on the structural distance between elements to be considered meaningful. It is important to note that this metric avoids consideration of non-important links in the network. Critically, structural distance requires any links to be mediated through a third element, requiring at least two independent links to be considered meaningful. Moreover, the structural relatedness (and therefore meaningfulness) grows with the increasing amount of co-linked elements. Therefore, the relatedness (or the structural distance) between two elements is a property of the network and hardly depends on a single direct link.

### 2.2. *Relatedness between nodes*

From the so obtained universe, we worked with the $N$ most related nodes to each given seed, based on an appropriated metric. It is worth emphasizing that two papers can be strongly related even if there is no direct link between them since they can be co-linked by other papers or co-link other papers. In these cases, the two nodes are structurally related and we can measure the relatedness between them using the normalized Google distance (NGD) [3], which provides excellent results for our purpose [30]. NGD is defined as

$$d_{\text{in/out}}(a,b) = \frac{\log(\max(|A|,|B|)) - \log(|A \cap B|)}{\log(|W|) - \log(\min(|A|,|B|))}, \tag{1}$$

where $a$ and $b$ refer to the corresponding papers, $A$ and $B$ represent the sets of nodes (or papers) that link to/from ($d_{\text{in/out}}$) $a$ and $b$, respectively, $W$ being the total number of nodes in the graph. Log refers to the base two logarithms, whereas $|X|$ represents the number of nodes in $X$. When $|A \cap B| = 0$, the corresponding distance is considered infinite. We can define two different distances between nodes $a$ and $b$: one for nodes that *link to* $a$ and $b$ ($d_{\text{in}}(a,b)$) (co-citation) and another for nodes that are *linked from* $a$ and $b$ ($d_{\text{out}}(a,b)$) (bibliographic coupling). The total distance ($d(a,b)$) was taken as the harmonic mean between the in/out distances, whereas the relatedness between nodes $a$ and $b$ was defined as $r(a,b) = \exp(-d(a,b))$ in the range [0,1].

Based on this definition, we determined the $N_j$ (outdegree of seed $j$) most related nodes to each seed and then calculated the relatedness matrix ($R$) among all the so obtained nodes. This matrix was then used to create an undirected weighted graph ($g$) representing the different elements' relationships. The weight of the link

connecting nodes $(i, j)$ was given by the corresponding element in the relatedness matrix $(R_{i,j})$. Finally, we manually removed a few nodes (nine in our case) that have little historic significance and add noise to the analysis (i.e. "Outline of the Renaissance" or "Index of Renaissance papers"). Graph $g$ contained 729 nodes and 82,031 edges.

### 2.3. *Data clusterization and visualization*

Nodes were assigned to different clusters according to what seed they were originally linked to. When a node was connected to more than one seed, it was assigned to the seed it was more related to. The obtained graph (with the identified clusters) was plotted using a force-directed layout that uses attractive forces between adjacent nodes and repulsive forces between distant nodes [8].

### 2.4. *Quantitative characterization*

Figure 1 shows a 2D visualization of the graph $g$, which is in fact a multi-dimensional entity. Although this representation is useful for qualitative analysis, complex networks analysis also allows quantitative characterization of the structure and the interactions of nodes and clusters in the network through different metrics.

### 2.5. *Assortative mixing*

A well-known phenomenon in social networks is the preference for nodes of one type to link other nodes of the same type; this behavior is called *assortative mixing* or *homophily*. Newman [20] defines an assortativity matrix $A$, where the elements $a_{i,j}$ represent the sum of the weighted links in the network connecting nodes from clusters $i$ and $j$. The corresponding normalized matrix is defined as $A_N = A/\|A\|$, where $\|A\|$ represents the sum of all the elements in $A$. Thus, the elements of $A_N$ measure the fraction of links connecting clusters $i$ and $j$. In addition, Newman defines the assortativity coefficient as

$$a = \frac{\mathrm{Tr}(A_N) - \|A_N^2\|}{1 - \|A_N^2\|}, \tag{2}$$

where Tr is the trace of the matrix. Note that $a$ is zero for a randomly mixed network and one for a perfectly assortative network.

### 2.6. *Modularity*

The modularity $Q$, is defined as [11]

