2020 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM)

A Longitudinal Analysis of a Social Network of Intellectual History

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***Abstract*—The history of intellectuals consists of a complex web of influences and interconnections of philosophers, scientists, writers, their work, and ideas. How did these influences evolve over time? Who were the most influential scholars in a period? To answer these questions, we mined a network of influence of over 12,500 intellectuals, extracted from the Linked Open Data provider YAGO. We enriched this network with a longitudinal perspective and analyzed time-sliced projections of the complete network differentiating between within-era, inter-era, and accumulated-era networks. We thus identified various patterns of intellectuals and eras and studied their development in time. We show which scholars were most influential in different eras, and who took prominent knowledge broker roles. One essential finding is that the highest impact of an era's scholar was on their contemporaries, and that the inter-era influence of each period was strongest on the consecutive era. Furthermore, we see quantitative evidence that there was no rediscovery of Antiquity during the Renaissance; rather, there has been a continuous reception of it since the Middle Ages.**

I. INTRODUCTION

"No self is of itself alone," wrote Erwin Schrödinger in 1918 [15] and noted, "It has a long chain of intellectual ancestors." The history of intellectuals is comprised of a myriad of such long chains, embedded in a tapestry of competing influences of "ageless" ideas, which —in the words of the French scholar Bonaventura D'Argonne in 1699—"embrace [...] the whole world" [9].

To understand the dynamics of influence and spread of ideas through history, the embeddness and interconnections of scholarship should be taken into account. A network approach offers to identify the most influential scholars via their positions in a network of intellectual influence through the history. This allows the study of their social relations [25], [11], [19], and to provide deep insights into the underlying social structure.

A recent study by Ghawi et al. [5] addressed the analysis of such a social network of intellectual influence, incorporating over 12,500 scholars from international origins since the beginning of historiography. In this paper, we build upon [5], and extend the analysis of that network by incorporating a temporal dimension. We analyze the network of scholars dependent to their time, adding a longitudinal perspective on how scholars formed networks. By doing so, we opt for an inclusive, global perspective on the history of intellectuals. This perspective of a vast longitudinal global network of intellectuals is a response to recent discussions on not-global-enough research within intellectual history [10]. We thus attempt to go beyond the traditional "master narratives" [4] of a Western European centrist view on intellectual history [23]. The goal of this paper is not only to understand how the influence relations among scholars evolved over time, but also to get deep insights on their influence on historical periods.

- How did these influence networks evolve over time?
- Who were the most influential scholars in a period?
- And which patterns of influence did emerge?

To answer these, we analyze the evolution of influences in time in order to identify periods and scholars, who stand out.

Our contributions are as follows:

- We incorporate a longitudinal perspective on the social network analysis of intellectuals based on a global periodization of history.
- We identify patterns of influence and their distribution in within-, inter-, and accumulated-era influence networks.
- We identify influence signatures of scholars and eras.
- We identify scholars with various knowledge broker roles.

This paper is organized as follows. Section II reviews related works. In Section III, we briefly outline the dataset's characteristics and pre-processing. Section IV presents the network analysis of the entire network, and its time-sliced projections into partial influence networks (within-era, inter-era, and accumulated-era), featuring their basic network metrics, degree distribution, and connectivity. In Section V, we identify different influence patterns of scholars and eras. Section VI is devoted to the longitudinal analysis of brokerage roles in scholars.

II. RELATED WORK

The term of intellectual history combines a plethora of approaches on discourse analysis, evolution of ideas, intellectual genealogies, and the history of books, various scientific disciplines, political thought, and intellectual social context [26], [7]. These studies are usually limited to specific regions or time spans as a trade-off for thorough comparative and textual analysis. Endeavors to write a "Global Intellectual History" [16] were criticized for focusing on the more well-known intellectual thinkers despite including a transnational comparative perspective [22].

Network methodologies allow analyzing intellectual history and as such the history of intellectuals as big data, encompassing time and space with a focus on their inter-connections. So far, computational methods have been used in the study of communication networks of the *respublica litteraria*, in which various studies modeled the Early Modern scholarly book and letter exchanges as networks. Among the first was "Mapping the Republic of Letters" at Stanford University in 2008 [1]. More recent studies have incorporated a temporal perspective on these epistolary networks [24].

IEEE/ACM ASONAM 2020, December 7-10, 2020
978-1-7281-1056-1/20/$31.00 © 2020 IEEE

A recent study [5] proposed to research the entire history of intellectuals with the means of a network approach. This paper defined the most influential as those with the longest reaching influence (influence cascades), and identified as such Antique and Medieval Islam scholars, and Karl Marx as the one with the most out-going influences. In this paper, we extend this analysis by incorporating a temporal dimension in order to establish a deeper insight on how these influences evolved in time.

Much research has been devoted to the area of longitudinal social networks [17], [13], [21], [12]. Longitudinal network studies aim at understanding how social structures develop or change over time, usually by employing panel data [11]. Snapshots of the social network at different points in time are analyzed in order to explain the changes in the social structure between two (or more) points in time in terms of the characteristics of the scholars, their positions in the network, or their former interactions.

