Journal of Historical Network Research

3 | 2019

C²DH
LUXEMBOURG CENTRE FOR
CONTEMPORARY AND DIGITAL HISTORY

UNIVERSITÉ DU
LUXEMBOURG

Journal of Historical Network Research 3 (2019)

Articles

Reviews

KÖSTNER, ELENA

Trimalchio's last will: shifting interactions between seeming and being

Journal of Historical Network Research 3 (2019) 1-29.

Keywords

Cena Trimalchionis, last will and testament, testamentary gift exchange, *amicitia*

Abstract

During the *cena Trimalchionis* – maybe the most prominent episode of Petronius' *Satyrica* – we come to know of different testamentary dispositions focusing on Trimalchio as legatee, heir, and especially as testator. To analyze and visualize these different roles here, I used an approach derived from historical network research: the *ego-alter*-dyad enables a systematic analysis of interpersonal interactions which can be regarded as the basis of most Roman last wills. In ancient Rome, the testament (in the sense of a last will and testament) means a unilateral last will by which an heir was appointed, or a person intended by law to be an heir was excluded from inheritance. Apart from the legal context, a testament was also regarded as ultimate as well as financial confirmation of *amicitia* and family ties. In this article the ties connecting Trimalchio with his former *patronus*, friends, family members, and slaves are visualized in different graphs. It is the aim of this paper to bring both sources and graphs into a dialogue and interpret them together. By doing so, Trimalchio's *mimus* which he

performed when reading out his last will is explained. He did not reciprocate any of his mutual friendship or family ties in his will, but he did make his friends and family members believe he would do so. Thus Trimalchio violates a societal norm which was of paramount importance in Roman society. In his *cena Trimalchionis* Petronius creates a bizarre *mimus* where the *dramatis personae*, especially Trimalchio, are shifting between authenticity and illusion, between seeming and being.

1 Introduction*

The following analysis is based on one episode of Petronius' *Satyrica* which is one of the few Roman novels that has been handed down from antiquity. Only a few episodes of the *Satyrica* have survived, but they allow us to follow the ramble of the protagonist and narrator Encolpius in Italy of the 60s of the 1st century A.D. But Encolpius and his friends Ascyltos and Agamemnon as well as their slaves Menelaus and Giton, who maybe is also Encolpius' lover, are wandering through a fictitious upside-down world. The preserved part begins in the surroundings of a school of declamation in Campania where Encolpius and Agamemnon debate the decline of oratory. But it seems that they do not prefer orderly studies, because there follows a spontaneous visit to a brothel, sex, a jealousy scene with Giton in the centre, robberies, and a veritable orgy. Encolpius and his friends slide from adventure to adventure through a topsy-turvy world. Despite ongoing quarrels, economic hardship binds them together, beguiles them into committing larcenies, buffooneries, and frauds. An invitation to the house of Trimalchio, a wealthy and eccentric freed man, is accepted by the friends and they experience a decadent banquet there. The so-called *cena Trimalchionis* is at the centre of this study. After the banquet, Ascyltos and Encolpius split in a quarrel. The latter, together with Giton and the aging poet Eumolpus, sets off for Kroton (Southern Italy), where they play a trick on the

* **Acknowledgments:** Parts of this paper were presented at the seminar on methodology of the Max-Weber-Program at the University of Erfurt in January 2019. I would like to thank Dr. Asuman Lätzer-Lasar for the invitation to Erfurt and for further remarks. My thanks for useful comments also go to Dr. Markus Gamper (University of Cologne), Dr. Maik Patzelt (University of Osnabrück), and the participants of the seminar.

Corresponding author: Elena Köstner, Chair of Ancient History, University of Regensburg, Elena.Koestner@ur.de

local legacy hunters: Eumolpus presents himself as a rich man and a potential testator, to be ensnarled by the legacy hunters.