$$Q = \frac{1}{W} \sum_C \left( W_c - \frac{S_c^2}{4W} \right), \tag{3}$$

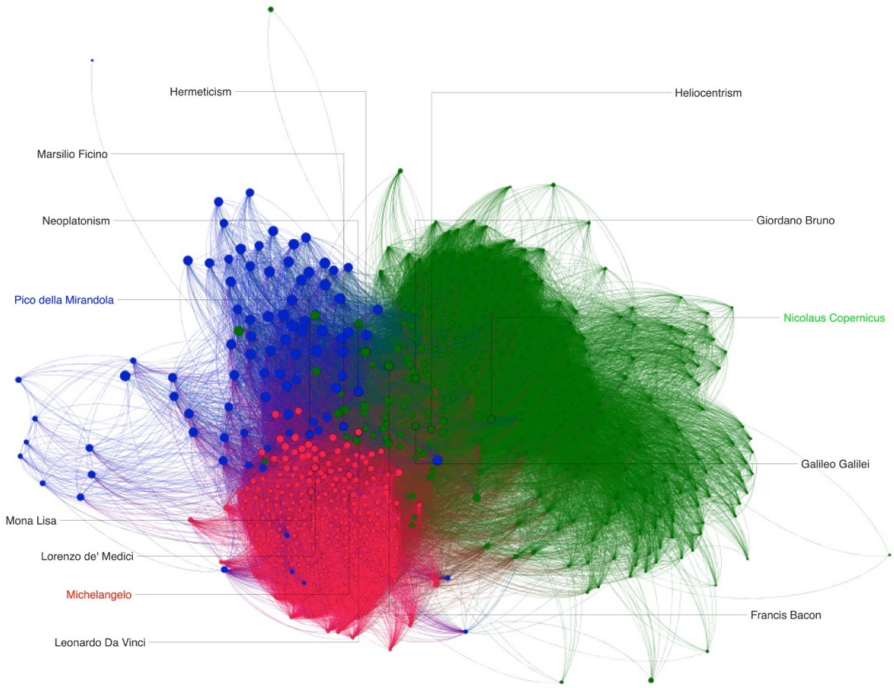


Fig. 1. (Color online) Map of the relationships among Copernicus, Michelangelo and Pico della Mirandola related clusters. Each dot represents a paper from Wikipedia (related to a person, a concept or an artistic/scientific/philosophical work). Thin lines represent links between different elements whereas their relative distance is inversely proportional to their relatedness according to the NGD (see Methods). The size of the nodes is proportional to their Stirling coefficient. Colors represent different clusters (disciplines) composed by the most related nodes to the given seeds: Copernicus (green), Michelangelo (red), and Mirandola (blue).

where the sum runs over all the clusters in the network, $W$ is the total weight of all links, $W_c$ is the total weight of internal links for each cluster $c$ and $S_c$ is the total weight (both internal and external) of all nodes in $c$. It is important to mention here that the maximum value of modularity for a given network has a non-trivial value that is given by

$$Q_{\text{Max}} = 1 - \sum_{C} \frac{S_c^2}{4W^2}. \tag{4}$$

For the general case, modularity is always minor or equal to one; in our particular case, $Q_{\text{Max}} = 0.88$.

### 2.7. *Weak and strong communities*

For a given network, we say that a community (cluster) is *strong* if the internal degree of each node (in such a community) is greater than its external degree. On the

other hand, if the *sum* of the internal degrees of the nodes exceeds the *sum* of their external degrees, the community is *weak* [6]. Therefore, a strong community is always a weak community, whereas the converse is not true.

### 2.8. *Openness*

Percentage of nodes for which the external degree is greater than its internal degree.

### 2.9. *Average degree*

This parameter is calculated for each cluster as the corresponding diagonal element of the normalized assortativity matrix (sum of the internal links for each cluster) divided by the number of nodes of the corresponding cluster.

### 2.10. *Stirling coefficient*

Provides an equilibrated way of measuring the variety, balance and disparity of individual nodes and is defined as [33]

$$D = \sum_{ij(i \neq j)} d_{ij} p_i p_j, \tag{5}$$

where $d_{ij}$ is the distance between clusters $i$ and $j$, and $p_i$ and $p_j$ are the fraction of the total degree (for the given node) that links the node to clusters $i$ and $j$, respectively. The sum runs across non-identical pairs of clusters ($i \neq j$).

### 2.11. *Participation coefficient*

Proposes a complementary way of measuring the interaction of a given node with different clusters and is defined as [12]

$$p(i) = 1 - \sum_{c} \left[ \frac{k_c^i}{\sum_c k_c^i} \right]^2, \tag{6}$$

where $k_c^i$ is the weighted sum of links of node $i$ to other nodes in the cluster $c$ and $\sum_c k_c^i$ is the total weighted degree of node $i$. The sum runs across all clusters in the graph. Therefore, the participation coefficient of a given node will be close to 1 if its links are uniformly distributed among all clusters and 0 if all its links are within its own cluster.

## 3. Results

Figure 1 shows a network representing the co-linkage interactions among Michelangelo, Copernicus, and Pico della Mirandola in the Italian Renaissance in Wikipedia. Colors indicate which cluster each node belongs to, whereas clusters account for the different domains: art, science, and philosophy. At a glance, we can

observe differences in the size, shape and density among clusters. The artistic domain (red), related to Michelangelo, is a rather close (0.69 in diameter and 0% openness) and densely connected (link's density of 0.56) cluster. On the other hand, philosophy-related nodes (blue) show a higher dispersion (diameter of 1.01) and a lower density of connections (0.02). The scientific cluster (green), composed by those nodes related to Copernicus, shows somehow intermediate link's density (0.28). Table 1 shows the structural characteristics of each cluster.

From a qualitative point of view, Fig. 1 shows that the algorithm accurately locates representative elements (either people, concepts, or works) on their appropriate relative position. Thus, Galileo Galilei, Copernicus, and Heliocentrism share connections in the science cluster (green) that interestingly enough also has "Hermeticism" as one of its nodes. The dense cluster of the arts includes patrons like Lorenzo de Medici, works like the Mona Lisa and artists like Da Vinci and Michelangelo. The more disperse philosophy cluster brings together Neoplatonism, Marsilio Ficino, and Mirandola, among others.

Figure 2 shows a visual representation of a subgraph of $g$ that accounts for those nodes with the highest participation coefficients ($p(i) > 0.40$). This graph enhances the interactions among nodes at the boundaries between disciplines. We can observe, attending to the size of the nodes (proportional to their Stirling coefficient) that the cluster of Mirandola (blue) is overrepresented, indicating its strong interaction with artistic and scientific ideas at that time. Thus, we find there Hermes Trismegistus, white magic, and microcosm–macrocosm analogy as some of the most outstanding nodes.