III. DATA

A. Data Acquisition and Preprocessing

The source of information used in this paper originated from YAGO (Yet Another Great Ontology) [14], a pioneering semantic knowledge base that links open data on people, cities, countries, and organizations from Wikipedia, WordNet, and GeoNames. At YAGO, an influence relation appears in terms of the `influences` predicate that relates a scholar to another when the latter is influenced by the ideas, thoughts, or works of the former. The accuracy of this relation was evaluated by YAGO at 95%. We extracted a dataset that encompasses all influence relationships available in YAGO, using appropriate SPARQL queries that implement mining techniques of social networks from Linked Open Data [6]. The result consisted of 22,818 directed links among 12,705 intellectuals that made up the nodes and edges of our target social network of influence. In order to incorporate a time dimension to our analysis, we extracted birth and death dates of each scholar. Some scholars had missing birth and/or death dates, which we deduced by subtracting 60 years from the death date, and vice versa, up to the symbolic year of 2020. When both dates were missing, we manually verified them. During this process we had to remove some entities, as they did not correspond to intellectuals. These were either 1) concepts, e.g., 'German_philosophy' and 'Megarian_school', 2) legendary characters, e.g., 'Gilgamesh' and 'Scheherazade', or 3) bands e.g., 'Rancid' and 'Tube.' To this end, we obtained a new dataset of 12,577 scholars with complete birth and death dates.

B. Periodization

In this paper, we do not use the classical concept of network snapshot, which is a static network depicted at a given point in time. Rather, we split the time span (i.e., the history) manually into consecutive periods (eras), and embed the network nodes (actors) into the eras in which they lived. This way, the micro-level influence among scholars can be viewed as a macro-level influence among periods of history. This enables the analysis of the influence network within each era (= within-era), between different eras (= inter-era), and in an accumulative manner (= accumulated-era). By introducing a longitudinal perspective, we split the time-span using a periodization that takes global events into account. Any periodization is a construct of analysis, as each field of research has its own timeline characterizing periods [20] which are dependent on different caesura for the respective object of research [18]. This complicates an overarching longitudinal perspective on a global scale. In order to match the internationality of scholars, we used Osterhammel's global periodization [18] and worked with six consecutive periods (eras): Antiquity (up to 600 AD), Middle Ages (600—1350), Early Modern Period (1350—1760), Transitioning Period (1760—1870), Modern Age (1870—1945), and Contemporary Period (1945—2020).

One conceptual challenge was to map scholars into eras. Many scholars fit to more than one period's timeline. We opted for a single era membership approach since it is more intuitive and easier to conceptualize. A single era membership of each scholar reduces the complexity of analysis and computations, while encompassing the essential membership of each scholar to a single era. It also offers adequate results when we compare eras, since it avoids redundancy. This approach does not change the influences of the scholar to scholars of other periods.

In order to assign a single era to a scholar, we used the following method: We calculated the midpoint of the scholar's lifespan ignoring the first 20 years of their age, as we assumed that scholars in general would not be active then. Then we assigned the era in which this midpoint occurs as the scholar's membership to an era. After this initial assignment process, we verified the global validity of assignments by counting the number of influence links from one era to another. We observed that there were some reverse links of eras, i.e., an influence relation from an actor in a recent era towards an actor assigned to an older era. Those anomaly cases (about 200) were basically due to:

- Errors in dates:
  - some dates were stated in the Hijri calendar, instead of the Gregorian calendar, and
  - some dates were BC and missing the negative sign.
- Errors in direction of the relationship: source and target actors were wrongly switched.
- Inappropriate era-actor assignments.

The anomalies due to errors have been manually corrected. The cases of inappropriate assignment were technically not erroneous. This usually happened when the influencer lived much longer than the influenced, elevating the influencer's period into a more recent one. We solved this by iteratively reassigning either the influencer backward to the era of the influenced, or the influenced forward to the era of the influencer. As a result, each scholar is assigned to exactly one era, such that no reverse links of eras exist. The final cleaned dataset consists of 22,485 influence links among 12,506 intellectuals.

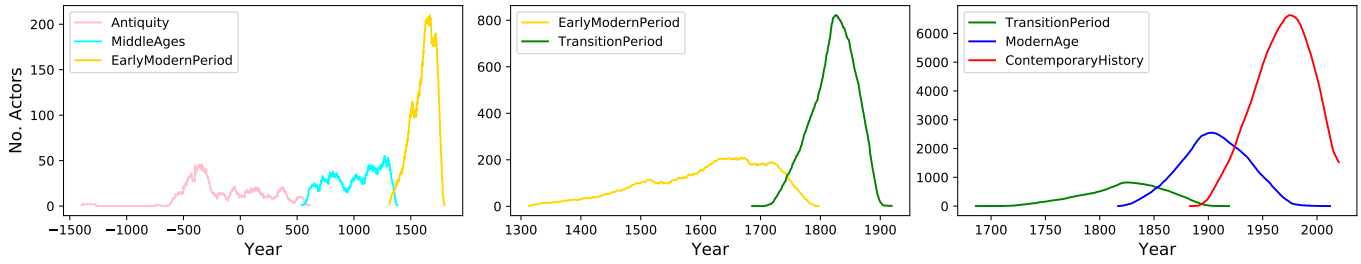

Fig. 1. Number of scholars alive in each year based on their assigned eras.