The partly dizzying, wild, and rapidly narrated plot seems untamable according to stylistic or formal constraints to any literary genre. Nikolas Holzberg for example sees the *Satyrica* as a "komisch-realistischen Roman" which does not fit formally or textually into any genre.[1] Because of the *Satyrica*'s fragmentarization, contemporary readers are thrust into the plot without knowing Petronius' intention.[2] And despite the satirical character of the novel, the individual episodes are characterized by a closeness to everyday life. It is a critique of imperial society, which no longer seems to offer any orientation to the individual. The *cena Trimalchionis*, for example, portrays *liberti* who are denied actual social advancement in spite of their persistent work and economic success. They remained *liberti*. It can be assumed that Petronius, who is perhaps identical with the senator mentioned in the 16th book of Tacitus' *Annals*, created an autonomous and vivid work, implementing his literary models as a montage, a comic as well as satiric adventure story.[3]

The most prominent passage of the *Satyrica* ist probably the *cena Trimalchionis* which has been much debated in research.[4] As already briefly explained at the beginning, Encolpius and his friends are invited by Agamemnon to the banquet of Trimalchio, a former slave (*libertus*), who had become wealthy and who now invites his guests to extraordinary meals and performances in his house. Petronius describes Trimalchio as a *nouveau riche*, a decadent *parvenu* who does not care about conventions and social norms at all.

---

1 Holzberg, "Der antike Roman," 22; cf. Perry, "Ancient Romances," 87; Courtney, *Companion to Petronius*, 24; Murgatroyd, "Petronius' *Satyrica*," 2013, 241; Sevéry-Hoven, "*Satyrica* of Petronius," 33–46; Roth, "Liberating the *Cena*," 614–615. Bracht Branham and Kinney, *Satyrica*, xxiii: "*Satyrica* (the neuter plural of the adjective *satyric*) is rather a heuristic metaphor for the moral ambiance of the fictional world Petronius has created."

2 Slater, "Reading the *Satyrica*," 18: "[…] the world of the *Satyrica* is full of surprises, of sudden and sometimes violent changes of action, scene, or mood […]."

3 Schönberger, *Satyrgeschichten*, 18; cf. Courtney, *Companion to Petronius*, 31–39; Slater, "Reading the *Satyrica*," 21–22. For further information about Petronius see Tac. ann. 16.17.1; 16.18.1–2; 16.19.5; Plin. nat. 37.20. Much more is not known about the author of *Satyrica*. Plass, *Game of Death*; Baldwin, "Tacitean Petronius," 15–18; Courtney *Companion to Petronius*, 5–9; Hill, "Ambitiosa Mors," 237–251; Slater "Reading the *Satyrica*," 27; Vout, "Neronian Culture," 101–103; Völker and Rohmann, "*Praenomen Petronii*," 660–676 and especially 660, footnote 1–2.

4 Cf. Harrison 1998, 580–585; Murgatroyd, "Petronius' *Satyrica*," 241. For an overview concerning the *Satyrica*'s fragmentation see Courtney, *Companion to Petronius*, 43–49; Slater, "Reading the *Satyrica*," 17–20.

The following episode can also be seen in this context: during this banquet the host Trimalchio reads out his last will. Apart from the legal context, a will was also regarded as the ultimate as well as financial confirmation of *amicitia* and family ties. It was quite unusual to read a will before the testator died. But this fits into Petronius' social criticism. Especially the connections resulting from wills, which existed between some participants of the *cena* as well as to persons who are not present during the banquet, are of special interest. Besides Trimalchio's role as *testator* I also stress his role as heir and legatee here, a role that remains underresearched. Wills can be used as a source to analyse interpersonal relationships as well as to scrutinize the obligations and expectations attached to them. From this point of view, it does not matter whether the persons and relationships to be analysed are known from historiography or from fictional texts.

Historical network research seems the appropriate approach to analyze and visualize the interactions between testator, heirs, and legatees, and to compare these links with other interpersonal relationships. I assume that in the abstract, an *amicitia* or *familia* relationship was based on two entities, the *ego* and the *alter*, and both together built a dyad which was above all based on reciprocity and mutual services. Both *ego* or *alter* can be joined to further entities displayed as nodes; together they form a network. Additionally, it was vital for friendship ties that *ego* and *alter* corresponded in main aspects and internal attitudes (*morum similitudo*). Ideally, *alter* can be regarded as *alter ego*. Furthermore, *ego* or the self regards oneself as a role model for the other. In modern literary studies, the concepts of otherness and alienness were used to determine the self, the other, and the stranger.[5] The other (*alter*) is not any other, but the other in a relationship between two coequal entities. By contrast, the stranger (*alius*) does not have any or almost no similarities with the *ego*; they are completely alien to each other. The *ego* or the self needs the other and, in some cases, also the stranger for acts of identity like self-description and self-rule. Foremost, the *ego* is interested in confirming the self as norm. Despite their origin in modern literary studies, the concepts of otherness and alienness will also be fruitful to analyze Roman *amicitia* relationships which occur in wills, as Roman friendship discourse already knows the *ego-alter*-dyad.[6]