Table 1. Structural, relational, and global properties of the network.

| Property | | Cluster (seed name) | | |
|---|---|---|---|---|
| | | Michelangelo | Copernicus | Mirandola |
| Structural | Size (# nodes) | 255 | 384 | 90 |
| | Diameter[a] | 0.69 | 1.54 | 1.01 |
| | Nodes' density[b] | 370 | 250 | 89 |
| | Links' density[b] | 0.56 | 0.28 | 0.02 |
| Relational | Community[c] | Strong | Weak | Weak |
| | Openness[c] (%) | 0 | 6.5 | 62.2 |
| | Average degree[c] | 1.50 | 0.48 | 2.11 |
| Global | Modularity[d] | 0.68 (0.88) [77%] | | |
| | Assortativity coefficient[d] | 0.71 | | |

*Notes*: [a]Diameter is defined as the average shortest pathlength. Note that for this network, the diameter is not topological/discrete, but based on a continuous measure (weight of links) and therefore it is not necessarily an integer.
[b]Densities are calculated dividing the number of nodes or the weighted sum of links by the diameter.
[c]Weak or strong communities, openness and average degree are defined as specified in the Methods section.
[d]For modularity, the actual value, the maximum expected value and the percentage with respect to this maximum are shown. The maximum value for the assortativity coefficient is one. Unless specified, all quantities are in arbitrary units.

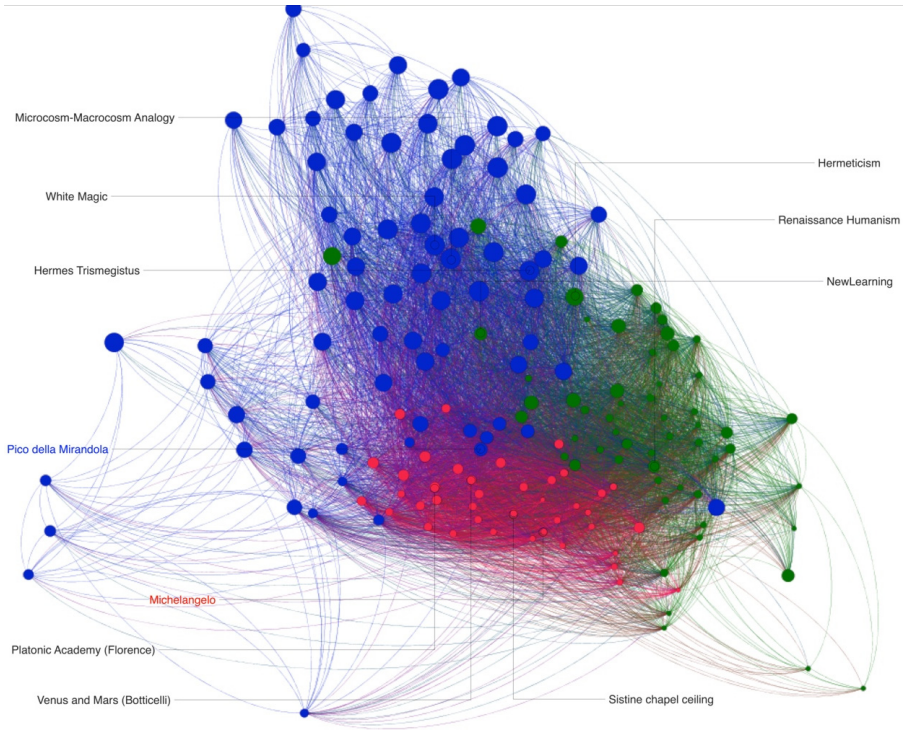


Fig. 2. (Color online) A subgraph of Fig. 1 showing the most relevant elements (people, concepts or works) for the relationships among Copernicus, Michelangelo and Pico della Mirandola related clusters in the Italian Renaissance. Only those nodes with participation coefficient higher than 0.4 are represented. The size of the nodes is proportional to their Stirling coefficient. Colors represent different clusters (disciplines) containing science- (green), art- (red), and philosophy- (blue) related elements.

It is also significant to observe that the nodes Hermeticism, Renaissance Humanism and New Learning belong to Copernicus' cluster (green), related to the scientific thinking of those years.

Figures 1 and 2 show that, when compared to historical accounts of the period and each respective discipline, the cultural network created around the figures of Michelangelo, Copernicus and Mirandola correctly establishes the relative position of and the interactions among the most relevant elements (people, concepts or works) in the period. Now we can move one step further and use complex networks tools to quantitatively analyze the structural characteristics of the network. Thus, we can extract meaningful information from the structure of the network analyzing its global metrics (modularity and assortativity), the cluster's characteristics and their interactions, and the connectivity of individual nodes.

Table 1 shows the most relevant structural, relational, and global properties of the graph $g$. From a global perspective, we observe that the assortativity coefficient is 0.71, which means that besides the observed clusterization, there is an important

number of links connecting nodes among different clusters. Furthermore, since the three seeds selected for this work belong into three different disciplines, we can talk in this mapping of an interdisciplinary transaction among elements from art, science and philosophy. In fact, the out of diagonal coefficients of the normalized assortativity matrix (see Table 2) show that 5.6% of the total links in the graph are connections between Copernicus' and Michelangelo's clusters. The same strength of interaction is observed for the clusters related to Copernicus and Mirandola. But the strongest interaction arises between Michelangelo and Mirandola related elements, with about 13% of the total links.

Modularity is also useful to quantify the partition of the network. In this case, we obtain a modularity of 0.68 (being 0.88 the maximum possible value for $Q$). This means that the observed modularity is around 77% of the expected maximum, which is in agreement with the relatively high observed homophily (assortativity).

Considering the cluster characterization, Michelangelo's cluster represents a strong community (see Methods) in agreement with its zero-openness coefficient. This means that none of the elements of this cluster has more connections with other clusters (external degree) than with its own cluster (internal degree). On the contrary, the science- and philosophy-related clusters (Copernicus and Mirandola) are weak communities with openness coefficients of 6.5% and 62%, respectively. In particular, Mirandola's cluster has (by far) the smallest nodes and links' density, as well as the largest diameter and average degree. As shown, each cluster presents its own features which can be related with the corresponding discipline and the characteristics in the period. We will discuss this in detail below.