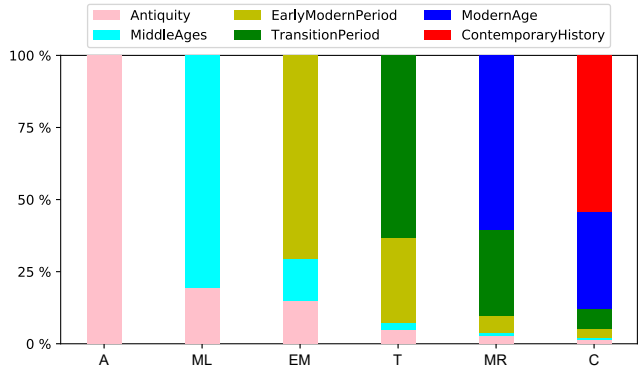

Fig. 2. Percentage of received influences in each era.

IV. ANALYSIS

Fig. 1 shows each era's continuous density of scholars based on their lifespan.

With scholars embedded in their respective eras, the entire influence network can be time-sliced: we projected it into several partial networks based on the source era (of the influencer) and target era (of the influenced scholar). When the source and target eras are the same, we call the partial network a *within-era* influence network. When the source and target eras are different, we call the partial network an *inter-era* influence network. There are no reverse links from a later era to a previous one due to pre-processing.

After time-slicing the whole network, we received six within-era networks corresponding to all the six eras, and 15 inter-era networks, corresponding to all chronologically ordered (but not necessarily consecutive) pairs of different eras. Moreover, we constructed six *accumulated-era* influence networks of scholars living up to and including a target era.

Fig. 2 shows the proportion of influence links among all pairs of eras. There, we can already make two major observations for inter- and within-era influence relations: For one, the highest fraction of influence received by scholars of each era comes from its own era. This means that the internal impact of any era is in general higher than its external impact. In absolute numbers, the vast majority of links occur within the Contemporary era, followed by links from the Modern Age to the Contemporary period, and within the Modern Age, which is clearly owed to the increased amount of scholars in these periods.

The inter-era influences of each period is strongest on its consecutive period. As our earliest period, Antiquity receives only influence links from itself, whereas the influence received in the Middle Ages are 82% internal, and 18% from Antiquity. Subsequently, the amount of the within-era influence shrinks throughout the consecutive periods, but still remains the biggest influence. Noteworthy here is the high proportion of influences of Antiquity on the Early Modern period, which represents their increased reception during the Renaissance. However, the proportionately many links of Antiquity to the Middle Ages reassert the shift in historical research that the Renaissance did not "rediscover" Antiquity, but was received before in the Middle Ages as well [3, p. 3—4].

A. Within-Eras Influence Networks

In the following, we analyzed the six *within-era* influence networks, which represent the internal impact of an era. We extracted the following metrics, as shown in Table I:

- Number of nodes N, and edges E, and density D.
- Average out-degree (= avg. in-degree due to the properties of a directed graph).
- Max. in-degree, max. out-degree, and max. degree.
- WCC: number of weakly connected components.
- LWCC: size of the largest weakly connected component.
- SCC: number of strongly connected components, when the number of nodes is > 1).
- Reciprocity and transitivity.

TABLE I
METRICS OF WITHIN-ERA NETWORKS

Era	A	ML	EM	T	MR	C
N	219	303	610	761	2102	6081
N/A	82%	86%	81%	70%	73%	85%
E	327	387	694	927	2806	7960
Density	.0068	.0042	.0019	.0016	.0006	.0002
avg. out-degree	1.49	1.28	1.14	1.22	1.33	1.31
max in-degree	12	9	17	27	21	26
max out-degree	20	16	23	32	68	58
max degree	32	20	32	41	73	58
WCC	11	21	94	108	208	582
Largest WCC	179	233	245	436	1495	4379
	82%	77%	40%	57%	71%	72%
SCC	0	2	6	8	31	38
Reciprocity	0	0.005	0.023	0.028	0.036	0.014
Transitivity	0.064	0.066	0.071	0.042	0.029	0.017

We included $\frac{N}{A}$ in Table I in order to contain that the number of nodes N in a within-era network could be less than the number of actors of that of era A. This is owing to the fact that not all scholars of an era necessarily participated in its within-era influence network. Some scholars influenced or were influenced by actors of different eras only. However, around 80% of scholars in each era were active in these within-era networks. The highest value of 86% of the Middle Ages refers to their relative self-containment as an era, as well as the lowest value in the Transitioning period of 70% refers to its high out-going influences.