---

5 For further information and bibliographic references concerning Historical Network Research as well as otherness, identity, and related fields see e.g. Assmann, *Problem der Identität*, 238–253; Köstner 2018b, "Ein gefundenes Fressen," 192, footnote 3; Köstner, "Partizipation, Alterität und Alienität," 14–23.

6 Cf. e.g. Aristot. pol. 1253a; 1285a; eth. Nic. 1156a; 1178a5; metaph. 10.3.1054b16; Plat. nom. 967–979; 949e–953e; soph. 256a; symp. 207d–e; Parm. 137c–e; rep. 5.470c1; 5.471b7; 9.586e2.

All information concerning the nodes and ties are taken from Petronius' *Satyrica*, more precisely from the episode about the *cena Trimalchionis*. The characters and their connections will be discussed in more detail in section 2.

(1) My focus is set on the characters who participated in the *cena Trimalchionis* or were mentioned in connection with wills during the banquet. Within the graphs the characters are displayed as nodes whereby different colors indicate the quality of their relationship with Trimalchio (family members, friends or external guests as well as testators respectively heirs not present during the banquet) as well as their appearance at the dinner and their interaction with others during the *cena*: the host Trimalchio and his wife Fortunata (both *liberti*) are displayed as pink nodes. Trimalchio's friends, who are all *liberti*, are represented in different shades of blue (the gradations are explained in more detail below as well as in Chapter 2 and in the corresponding graph). These men have known each other for a long time and can rely on what they have experienced together. Trimalchio's slaves who work during the *cena*, i.e. serve food and drinks, are represented as orange nodes. They differ from Trimalchio and its guests in their legal and social status as *servi*. Encolpius and his friends are displayed as green nodes. Their legal and social status varies: while Encolpius, Ascyltos and Agamemnon were likely Roman citizens (*civis Romani*) or *liberti* (the text does not allow a more precise definition), Giton and Menelaus were slaves. Although Agamemnon had received an invitation to Trimalchio's banquet, it cannot be assumed that they knew the host, his other guests or the slaves well. It was not unusual to invite members of a school of declamation to a *cena* to provide entertainment. Those mentioned in connection with wills during the dinner but not present are shown as grey nodes.

(2) The ties visualize the interaction between the persons. On the one hand, there are the relationships that are known in the context of wills: thus who is the testator, who are the heirs and the legatees and what binds them together? So, it is about the appreciation of mutual services (e.g. financial and legal support) and gifts (e.g. wishes for recovery, invitation to the theatre) in a will. Petronius does not go deeper into such services and gifts. This exchange was obligatory between friends or family members, but it had already taken place before the banquet.

On the other hand, the interactions between the participants of the *cena Trimalchionis* are presented in order to compare them with those known in connection with wills. In that context 'intensity' seems to be a suitable category, in order to differentiate these interactions. Thus, only those relationships are displayed within the graphs which indicate a deeper, more intense interaction during *cena*: not only listening to a conversation or doing small talk, as e.g. Encolpius and his friends do, but in fact having more intense conversations and discussions with each other, e.g. about mutual *amici*, as Trimalchio's friends do. Thus, it matters how long they knew each other and what they have in common.