From a qualitative point of view, we can see there are certain elements (either people, concepts or works) that significantly contribute to weave the network by connecting with nodes from different clusters. These particular nodes constitute the so-called *knowledge dealers*, since they are responsible for circulating ideas and concepts between different knowledge disciplines. Quantitatively, these nodes can be identified using the Stirling coefficient, which has been effectively employed to analyze diversity in science, technology and society [16]. Table 3 shows the top twenty-five nodes, according to the Stirling coefficient, for each cluster. We classified these knowledge dealers according to their historical moment with respect to the

Table 2. Normalized assortativity matrix.[a]

| | | |
|---|---|---|
| 0.383 | 0.056 | 0.130 |
| 0 | 0.184 | 0.058 |
| 0 | 0 | 0.190 |

*Notes*: [a]The elements of the normalized assortativity matrix ($a_{i,j}$) indicated the fraction of weighted links that connect nodes between clusters $i$ and $j$. Only the upper triangular matrix is defined.

Table 3. Stirling ranking for nodes on each cluster.[a]

| Cluster (seed name) | | |
|---|---|---|
| Michelangelo | Copernicus | Mirandola |
| Aldus Manutius | Publio Fausto Andrelini | Johannes Trithemius |
| Francesco Cattani da Diacceto | Hermeticism | **Theurgy** |
| Oration on the Dignity of Man | Humanism in France | Henosis |
| Giovanni di Bardo Corsi | François Rabelais | Meister Eckhart |
| Coluccio Salutati | New Learning | Pseudo-Aristotle |
| **Cosimo de' Medici** | Francis Bacon | Heinrich Cornelius Agrippa |
| Platonic Academy (Florence) | Renaissance Philosophy | *Angelus Silesius* |
| Leonardo da Vinci | Hermetica | Porphyry (philosopher) |
| Cristoforo Landino | Bessarion | White Magic |
| Giovanni Cavalcanti (poet) | *Frances Yates* | **Microcosm–Macrocosm Analogy** |
| Venus and Mars (Botticelli) | Renaissance Humanism | **Ammonius Saccas** |
| Terribilità | *Bibliotheca Philosophica Hermetica* | **Hermes Trismegistus** |
| Niccolò Machiavelli | Franciscus Patricius | **Chaldean Oracles** |
| Leonardo Bruni | Lorenzo Valla | *Giordano Bruno and the hermetic tradition* |
| Girolamo Savonarola | Tommaso Campanella | *René Guénon* |
| Renaissance Humanism in Northern Europe | Giordano Bruno | de vita libri tres |
| John Argyropoulos | Laurentius Corvinus | *Marcello Malpighi* |
| Gentile de' Becchi | John Dee | **Iamblichus** |
| Francesco Guicciardini | Nicholas of Cusa | Perennial philosophy |
| Villa Medici at Careggi | **Albertus Magnus** | *Antoine Faivre* |
| Leon Battista Alberti | Italian Renaissance | Paracelsus |
| Lorenzo de' Medici | History of Philosophy in Poland | Christian Kabbalah |
| Poggio Bracciolini | *Roman Ingarden* | *Paul Oskar Kristeller* |
| Poliziano | *Continuity thesis* | Three books of occult philosophy |
| Raphael | **Renaissance of the 12th-Century** | **Asclepigenia** |

*Notes*: [a]Top 25 elements for each cluster according to the Stirling coefficient. Items in italics correspond to *future* elements; those that appears after the period of time here considered. On the contrary, items in bold represent those elements that existed before the period of time under consideration. Normal font refers to elements in the period we are considering in this work, 1463–1564, the century covering from Mirandola's birth (eldest of the three) to Michelangelo's death (latest to die).

period analyzed in this work. *Future* and *past* nodes refer to elements that only existed after or already pre-existed in our time window, respectively.

We observe that there are few *future* nodes in Table 3, none of them in the cluster associated to Michelangelo. In this cluster, there is a first group of nodes related to the arts: Leonardo da Vinci (1452–1519), the artistic concept of *terribilità*, Botticelli's *Venus and Mars*, the architect, artist and polymath Leon Battista Alberti (1404–1472), the poets Giovanni Cavalcanti (1444–1509) and Poliziano (1454–1494), to whom Mirandola will dedicate his *On Being and the One* [37]. A second group of knowledge dealers is directly related to politics through the Medici family: Cosimo de' Medici (1434–1464), Lorenzo de' Medici (1469–1492), to whom Salviati,

the editor of Mirandola's *Heptaplus* will dedicate the work, Vila Medici at Careggi [37]. We also find Coluccio Salutati (1331–1403) and Giovanni di Bardo Corsi (1472–1547), two Florentine politicians, Girolamo Savonarola (1452–1498), Francesco Guicciardini (1483–1540), and Niccolò Machiavelli (1469–1527). Another important non-negligible group of knowledge dealers could be tagged as belonging to the philosophical movement of Renaissance "Neoplatonism". Francesco Cattani da Diacceto (1466–1522) was a well-known Florentine Neoplatonist whereas the Platonic Academy at Florence, where Ficino taught, was the most important place of this school of thought in the city. Cristoforo Landino (1424–1498) and Gentile de' Becchi (1420/1430–1497) were professors at this Academy. It is worth mentioning the appearance on the list of Aldus Manutius (1449/1452–1515), the most prominent publisher of the period. Finally, we have Mirandola's *On the Dignity of Man*, whose initial words borrow from the hermetic tradition and exemplify the role Neoplatonism play in shaping up the cultural context from which our three characters emerge.