Over all eras, the amount of nodes and edges steadily increased, while the density of networks decreased. On average, the out-degree revolves around 1.25, where the highest value of 1.5 occurs in Antiquity, and the lowest of 1.14 in the Early Modern period. When we compare the evolution of the max. out-degree in time, we find that the expected continuous increase did not always hold due to two exceptionally high observations at Antiquity and the Modern Age. Mutual ties among contemporaries were in general very low. We can report none in Antiquity, and only one in the Middle Ages between Avicenna and Al-Bīrūnī. In the Early Modern period, eight mutual relations were observed, including, e.g., Gottfried Leibniz (1646—1716) and David Bernoulli (1700—1782), whereas 13 mutual relations in the Transitioning period, such as Friedrich Engels (1820—1895) and Karl Marx (1818—1883), or Johann Goethe (1749—1832) and Friedrich Schelling (1775—1854). In the Modern Age, the number of mutual ties increased to 51 (e.g., Jean—Paul Sartre (1905—1980) and Simone de Beauvoir (1908—1986)); and to 54 in the Contemporary period.

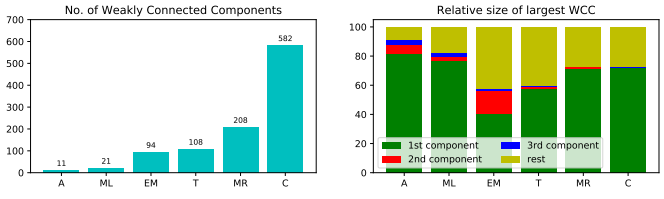

Fig. 3. Weakly connected components in within-era influence networks

Fig. 3 shows the number of weakly connected components (WCCs) in the within-era networks of each era, and the relative size of the largest ones w.r.t the whole corresponding network. The number of WCCs increased gradually over the consecutive eras. In general, the networks consisted of one giant component, which encompassed the majority of nodes, while the rest of components were relatively smaller. This was particularly developed in Antiquity and the Middle Ages, where the giant components constitute of 82% and 77% of the nodes, while the second largest were at 6% and 3%, respectively. The Early Modern period constitutes an exception to this giant component rule: the largest one was only at 40%, and the second largest at 16%. Looking at their composition, the first consisted of natural scientists, mathematicians, and philosophers, such as Descartes, Newton, and Leibniz, while the smaller one was compromise of artists and painters, such as Rembrandt and Raphael. The single giant component phenomenon appeared again in subsequent eras. For instance, in the Transitioning period, there were 108 WCCs, where the largest two incorporated 57% and 1.3% of the nodes. In the Modern and Contemporary Age, the largest components comprised about 70% of nodes.

TABLE II
TOP 5 ACTORS, PER ERA, BASED ON OUT-DEGREE IN WITHIN-ERA INFLUENCE NETWORKS.

Antiquity		MiddleAges		EarlyModern	
Plato	20	Avicenna	16	John Locke	23
Aesop	13	Muhammad	11	René Descartes	22
Pythagoras	10	Al-Ghazali	11	Isaac Newton	15
Plotinus	10	Banū Mūsā	8	Hugo Grotius	13
Euhemerus	10	J. S. Eriugena	8	Leibniz	11
Transition		**Modern**		**Contemporary**	
Goethe	32	Nietzsche	68	Vladimir Nabokov	58
Hegel	29	Jules Verne	35	Friedrich Hayek	50
Lord Byron	24	Henri Bergson	35	Richard Pryor	50
Immanuel Kant	22	Leo Tolstoy	24	Jacques Derrida	48
von Schelling	17	Edmund Husserl	22	Michel Foucault	47

Who was most influential on their contemporaries? Table II lists the top five scholars per era based on their out-degree in the within-era influence networks. The highest within-era out-degree over all times was achieved by Friedrich Nietzsche (1844—1900) of the Modern Age with 68 outgoing influence links to other scholars of his era.

B. Inter-Era Influence Networks

Inter-era influence networks are partial networks where the source era precedes the target era. We interpreted these networks as bipartite, as the actors belong to different groups; the source era and the target era. Therefore, only edges between nodes sets are possible.

TABLE III
METRICS OF INTER-ERAS INFLUENCE NETWORKS

source → target	N	E	N_s	N_t	D	in-degree avg	in-degree max	out degree avg	out degree max
A → MA	82	87	38	44	.052	1.98	7	2.29	12
A → EM	117	145	46	71	.044	2.04	7	3.15	19
A → T	66	66	29	37	.062	1.78	5	2.28	11
A → MA	101	114	42	59	.046	1.93	11	2.71	23
A → C	169	177	49	120	.030	1.47	6	3.61	46
ML → EM	149	144	66	83	.026	1.73	9	2.18	21
ML → T	52	36	22	30	.055	1.20	5	1.64	6
ML → MR	77	62	27	50	.046	1.24	4	2.30	12
ML → C	146	121	50	96	.025	1.26	6	2.42	34
EM → T	392	432	159	233	.012	1.85	16	2.72	24
EM → MR	262	269	101	161	.016	1.67	13	2.66	15
EM → C	437	432	125	312	.011	1.38	7	3.46	35
T → MR	1,111	1,373	436	675	.005	2.03	19	3.15	53
T → C	888	1,041	212	676	.007	1.54	9	4.91	112
MR → C	3,817	4,885	1,271	2,546	.002	1.92	17	3.84	78

Table III shows the metrics for those inter-era influence networks. In general, each era had the most links with its consecutive era, and additionally with the Contemporary period's scholars. Exception to this was Antiquity, which saw its first peak with the Early Modern period relating to Renaissance interests. Their densities were again decreasing through the combinations, except for those periods that had

less links to other periods, such as the Middle Ages to the Transitioning period.