participants of the *cena Trimalchionis* and testators or heirs	social status (with regard to Trimalchio)	legal status	testamentary relationships	intensity of interactions (with regard to Trimalchio)
Trimalchio	*familia*	*libertus*	yes	----
Fortunata	*familia*	*liberta*	yes	xxx
C. Pompeius	*familia*	*civis*	yes	xxx
Emperor	*'amicus'*	*civis*	yes	x
Pansa	*amicus*	*libertus?*	yes	xx
Saltuarii	*servi*	*servi*	no	xx
Encolpius	*amicus/external*	*civis?*	no	-
Ascyltos	*amicus/external*	*civis?*	no	-
Agamemnon	*amicus/external*	*civis?*	no	x
Giton	*servus/external*	*servus*	no	-
Menelaus	*servus/external*	*servus*	no	-
Hermeros	*amicus*	*libertus*	no	xxx
C. Iulius Proculus	*amicus*	*libertus*	no	xxx
C. Pompeius Diogenes	*amicus*	*libertus*	no	xxx
Damas	*amicus*	*libertus*	no	xxx
Seleucos	*amicus*	*libertus*	no	xxx
Phileros	*amicus*	*libertus*	no	xxx
Ganymed	*amicus*	*libertus*	no	xxx
Echion	*amicus*	*libertus*	no	xxx
Niceros	*amicus*	*libertus*	no	xxx
Plocamus	*amicus*	*libertus*	no	xxx
Habinnas	*amicus*	*libertus*	no	xxx
Scintilla	*amica*	*liberta*	no	xxx
Philagyrus	*servus*	*servus*	yes	xx
Menophila	*serva*	*serva*	yes	xx
Cario	*servus*	*servus*	yes	xx
Dionysios	*servus*	*servus*	no	x
Croesus	*servus*	*servus*	no	x
Carpus	*servus*	*servus*	no	x
Daedalus	*servus*	*servus*	yes	x
Stichus	*servus*	*servus*	no	x

Table 1. Comparison of testamentary and interpersonal relationships. Relationships based on the *cena Trimalchionis* and with regard to Trimalchio as central hub: social status of the participants displays mutual obligations and expectations within the context of *amicitia* and *familia* (*familia*, *amicus*, *amicus/external*, *servus*); legal status may have a limiting effect (*libertus/liberta*, *servi*, *civis*); intensity of interactions: high (xxx), middle (xx), low (x), no interaction (-).

Trimalchio and his friends are close to each other because they share a common past. Encolpius and his friends came to the *cena* by invitation. But it seems that, according to the text, Agamemnon and Trimalchio were not close friends in the past. Their interactions during the banquet remain rather superficial; this also applies to the relationship between Encolpius or Ascyltos and the host.

These relationships depend furthermore on the social and legal status of the individuals. For example, the *servi* are in contact with all the guests, i.e. they serve food and drinks and engage in small talk. Their interactions remain on a rather superficial level because they do not have the same social as well as legal status. Therefore, these relationships are not displayed within the graphs, though the slaves know each other very well (they may have been working together in the household of Trimalchio for years). These relationships are displayed within the graph. To sum up for the moment: one part of the relationship is defined by testamentary interactions, between testator, heir or legatee. Another part of the relationships is determined by intensity, e.g. the deep closeness and familarity among the *liberti* or the distance of Encolpius and his friends towards the other guests and the *host*; Petronius depicts them as observers of the scenery, captivated by fascination and horror. In his *Satyrica*, Petronius alienates the social relationships of Roman society, focusing on the group of the *liberti*. The aim of this paper is to find out whether these different forms of interpersonal relationships are congruent, whether there were any distinctions, and how is this related to the Trimalchio's *mimus*.

(3) I create graphs with the software *Visone* to visualise interpersonal and testamentary relations. Besides using graphs, the theoretical framework derived from historical network analysis – the *ego-alter*-dyad – is applied to analyze social and testamentary relationships. As already mentioned, different categories define the ties shown within the graphs. To my mind, it is essential to present all these different ties in one graph and to display in color and in different line types those relationships which are actually important and belong to a certain text passage. In particular, the markings of some ties illustrate e.g. Petronius' narrative structures, interpersonal relationships and testamentary interactions. It is the aim of this paper to bring both sources and graphs into a dialog and interpretate them together. By this means, Trimalchio's *mimus,* which he performed when reading out his last will is explained. He did not reciprocate any of his mutual friendship or family ties in his will, though he makes his friends and family members believe he would do so. Thereby, Trimalchio violates a societal norm which was of paramount importance in Roman society. In his *cena Trimalchionis* Petronius creates a bizarre *mimus* where the *dramatis personae*, especially Trimalchio, were shifting between authenticity and illusion, between seeming and being. Moreover, the bizarre and dazzling episode concerning the *cena Trimalchionis* and particularly the publication of the host's will is suitable to demonstrate the connection between source material and

graphs, their joint interpretation, and the application of network analysis to a fictional text from the Roman Imperial Period.