Mirandola's cluster presents the largest number (six) of knowledge dealers belonging to the future category[a], closely followed by Copernicus' cluster[b] (four). These nodes are related to the traditions of mystery religions that Mirandola syncretizes in his work [55], which connects Neoplatonism and Hermeticism with cabbala studies (white magic and Christian kabbalah) that circulated widely in Europe (Paracelsus, Agrippa) for several centuries, and reached to Victorian England (especially with William Blake's illuminism) and 19th-Century France. This tradition was very influential for scholars such as Antoine Faivre or Frances Yates in the 20th-Century. The relationship with Hermeticism is very transversal as reflected by the fact that the node "Hermeticism" belongs to the Copernicus' cluster. Mirandola's cluster also includes an important number of *past* nodes, most of them related to Neoplatonic concepts. In this category, we have "theurgy", "henosis", or "microcosm–macrocosm analogy"; a set of spiritual and philosophical ancient texts, like the "Chaldean Oracles"; and different ancient philosophers from the Neoplatonic tradition, such as Ammonius Saccas (175–242), Iamblichus (245–325), Asclepigenia (430–485), and Hermes Trismegistus[c] [40]. All the other nodes are related to "contemporary" Neoplatonism.

[a] Angelus Silesius (1624–1677), a Polish poet and mystic of the 17th-Century; Marcello Malpighi (1628–1694), founder of histology; René Guénon (1886–1951), a 20th-Century French philosopher very much interest in Hermeticism; Antoine Faivre (1934), a contemporary scholar on esoterism; Paul Oskar Kristeller (1905–1999), a German philosopher specialized in early modern humanism; and Frances Yates' book, *Giordano Bruno and the hermetic tradition* (1964).

[b] Frances Yates (1899–1981), a prestigious historian specialized on esotericism during the Renaissance; Roman Ingarden (1893–1970), a phenomenologist who studied Polish aesthetics; the Bibliotheca Philosophica Hermetica, founded in 1957; and the "Continuity thesis", a historical hypothesis which denies the epistemological discontinuity between the European Middle Ages and the early modern period.

[c] According to Frances A. Yates, "the dating by Isaac Casaubon in 1614 of the Hermetic writings as not the work of a very ancient Egyptian priest but written in post-Christian times, is a watershed separating the Renaissance from the modern world. It shattered at one blow the build-up of Renaissance Neoplatonism with its basis in the *prisci theologi* of whom Hermes Trismegistus was the chief. It shattered the whole position of the Renaissance Magus and Renaissance magic with its Hermetic-cabalist foundation, based on the ancient 'Egyptian' philosophy and Cabalism."

We performed the same analysis using Marsilio Ficino as a seed instead of Mirandola, since Ficino is the other great Neoplatonic philosopher of the Renaissance, and the results were very similar to those found when Mirandola is the chosen seed for Philosophy. This test confirmed the role of Neoplatonism rather than that of the individual philosophers in the transactions across disciplines. We chose Mirandola because his biography makes him more of a contemporary with Copernicus and Michelangelo than Ficino. However, the focus of the analysis is on the resulting clusters of disciplines and their interactions rather than on the three seeds. In our method, individuals have a meaningful role when it comes to analyzing which individuals have the highest Stirling ranking, that is, which of them are better positioned as "knowledge dealers" in the network. According to the data, Asclepigenia (4th-Century) was more relevant for the exchange of knowledge among art, science and philosophy than Copernicus, Michelangelo or Pico della Mirandola. This is why we state that some elements related to Mirandola's cluster (those associated with Hermeticism and Neoplatonism) are central from the point of view of the exchange of knowledge between disciplines (higher Stirling coefficient).

In the case of Copernicus's cluster, we notice an important group of Renaissance humanists and poets, most of them contemporaries of Copernicus. The list highlights Giordano Bruno (1548–1600), Francis Bacon (1561–1626), two of the first disseminators of heliocentrism in Europe, and François Rabelais (1483/1494–1553), a main figure of French humanism, which seems very much connected with Copernicus, at least in the Wikipedia ("Humanism in France" is another of his knowledge dealers). However, for the rest of the names, none of them were the most prominent in their field, although they were connected with the most prominent scholars of the period. For instance, Publio Fausto Andrelini (1462–1518), an Italian poet and humanist, close friend of Erasmus of Rotterdam, who studied at the University of Bologna, like Copernicus, and taught poetry at the University of Paris. The list contains other important precursors of Humanism and Renaissance Neoplatonism. It also extends to Albertus Magnus (1200–1280), one of the most recognized commentators of Aristotle in the Middle Ages, but known in the Renaissance also as a mystic and alchemist for a series of alchemic books falsely attributed to him to increase the prestige of these texts[d] [15].

## 4. Discussion

From a global network perspective, we can say that Mirandola's cluster provides the key to this emerging cultural network of the Italian Renaissance as represented by our three seeds and this suggests that Copernicus and his work share points of contact with the Neoplatonists.

[d]In response to Ermolao Barbaro's critcism of Thomas Aquinas and Albertus Magnus on the account of their "unsophisticated and inelegant Latin", Pico took the view that "what matter in philosophy was not words but reason, not style but substance."

Mirandola's cluster is made up by the connections with Florence and its Platonic Academy of Florence, and by the intellectual context created by and surrounding Neoplatonism, Pico's own biography (for instance, Lorenzo de Medici's intervention on his behalf and his escape to Florence to avoid Pope Innocent VIII commission to investigate the orthodoxy in his 900 theses) illustrates the nexus that Florence and Neoplatonism formed in the period of time covered by our study [5]. Also, Mirandola's cluster reflects an interesting phenomenon. A great deal of the success and impact of Neoplatonism in this time is related to Mirandola's (and Ficino's) ability to synthesize and syncretize various appearances of Neoplatonic thought and testimonies across different cultural formations [5]. The construction of the knowledge within this cluster also shows that some historians have mostly embarked on a task analogous to that of Mirandola with his own Neoplatonic sources, but now to decipher Mirandola's thought and its connections to past and contemporary Neoplatonism. The sub-theme of Neoplatonism that jumps out of Copernicus' and Michelangelo's clusters is Hermeticism, that is, the role that the doctrines attributed to Hermes Trismegistus played in the construction of the Neoplatonic corpus as it was understood in the context of the Platonic Academy of Florence. This theme of Hermeticism[e] [31] is prevalent in Mirandola's cluster, but we also saw it emerges in the science cluster and it actually provides a common thread throughout the three clusters.