Which scholar influenced a successive era the most? Table IV shows the scholars with the highest degrees in the inter-era networks. Noteworthy here is Karl Marx, who had the highest out-degree over all times from the Transitioning period to the Contemporary age, followed by modern philosopher Friedrich Nietzsche and Martin Heidegger on Contemporary scholars.

C. Accumulative Influence Networks

For each era, we constructed an accumulative influence network of all influence links among scholars who lived up to and including that era. We performed essential social network analysis on these six *accumulated-eras* networks, which combine the internal and external impact of eras. The final network of the Contemporary Age is the same as the complete network over all periods [5].

Fig. 4 shows the best connected scholars for each era —those that influenced at least 10 others —in the final accumulated network. We clearly see two joined networks of hubs. The right section is very diverse in terms of including different eras and different fields such as philosophy, theology, and science scholars. The left section consists mainly of writers since the Long 19th Century (1789—1914); Alexander Pushkin (1799—1837) is one of the eldest nodes there. This writers' network shows little diversity in comparison to other historical periods and consists mostly of Modern and Contemporary age writers. That writers are less connected to the philosophy, theology, and science scholars shows that these groups referenced themselves more consistently.

Table V shows the metrics of accumulated-era networks. Regarding node degrees change over consecutively accumulated eras, we observe that at all eras the maximum out-degree is greater than the maximum in-degree. Moreover, those maximum degrees continuously increase over eras, in contrast to within-era networks. The average out-degree changes slightly over time, taking its lowest value of 1.45 at Middle Ages, and highest value of 1.8 at Contemporary age. Noteworthy is the drastic collapse of the largest Weak Component in the Early Modern period, which has steadily risen since.

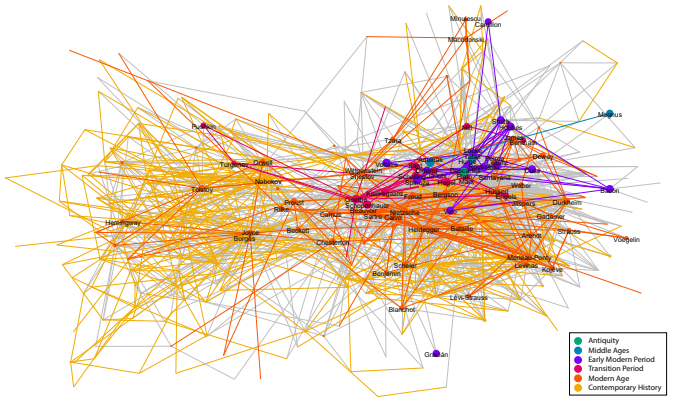

Fig. 4. Network of the most influential actors with at least 10 out-going influences. Node size = proximity prestige, node color = era, links within an era are colored with the color of the era, the other links are gray.

Who was the most influential intellectual in an era? Fig. 5 shows the evolution of the 10 most influential scholars in the complete network based on their out-degree progression in the accumulative networks.

The top two ranks of the most prolific scholars were consistently taken over by Antique philosophers Plato, and Aristotle (who among contemporaries was only in rank 6) Contemporary scholars came on third rank in the Middle Ages (Avicenna), in the Early Modern period (Ibn Tufail, John Locke, René Descartes), and in the Transitioning period (John Locke, Johann Goethe). This changed in the Modern Age, when Transitioning period scholars Immanuel Kant and Hegel took the first ranks. Aristotle still remained in the top five. The highest out-degree over all times is observed at the Contemporary Age, where Karl Marx had 158 out-going influence links to other scholars of all eras, followed by Nietzsche, Hegel, and Kant.

V. Patterns of Influence over Eras

In this section, we study the influence patterns of scholars over eras. We construct influence signatures based on how

TABLE IV
TOP SCHOLARS WITH HIGHEST OUT-DEGREE IN THE INTER-ERA NETWORKS

s → t	First Rank		Second Rank	
A → ML	Aristotle	12	Augustine of Hippo	6
A → EM	Aristotle	19	Plato	14
A → T	Aristotle	11	Plato	9
A → MR	Plato	23	Aristotle	16
A → C	Aristotle	46	Plato	32
ML → EM	Ibn Tufail	21	Thomas Aquinas	9
ML → T	Petrarch	6	Dante Alighieri	5
ML → MR	Dante Alighieri	12	Thomas Aquinas	11
ML → C	Thomas Aquinas	34	Dante Alighieri	10
EM → T	J. J. Rousseau	24	Shakespeare	21
EM → MR	Baruch Spinoza	15	Shakespeare	15
EM → C	Shakespeare	35	David Hume	25
T → MR	Immanuel Kant	53	Karl Marx	43
T → C	Karl Marx	112	Hegel	67
MR → C	Nietzsche	78	Martin Heidegger	73