2 The *cena Trimalchionis*: "*Ergo, inquit, cum sciamus nos morituros esse, quare non vivamus?*"[7]

2.1 The *dramatis personae* of the *cena Trimalchionis* and further characters

To begin with, the *dramatis personae* present at the *cena Trimalchionis* and the relationships only mentioned during the *cena* and related with the host Trimalchio and wills must be gathered. In this context and first of all, we must start with the narrator Encolpius. He seems to slide without any orientation from adventure to adventure through the topsy-turvy world of the novel.[8] At his side, we meet Giton, his lover and/or his slave.[9] Encolpius and Giton can be regarded as the original dyad, but in chapter 10.7 Ascyltos joins the two; he is expanding the original dyad to a "love-triangle" (until chapter 98).[10] Encolpius, Ascyltos, and maybe also Giton are *scholastici*, which does not necessarily mean that they study oratory. In fact, they can be regarded as "groupies […] who hung around the schools of declamation and […] aped their style in everyday dealings."[11] In the surroundings of such a school of declamation these three men got in contact with Agamemon who was perhaps a teacher of oratory. In Agamemnon's company Encolpius, Ascyltos, Giton as well as Agamemnon's slave Menelaus attend Trimalchio's dinner (Figure 1). Within the graph, they are represented by green nodes. Based on the text, it can be assumed that they knew each other well, but not the host or his other guests, as will become apparent later.

---

7 Petron. 72.2: "Well, well, if we know we must die, why should we not live?" (for all *Satyrica*-passages see Petronius/Seneca. 1969. "Satyricon – Apocolocyntosis", edited and translated by Michael Heseltine, William H. D. Rouse and Eric H. Warmington, Loeb Classical Library London: Heinemann).

8 Cf. Walsh, "Roman Novel", 234–235; Murgatroyd, "Petronius' *Satyrica*", 243.

9 The *Satyrica* does not make doubtlessly clear if Giton was Encolpius slave or his boyfriend or maybe both.

10 Cf. Courtney, *Companion to Petronius*, 49; Andreau, "Freedmen in the *Satyrica*", 117.

11 Courtney, *Companion to Petronius*, 39–40; cf. Petron. 10.6; 39.5; 61.4.

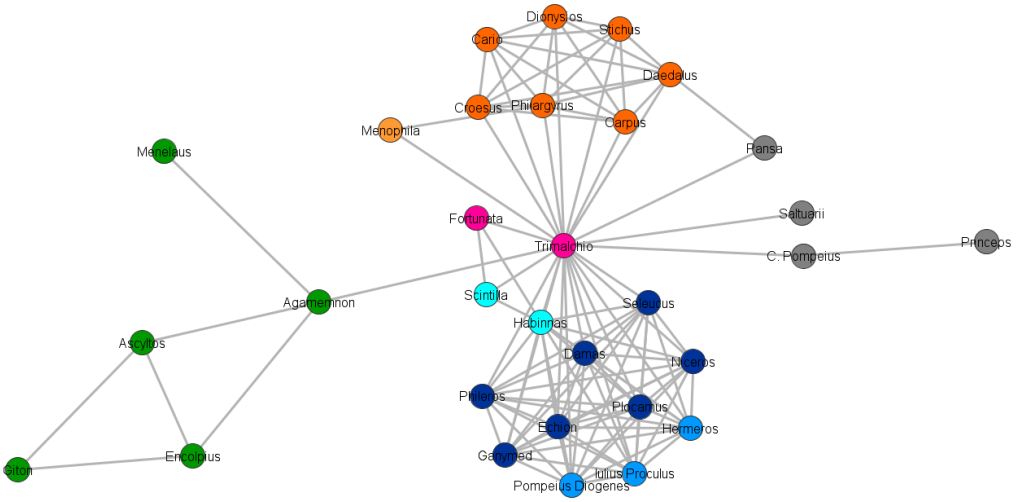

Figure 1. The nodes show the participants of Trimalchio's *cena* and the persons related to Trimalchio by testamentary dispositions. The different colors display their social or legal status (*servi*, *liberti*, or *cives*) and the quality of their relationship to Trimalchio (family members in pink, slaves in orange, friends in different shades of blue, external guests in green, and persons mentioned during the *cena* in relation with testamentary dispositions but not yet present in grey). The ties visualize the interaction between the individuals, whereby 'intensity' determines them as well as the legal status of the persons which limits their scopes.