To understand Copernicus' cluster, it is very important to consider the effect of posterior elaborations of the history of science, as conveyed by the *future nodes* in this cluster. The debates about the posterior impact of the theory of Heliocentrism, on the one hand, and about the description of his scientific method as disruptive or continuous with respect to medieval science, on the other, are crucial to understanding the main elements in Copernicus' cluster. Here, we find the discussion continuity/rupture around the scientific revolution, engaged by continuity historians of science such as Pierre Duhem (1861–1916) and George Sarton (1884–1956), and scholars such as Gaston Bachelard (1884–1962), defenders of an epistemic revolution.

Our analysis shows that, as stated by various renowned historians of science [14, 16, 17, 22, 23, 32, 38, 39], there exist important resonances of Neoplatonism in Copernicus' new models. We advance that there are various ideas playing at the same time in Copernicus' cluster and its relationship to Neoplatonism. First of all, the understanding by Copernicus of the Universe as a system with symmetry and correlation, as mentioned by Mirandola, among its parts, and noted in Copernicus' *De Revolutionis Orbium Coelestium* [22]. Second of all, the adoption of the Neoplatonic symbolic image of the Sun-God as the center of the universe. Finally, the reliance of his theory on a "method" similar to that of Neoplatonism (syncretism,

[e]It is attributed to Marsilio Ficino the theory of a relation between Hermes Trismegistus and Greek philosophers. This view was based on the wrong fact that "the author of the Hermetica was a man who lived in the time of Moses" what made Ficino believe that "Plato had derived his theology, through Pythagoras, from Trismegistus."

critical review of old data, and the collection and reconciliation of tables of previous measurements to harmonize them [23]), that Mirandola uses to explain the variations of the equinoxes based on mathematics and the authority of Pythagoras (Plato's teacher according to the reconstruction by Neoplatonism). All this in a context that Whitehead has described as a "historical revolt" and "anti-rationalistic, because the rationalism of the scholastics required a sharp correction by contact with brute fact [39]."

*The Copernican Revolution* [16] introduces Copernicus as a participant in the Neoplatonic tradition. According to Thomas Kuhn, Neoplatonism is one of the main elements in the scientific revolution produced by Copernicus. There are also mentions of the identification of the Sun as God by Marsilio Ficino and how it affected Copernicus, and of the aesthetic character of Copernicus' work, elements highlighted by Kuhn and other scholars [32]. Moreover, the adoption of the symbolic image of the Sun-God as the center as a platonic representation of the universe, common in Neoplatonic circles and in different artistic works is developed by Hutchison [14]. This symbolic image, deeply developed by Mirandola [14], is strongly related to the concepts of symmetry, correlation among the parts, and syncretism. All of them are present in Copernicus theories, although he considered this the representation of the empyrean universe, supported by technical and astronomic measurements, and not of a symbolic one. Westman points out the humanistic "appeal to Pythagorean authority" [38] in his theory. And there exists bibliography showing Copernican astronomy as part of a social puzzle, some of whose pieces are a calendar reform, academic criticism of Aristotle, and "the rise of Renaissance Neoplatonism" [17], and analyzing the relationships between (Neoplatonic) magic and early modern science [13].

Our network analysis has shown a highly interdisciplinary context in which connections across different domains of knowledge creation are key to our understanding of that context. When faced with these types of contexts, scholars interested in interdisciplinary interactions had to perform a comprehensive bibliographic research, select a limited number of what they consider the most relevant books or journals, and carefully read them in what is known as a *close reading*. In contrast to this, at the beginning of the 21st-Century, scholar Franco Moretti proposed the concept of *distant reading*, a methodology based on the use of large-scale data [18, 19] nowadays known as computational studies of texts [11]. Beyond the intense debate between distant and close reading [34], we suggest that both approaches are complementary, in agreement with other scholars [2]. However, the problem is that the *close reading* hardly sees the big picture whereas the *distant reading* misses the details. The method proposed in this work is based on combining both perspectives. This leads us to what we call *focus reading*, which combines the use of complex networks analysis to find the most relevant works, people and ideas (among millions of them) with the corresponding close reading of the selected works. By adopting this method, using a proper combination of analytical and hermeneutic tools, we can

focus on both the broader view and the details of the interactions among art, science and philosophy.

A focus reading of Copernicus' cluster supports the general hypothesis, developed by historians of science, that puts Copernicus' methods in contact with the Neoplatonic tradition. Nodes with the highest Stirling coefficients in Copernicus' cluster provide us with some clues. The largest group of nodes on the list of Stirling coefficients is that formed by Renaissance humanists and Neoplatonic philosophers. Thus, in the network resulting from Wikipedia's depiction of the cultural context of the period of study, Copernicus is represented as part of the network of Neoplatonic humanists and poets, sharing studies, universities and interests with them. This is a network not only formed by the most prominent thinkers of Neoplatonism, but by many of the followers of the prominent figures. This depiction is reinforced by the entries of the list related to concepts or categories, such as "Hermeticism", "Hermetica", "Renaissance Philosophy", "New Learning", "Italian Renaissance" or "Renaissance Humanism".