TABLE V
METRICS OF ACCUMULATIVE-ERA NETWORKS

Era	A	ML	EM	T	MR	C
N	219	552	1,227	2,141	4,697	12,506
E	327	801	1,784	3,245	7,869	22,485
N_{src}	54	155	388	677	1,501	3,890
N_{inner}	71	178	353	597	1,331	3,080
N_{sink}	94	219	486	867	1,865	5,536
Density	.0068	.0026	.0012	.0007	.0004	.0001
avg. out-degree	1.49	1.45	1.45	1.5	1.68	1.80
max in-degree	12	16	26	38	48	48
max out-degree	20	24	41	52	75	158
max degree	32	36	50	60	116	196
WCC	11	30	110	211	390	817
Largest WCC	179	441	797	1513	3550	10192
	82%	80%	65%	71%	76%	81%
SCC	0	2	8	16	47	85
Reciprocity	0	0.002	0.010	0.014	0.019	0.011
Transitivity	0.064	0.067	0.064	0.056	0.039	0.021

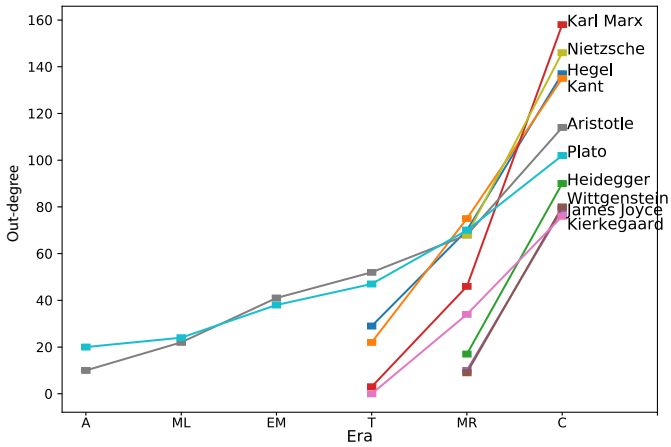

Fig. 5. Top 10 of the most influential intellectuals of the complete network based on their out-degree, and their progression in the accumulated-era networks.

much on average a scholar influenced an era, and which patterns of directed influences characterize an era.

1) Influence Power of Scholars: For each scholar, we construct their influence signature as a sequence of their influence links towards each era, starting from their own. For example, the influence signature of Aristotle was $[10, 12, 19, 11, 16, 46]$, which meant he had 10 influence links within Antiquity, 12 links towards the Middle Ages, etc. Using those signatures, we define the *longitudinal influence power* of a scholar as the average of their influence signature. A scholar would have a high influence power when he has (1) a high number of influence links, (2) over all or many eras. In contrast, having few influence links over several eras, or many links over few eras would give a low value of this influence power measure. For example, with an average around 19 both Aristotle and Shakespeare had similar influence powers. In absolute numbers, Aristotle had almost twice the number of Shakespeare's influence links (114 to 73, respectively). While Aristotle influenced all 6 eras, and Shakespeare only 4, the ratio of the links per era decreased for Aristotle, resulting in their similar influence powers. This measure provides an indicator of the influence power of an intellectual throughout history, and combines both the intensity and the diversity of influence.

Influence power also allows us to compare scholars from different eras. Table VI shows the top 5 scholars based on the longitudinal influence power. Here, Aristotle, Thomas Aquinas, William Shakespeare, Karl Marx, Friedrich Nietzsche, and the writer Vladimir Nabokov (1899—1977) are identified by their influence power as the most influential intellectuals of their respective periods. The highest longitudinal influence powers over all times had Nietzsche (73), followed by Nabokov (58) and Marx (52).

2) Influence Patterns: Which directed influences were most common in an era? We derive these influence patterns of eras by replacing any non-zero entries by X of the scholar's influence signatures, and aggregate all occurrences of each

TABLE VI
TOP 5 ACTORS BASED ON THE LONGITUDINAL INFLUENCE POWER.

Antiquity		MiddleAges		EarlyModern	
Aristotle	19.0	Thomas Aquinas	12.6	William Shakespeare	18.2
Plato	17.0	Dante Alighieri	6.0	Baruch Spinoza	14.8
Augustine of Hippo	6.0	Ibn Tufail	5.8	René Descartes	14.0
Plotinus	4.7	Avicenna	4.6	John Locke	13.0
Heraclitus	4.2	Al-Ghazali	3.6	David Hume	12.5
Transition		**ModernAge**		**Contemporary**	
Karl Marx	52.6	Friedrich Nietzsche	73.0	Vladimir Nabokov	58.0
Hegel	45.7	Martin Heidegger	45.0	Friedrich Hayek	50.0
Immanuel Kant	45.0	Ludwig Wittgenstein	40.0	Richard Pryor	50.0
Søren Kierkegaard	25.3	James Joyce	39.5	Jacques Derrida	48.0
Fyodor Dostoyevsky	23.0	Sigmund Freud	32.0	Michel Foucault	47.0

pattern for each era. We thus ignore the actual values of influence (intensity), but keep the temporal effect (diversity). For example, the influence pattern $[X, 0, \cdots, 0]$ means that the scholarly influences goes to the first (own) era only, with no influence on other eras. The pattern $[X, X, \cdots, X]$ signifies that the influence is distributed over all applicable eras, regardless of the actual values. Table VII gives the top patterns of each era with the pattern's frequency of occurrence with regard to the respective era.