Perhaps Encolpius and his friends were invited to entertain Trimalchio's guests and in return they were offered free meals and drinks during the dinner. Despite, or maybe because of these prospects, their motivation to attend the dinner was pretty poor:

> *"Venerat iam tertius dies, id est expectatio liberae cenae, sed tot vulneribus confossis fuga magis placebat quam quies. Itaque cum maesti deliberaremus quonam genere praesentem evitaremus procellam, unus servus Agamemnonis interpellavit trepidantes et: 'Quid? vos, inquit, nescitis hodie apud quem fiat? Trimalchio, lautissimus homo. … Horologium in triclinio et bucinatorem habet subornatum, ut subinde sciat quantum de vita perdiderit!'"*

> "The third day had come. A good dinner was promised. But we were bruised and sore. Escape was better even than rest. We were making some melancholy plans for avoiding the coming storm, when one of Agamemnon's servants came up as we stood hesitating, and said, 'Do you not know at whose house it is today?

> Trimalchio, a very rich man, who has a clock and a uniformed trumpeter in his dining-room, to keep telling him how much of his life is lost and gone.'"[12]

In company of Agamemnon and Menelaus, Encolpius, Ascyltos and Giton go to the house of Campania's richest man (displayed in the graph as a pink node), C. Pompeius Trimalchio, a bald-headed, fat man wearing a scarlet robe and jewelry.[13] He phenotypically embodies the crude *nouveau riche* and vulgar host. His habits complement his appearance: he leaves his guests alone for quite a long time to use a potty, he advertises flatulating at any time, and encourages his guests to comment on his intestinal activity. On the one hand, Petronius draws the picture of a decadent and awkward *nouveau riche*. On the other hand, he describes Trimalchio as a self-made man, a *libertus* who first gained wealth due to commercial activities, then lost property but is on the social and financial ascendant again due to his financial transactions and income from letting and leasing, as well as from his estate (*villa rustica*).[14] He must have been a rich man indeed, as he is a *sevir Augustalis*, an office which requires wealth. In Trimalchio's eyes, wealth stands for status and reputation. But – and this is typical for a *parvenue* in the *Satyrica*'s interpretation – he lacks decency and morality. Gilbert Bagnani, e.g., calls him a *noveau riche* without any social ambitions but with a pronounced sense for swank and pomp.[15] The luxurious living was only possible because of his economic success, for which his wife was responsible, too. Fortunata is described as a former chorus girl ransomed by Trimachio.[16] Her keen eye and business skills helped Trimalchio prevent further financial losses.

Trimalchio invited his guests to his house – allegedly located in a *Graeca urbs* – which he converted into an extraordinary palace with, amongst others, four dining rooms, 20 bedrooms and two marble halls decorated with wall paintings showing the milestones of his life.[17] It is a fantastical architecural construction in narrative fiction, which did not exist in real life, but is absolutely necessary for the novel. Petronius invented a house of a manner which his readers and audience were expecting, and which they associated with a person like Trimalchio. The interior design of the rooms follows the exterior, as does the dining room where the *cena* and the reading of the will take place. The dining

---

12 Petron. 26.7–9; cf. Bechet, "Fear and Irony," 118–119.

13 Cf. Petron. 27.

14 Cf. Bagnani, "Trimalchio," 87–89; Brown, *Character-Portrayal*, 18–19; Andreau, "Freedmen in the *Satyrica*," 115; Ramsey, "Freed Slave," 73–74; Petron. 30.2; 71.12.

15 Cf. Bagnani, "Trimalchio," 78–79. Concerning Trimalchio's origin and childhood see Bagnani, "Trimalchio," 78–87; Wade Richardson, "Young Trimalchio," 201; Baldwin, "Young Trimalchio," 143–146; Petron. 44.4; 75.10–11; 71.7; 97.2.