However, the significance of this method is especially evident in relation to some details that sometimes appear eclipsed by the big picture of the dominant discourse created by the hermeneutic perspective. We present them as suggestions of possible relationships that could be part of further research projects developed by the experts. For instance, it is with this focus reading that one finds the importance of the University of Padua, where Copernicus studied [38]. An important number of the knowledge dealers in the science cluster were professors and/or studied there too. Furthermore, Padua was the first Italian university which introduced the humanist pedagogical reformation. This reformation focused on the structuring of higher education around five disciplines: poetry, grammar, rhetoric, history, and moral philosophy. Copernicus and his theory of heliocentrism, shared geographies, interests, ideas, and intellectual discussions with the scholars of the University of Padua, within the context of their humanistic reformation. But Padua was well known during the Italian Renaissance as an important center of Aristotelianism. It was there that Mirandola developed a deep respect for the Aristotelian corpus, as it appears in his works [27], and was eventually reflected in his syncretism [5]. Copernicus was immersed in a network where not only the discussion was about Neoplatonism, but also on Aristotelianism, what may explain the appearance of an Aristotelian/Thomist philosopher such as Albertus Magnus on the list of nodes with higher Stirling coefficients in Copernicus' cluster.

In the case of Michelangelo and his cluster, considering the closeness of the (art) cluster associated to Michelangelo, the "contemporaneousness" of the nodes with the most remarkable Stirling coefficients, and its special relationship to the cluster of Mirandola (13% of the total links of the graph, and an important group of nodes of Neoplatonic thinkers among its highest Stirling coefficients), it is clear that both Michelangelo's training in the Florentine Academy and the presence of Neoplatonism

in his own poetry [25] would suggest that he was aware of this Neoplatonic symbolic representation.[f]

We suggest that Neoplatonism and its social circles make up the bridges that truly enable an interdisciplinary dialogue between science, philosophy and the arts in Italian Renaissance Humanism. This hypothesis agrees with the bibliography that relates Copernicanism and Renaissance arts, and is supported by the fact that Neoplatonic images such as the Sun-God (Christ) symbolism would be one of the missing pieces to rebuild this relationship [14, 32].

## 5. Conclusions

Our results show how complex networks analysis can be used to reveal hidden transactions between Copernicus, Michelangelo and Pico della Mirandola during the Italian Renaissance, as covered by Wikipedia. This type of knowledge is usually difficult to locate and analyze due to the feedback loop created within the boundaries of specific disciplines between the analytical and conceptual tools used and the phenomena studied. The existence of this feedback loop along with organizational uses and habits specific to each discipline underline the need to advance in the development of new tools to target specific interdisciplinary knowledge spaces that otherwise fall through the cracks of established disciplines. These new tools for interdisciplinary knowledge discovery and analysis are to be tailored to the chosen data source (in our case, Wikipedia), the type of evidence sought (in our case, historical), and the hypothesis underpinning the enquiry (in our case, exchanges across disciplines are relevant to the emergence of preeminent people and ideas).

It is assumed that, especially in transitional periods of History such as the 16th-Century, new types of knowledge that overcome the boundaries of the disciplines established up to that moment are produced. In most cases, such as the Renaissance, finding the origins, interactions and processes that gave rise to that knowledge require the collaboration of experts across multiple domains who can bring diverse perspectives and different toolsets to shed light on the context. This transdisciplinary approach comes together in our paper as the core of the main historical question that we pose: if the universal man of the Renaissance is that who has abandoned the boundaries of the different areas of knowledge and action, where are located the connections across disciplines for Copernicus, Michelangelo and Mirandola?

The deployment of Stirling coefficients as exploratory lenses across disciplines has proven fruitful in one more respect. The names associated with the highest Stirling coefficients (the knowledge dealers) can be organized according to their temporal location vis-a-vis the three protagonists of our enquiry. This is certainly, in part, a side effect of the structure of Wikipedia, but we argue that it is also evidence of how historical information is accumulated and utilized by historians in different

[f]The cultural context that surrounded Michelangelo and that connects the Renaissance pictorial tradition with Neoplatonism is well known [21].

moments. Our method unfolds these three different temporal perspectives as different analytical lenses on the relations among our subjects. The resulting view of the problem at hand expresses the continuity of the historiography about our three subjects without forcing the evidence into an apparent linear continuity that is not always present in the emerging network that we have analyzed. This method postulates the existence of a *network-continuity* in the construction of knowledge about our subject-matter that is better expressed at the level of meta-analysis by the relations between the three seeds (Michelangelo, Copernicus, and Mirandola), and also of the knowledge-dealers whose appearance is relevant irrespective of their relative chronology to the subjects of analysis. We call these knowledge dealers that cannot be ascribed to a singular historical moment in relation to our seeds and are key to the knowledge built around different disciplines and/or historical periods, "time-independent" knowledge dealers.

Finally, we have shown that our method helps advance the dialogue about the scale, methods and evidence in the emerging field of Cultural Analytics as well as in data-driven Digital Humanities. To this end, we proposed the notion of "focus reading", the combination of complex networks analysis as exploratory tool to place the *loci* (people, ideas, works) of interdisciplinary knowledge with the corresponding close reading to project the relevant information from those *loci* into the emerging connections. By doing this, we are able to also propose that within the frame delineated by the transformation of Wikipedia content into a dataset susceptible of analysis as a network, as described here. Focus reading provides a mapping of the context of possible worlds available to readers and writers to use Wikipedia as a tool for the creation of knowledge.