TABLE VII
TOP FREQUENT INFLUENCE PATTERNS OF ERAS (FROM LEFT TO RIGHT)

	A	ML	EM	T	MR	C	
Antiquity	×	0	0	0	0	0	43%
	0	0	0	0	0	×	8%
	0	×	0	0	0	0	7%
	0	0	×	0	0	0	7%
MiddleAges		×	0	0	0	0	56%
		0	×	0	0	0	9%
		×	×	0	0	0	7%
		0	0	0	0	×	6%
EarlyModern			×	0	0	0	51%
			0	×	0	0	13%
			0	0	0	×	7%
			×	×	×	×	7%
Transition				×	0	0	35%
				0	×	0	29%
				×	×	×	11%
				×	×	0	9%
				0	0	×	8%
				0	×	×	7%
ModernAge					0	×	38.8%
					×	0	36.7%
					×	×	24.5%
Contemporary						×	100%

For example, for the Middle Ages the most frequent pattern is $[-, X, 0, 0, 0, 0]$, which represents that 56% of scholars only influenced contemporaries with no influences on other eras. Over all eras, the most common pattern was within-era influence, followed by the influence on the consecutive period. Exception to this rule is the Modern period, which experienced the reverse, and had a higher influence on the Contemporary period than on its own. Since the Early Modern period, the pattern of influencing all successive eras including its own becomes more frequent (from 7% on), and rises with each successive period.

VI. BROKERAGE ROLE

Which roles had scholars in regard to their influence on others? By following the brokerage approach by Gould and

Fernandez [8], we infer on the roles of scholars by analyzing the non-transitive triads, in which node A has a tie to node B, and B has a tie to node C, but there is no tie between A and C. In these triads, B is thought to play a structural role called a *broker*.

The possible roles are shown in Fig. 6, which are adapted from the work of Gould and Fernandez in [8], and Everett and Borgatti [2].[1] This allows us to consider to what extent a node's importance is based on joining two nodes that are members of the node's own era, or on joining others outside their group. We interpret nodal membership in groups as eras.

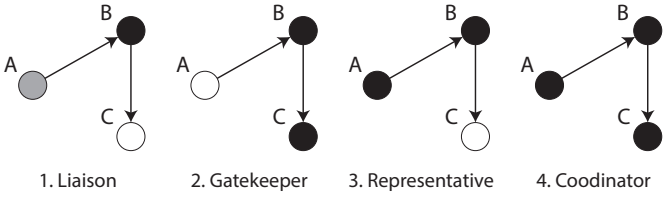

Fig. 6. Brokerage Roles of the top right node of each triad, adapted from Gould and Fernandez (1989) [8].

In Table VIII, we analyze the above-described brokerage roles for each period. Over all eras, 23% of all scholars have on average at least one of the above described brokerage roles. Since the Early Modern period, the amount of scholars with exactly one brokerage role remains very stable at about 12—13%, slightly higher in the Antiquity and Middle Ages. Both the first and the last of the periods could have a maximum of 2 different brokerage roles, because pre-processing didn't allow reverse links. Therefore, Representative and Liaison brokerage was impossible for Contemporary, as well as Liaison and Gatekeeper brokerage for Antiquity. Coordinator and Gatekeeper roles represent the scholars importance within their own period. Gatekeeper had inter-period influences and in turn influenced their contemporaries. The scholars with the highest scores for Gatekeeper in their respective periods are medieval polymath Avicenna (980—1037), Early Modern philosopher René Descartes (1596—1650), and Immanuel Kant (1724—1804), Friedrich Nietzsche (1844—1900), and Michel Foucault (1926—1984). The Coordinators with the highest scores are Plato, Avicenna again, John Locke (1632—1704), Johann Goethe (1749—1832), Friedrich Nietzsche, and contemporary horror writer Stephen King (born 1947). As Coordinators, these scholars represent a within-period influence. Liaison brokers have the longest time frame of influence, which includes three successive periods. Thomas Aquinas, the Dominican friar (1225—1274), and Early Modern philosopher Baruch Spinoza (1632—1677) had the highest scores, and again Immanuel Kant and Friedrich Nietzsche as Liaisons. Representatives took the reverse role of an Gatekeeper: they have a within-era influence that spread to a successive era. Plato, Thomas Aquinas, David Hume (1711—1776), Karl Marx (1818—1883) and Martin Heidegger (1889—1976) stand out.