## References

[1] Basov, N. and Kholodova, D., Networks of context: Three-layer socio-cultural mapping for a Verstehende network analysis, *Soc. Netw.* **69** (2021) 84–101.
[2] Bode, K., The equivalence of "Close" and "Distant" reading; or, toward a new object for data-rich literary history, *Mod. Lang. Quart.* **78** (2017) 77–106.
[3] Cilibrasi, R. L. and Vitanyi, P. M. B., The Google similarity distance, *IEEE Trans. Knowl. Data Eng.* **19** (2007) 370–383.
[4] Eom, Y.-H., Aragón, P., Laniado, D., Kaltenbrunner, A., Vigna, S. and Shepelyansky, D. L., Interactions of cultures and top people of Wikipedia from ranking of 24 language editions, *PLoS One* **10** (2015) e0114825.
[5] Farmer, S. A., *Syncretism in the West: Pico's 900 Theses (1486). The Evolution of Traditional Religious and Philosophical Systems* (ACMRS Publications, Tempe, 1998).
[6] Fortunato, S., Community detection in graphs, *Phys. Rep.* **486** (2010) 75–174.
[7] Freitas, R., Cultural mapping as a development tool, *City Cult. Soc.* **7** (2016) 9–16.
[8] Fruchterman, T. M. J. and Reingold, E. M., Graph drawing by force-directed placement, *Softw. Pract. Exp.* **21** (1991) 1129–1164.
[9] Gabella, M., Cultural structures of knowledge from wikipedia networks of first links, *IEEE Trans. Netw. Sci. Eng.* **6** (2019) 249–252.

[10] Goldfarb, D., Merkl, D. and Schich, M., Quantifying cultural histories via person networks in Wikipedia, (2015).
[11] Goldstone, A., The doxa of reading, *PMLA, Publ. Mod. Lang. Assoc. Am.* **132** (2017) 636–642.
[12] Guimerà, R. and Amaral, L. A. N., Functional cartography of complex metabolic networks, *Nature* **433** (2005) 895–900.
[13] Henry, J., *The Scientific Revolution and the Origins of Modern Science* (Macmillan, New York, 1997).
[14] Hutchison, K., An angel's view of heaven: The mystical heliocentricity of medieval geocentric cosmology, *Hist. Sci.* **50** (2012) 33–74.
[15] Kraye, J., *Philologists and Philosophers* (Cambridge University Press, Cambridge, 1996).
[16] Kuhn, T. S., *The Copernican Revolution* (Harvard University Press, Harvard, 1957).
[17] Kuhn, T. S., *The Structure of Scientific Revolutions*, 2nd edn. (The University of Chicago Press, Chicago, 1970).
[18] Moretti, F., *Graphs, Maps, Trees: Abstract Models for a Literary History* (Verso, New York, 2005).
[19] Moretti, F., *Distant Reading* (Verso, New York, 2013).
[20] Newman, M. E. J., The structure and function of complex networks, *SIAM Rev.* **45** (2003) 167–256.
[21] Panofsky, E., *Meaning in the Visual Arts* (The University of Chicago Press, Chicago, 1955).
[22] Pérez, C. M., *Sobre las Revoluciones* (Tecnos, Madrid, 1987).
[23] Ravetz, J. R., *Astronomy and Cosmology in the Achievement of Nicolaus Copernicus* (Ossolineum, Wroclaw-Warszawa-Kraków, 1965).
[24] Restivo, S., *Einstein's Brain* (Springer Nature, Berlin, 2019).
[25] Robb, N. A., *Neoplatonism of the Italian Renaissance* (Octagon, New York, 1968).
[26] Robert, S., *Context* (Oxford Academic, 2014).
[27] Rodríguez, T., El aristotelismo de Giovanni Pico della Mirandola y la concordia entre Platón y Aristóteles, *Prax. Filos.* **49** (2019) 39–59.
[28] Sawyer, R. K., *Explaining Creativity* (OUP, USA, 2012).
[29] M. Schich *et al.*, A network framework of cultural history, *Science* **345** (2014) 558–562.
[30] Schwartz, G. A., Complex networks reveal emergent interdisciplinary knowledge in Wikipedia, *Humanit. Soc. Sci. Commun.* **8** (2021) 127.
[31] Scott, W., *Hermetica. The Ancient Greek and Latin Writings which Contain Religious or Philosophic Teachings Ascribed to Hermes Trismegistus* (Shambhala, Boston, 1993).
[32] Shrimplin, V., Michelangelo, Copernicus and the Sistine chapel, *Proc. Int. Astron. Union* **5** (2009) 333–339.
[33] Stirling, A., A general framework for analysing diversity in science, technology and society, *R. Soc. Publ.Org.* **4** (2007) 707–719.
[34] Underwood, T., *Distant Horizons* (University of Chicago Press, Chicago, 2019).
[35] Wagner, C., Garcia, D., Jadidi, M. and Strohmaier, M., It's a man's Wikipedia? Assessing gender inequality in an online encyclopedia, *Proc. Int. AAAI Conf. Web Social Media*, Vol. 9 (2021), pp. 454–463.
[36] Wagner, C., Graells- Garrido, E., Garcia, D. and Menczer, F., Women through the glass ceiling: Gender asymmetries in Wikipedia, *EPJ Data Sci.* **5** (2016) 5.
[37] Wallis, C. G., Miller, P. J. W. and Carmichael, D., *On the Dignity of Man, On Being and the One* (Bobbs-Merrill, Indianapolis, 1977).
[38] Westman, R. S., The astronomer's role in the sixteenth-century: A preliminary survey, *Hist. Sci.* **18** (1980) 105–147.

[39] Whitehead, A. N., *Science and the Modern World* (Cambridge University Press, Cambridge, 1953).
[40] Yates, F., *Giordano Bruno and the Hermetic Tradition* (The University of Chicago Press, Chicago, 1964).
[41] Zant, S. E., Jaffrès-Runser, K., Frahm, K. M. and Shepelyansky, D. L., Interactions and influence of world painters from the reduced Google matrix of Wikipedia networks, *IEEE Access* **6** (2018) 47735–47750.
[42] Zhirov, A. O., Zhirov, O. V. and Shepelyansky, D. L., Two-dimensional ranking of Wikipedia articles, *Eur. Phys. J. B* **77** (2010) 523–531.