From Middle to Modern Age, the amount of scholars with all four brokerage roles steadily increased. Noteworthy here were Thomas Aquinas (Middle Ages), Gottfried Leibniz (Early Modern Period), Georg Hegel (Transitioning Period), and Martin Heidegger (Modern Age), who appeared most often in super brokerage roles: They combined Liaison, Gatekeeper, Representative, and Coordinator roles alike in their respective periods. Surprisingly though, scholars with 3 brokerage roles were roughly ten times less common than those with all brokerages (compare Table VIII).

TABLE VIII
NUMBER AND FRACTION OF ACTORS TAKING 1, 2, 3, OR 4 ROLES

No. of Roles	1	2	3	4
Antiquity	55 (21%)	30 (11%)		
MiddleAges	62 (18%)	32 (9%)		12 (3%)
EarlyModern	101 (13%)	51 (7%)	2 (0.3%)	38 (5%)
Transition	136 (12%)	87 (8%)	6 (0.8%)	70 (6%)
ModernAge	363 (13%)	269 (9%)	5 (0.7%)	200 (7%)
Contemporary	879 (12%)	536 (7%)		
overall	1,596	1,005	13	320
	12.8%	8.0%	0.1%	2.6%

VII. CONCLUSIONS

In this paper, we incorporated a longitudinal aspect in the study of the influence networks of scholars. First, we extracted their social network of influence from YAGO, a pioneering data source of Linked Open Data, which records the main influences of and by intellectuals available from Wikipedia, WordNet, and GeoNames. Rigorous pre-processing resulted in a network of 12,705 intellectuals with 22,818 edges, including information on each scholar's era. We opted for a global approach for the periodization of history to match the internationality of scholars, resulting in six consecutive eras to study.

Our main question was whether we could identify patterns of influence, and their change over time. Therefore, we performed essential network analysis on every time-sliced projection of the entire network in within-era, inter-era, and accumulated-era influence networks. We investigated their social network metrics, degree distribution, and connectivity. An influence pattern throughout all eras was that the internal impact of any era was higher than its external impact. The vast majority of scholars influenced scholars of their own period (= within-era influence) with a relatively stable average out-degree. There were only a few instances of reciprocity. When accumulating eras, the max. degrees drastically increased. However, over all eras the maximum out-degree stayed greater than the maximum in-degree. In inter-era influence networks, each era hat the most influence on the consecutive one, and the Contemporary period. The exception to this rule was a spike in the absolute links of antique influences on the Early Modern period, representing the increased reception of antique scholars during the Renaissance. However, proportionally Antiquity's influence on Early Modernity was as high as on the Middle

[1]The fifth brokerage role, the *Consultant*, where A and C belong to one period, and B belongs to another, is not possible in our network, as we didn't allow reverse influences of a more recent period onto a previous one by pre-processing.

Ages, which reasserts the shift in historical research that the Renaissance thinkers did not "rediscover" Antiquity, but that medieval scholars also received it [3, p. 3—4].

With a longitudinal perspective, we can add a more pronounced view on who the most influential intellectuals are. The scholar with the highest out-degree over all periods on contemporaries (= within-era) was Modern age scholar Friedrich Nietzsche. Plato in Antiquity, Avicenna in the Middle Ages, John Locke in the Early Modern period, Johann Goethe in the Transition period and Vladimir Nabokov in the Contemporary period were the most influential on the contemporaries of their respective periods.

When accumulating eras, the most influential intellectuals of an era change: here, Plato was the most influential for Antiquity and the Middle Ages, Aristotle for the Early Modern and Transitioning period, Immanuel Kant for the Modern Age. In the Contemporary period, and therefore for the complete network of intellectuals, Karl Marx.

In the inter-era network analysis, Transitioning period scholar Karl Marx had the highest out-degree over all times to the Contemporary age. Modern intellectuals Friedrich Nietzsche and Martin Heidegger took second place over all time for the Contemporary period.

We constructed the longitudinal influence power of intellectuals based on the average of their influences on eras, which favors consistency of influence. Here, again, Aristotle, Thomas Aquinas, William Shakespeare, Karl Marx, Friedrich Nietzsche, and Vladimir Nabokov were the most consistently influential intellectuals of their respective periods. Nietzsche, Nabokov, and Marx had the highest influence.

In terms of knowledge brokering, we could identify Coordinator, Gatekeeper, Representative and Liaison knowledge brokers, whom we interpreted as passing influence between and within eras. We found that the scholars with all four different brokerage roles were medieval scholar Thomas Aquinas, Early Modern polygraph Gottfried Leibniz, Georg Hegel of the Transitioning period, and the Modern philosopher Martin Heidegger.

This study of the longitudinal patterns of influence is such suited to further the insights on the interconnections of influence of thinkers and the dynamics of eras alike.

Therefore, we plan to study the evolution of communities in these accumulated networks in future work. Another direction of research would be to study the effects of different periodizations on the importance of scholars, as well as deriving an automated periodization based on the dataset. In addition, we would like to compare this YAGO network of intellectual influence with a more detailed network of scholars based on the main books on intellectual history, in order to establish their differences and insights in this field of study.

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