16 Cf. Petron 37.1–7; 66–67; 74.13–77.7; Brown, *Character-Portrayal*, 38.

17 Cf. Bagnani, "House of Trimalchio," 17; Petron. 77.4.

room's entrance was decorated with a bronze ship's prow as well as *fasces* and axes, the consul's insignias. It seems that Trimalchio, a former slave, appropriated the insignias and symbols of Rome's highest office, although he could not actually hold the office; this is Petronius' point exactly. In this opulent dining room, Trimalchio and his guests use exquisite tableware and feast on select and extraordinary dishes. One small glimpse must suffice here to give an impression of this banquet, which Emily Gowers describes as "a dizzying synesthetic experience":

> *"[…] in quo positus erat primae magnitudinis aper, et quidem pilleatus, e cuius dentibus sportellae dependebant duae palmulis textae, altera caryatis, altera thebaicis repleta. Circa autem minores porcelli ex coptoplacentis facti, quasi uberibus imminerent, scrofam esse positam significabant."*
>
> "[…] a tray was brought in after them with a wild boar of the largest size upon it, wearing a cap of freedom, with two little baskets woven of palm-twigs hanging from his tusks, one full of dry dates and the other of fresh. Round it lay suckingpigs made of simnel cake with their mouths to the teats, thereby showing that we had a sow before us."[18]

During the *cena*, Encolpius, Ascyltos, Agamemnon, and their slaves stayed in the background, listened to the conversations and watched the action: the *liberti* are talking mostly about mutual friends and sometimes they are disputing with each other. They are watching Trimalchio's slaves – Carpus, Daedalus, Croesus, Dionysus, Stichus, Philargyrus, and Cario (orange nodes within the graph) – serving dishes and interacting with the guests.[19] Encolpius and his friends appear only as observers, they mostly remained passive and maintained a certain distance to the action; this becomes clear in the graph, too. Within these intertwinings, Agamemnon can be regarded as broker (Figure 1): with his tie to Trimalchio he connects different clusters, viz. he enabled Encolpius and his friends to participate in the *cena*, whereby they still remained outsiders. Agamemnon bridges what I call the Encolpius-cluster with the clusters of Trimalchio's *amici* as well as with the cluster of his slaves. Of course, Trimalchio as central hub – host and testator – connects the different clusters consisting of his *amici*, *servi*, and external guests. Of course, we have to rely on the information

---

18 Petron. 40.3–4; Gowers, "Tasting the Roman World," 94; cf. Arrowsmith, "Luxury and Death," 304–331.

19 Relating to the slaves mentioned during the *cena Trimalchionis* Barry Baldwin ("Domestic Staff", 96) also states Cinnamus, Menophila und Nasta. But it is not clear if these were in fact working at Trimalchio's dinner, hence they were not mentioned in the graph (apart from Menophila).

given in the text. Although the *Satyrica* is fiction, but it is also a critique of society that scrutinizes interpersonal relationships and the norms associated with them.

Trimalchio can be understood as the heart of the *cena*, the guests pay close attention to him, and he enjoys it. This interpretation is supported by betweenness centrality, i.e. a measure of centrality in a graph based on the shortest paths. And this is also where Mark Granovetter's considerations on weak ties and Ronald Burt's theory on structural holes can be introduced: even though the relationship linking Agamemnon and Trimalchio must be regarded as weak and rather superficial, their tie bridges a structural hole.[20] Structural holes occur when two or more close-meshed, homogeneous network clusters are connected by only one or a few bridges. Although Agamemnon receives an invitation to the *cena*, it seems that he does not belong to the inner circle of Trimalchio's *liberti*. In Roman society it was apparently not unusual to invite guests as entertainers and grant them free meals and drinks in return, especially when one hoped that their rhetorical skills would contribute to the entertainment. So there must not necessarily have been an intensive connection between Agamemnon and Trimalchio. Actors flanking such a bridge over structural holes like Trimalchio and Agamemnon boast a higher betweenness centrality, which identifys them as brokers. Additionally, the cluster of Trimalchio's *amici* as well as the cluster of his *servi* show high density. The persons within these clusters are interacting with each other during the dinner, but their social respectively legal status separates the members of the two clusters. While the slaves serve food and drinks and ensure a smooth flow among each other, their interactions with Trimalchio and his guests are very limited (e.g. instructions to the slaves and their short replies). In contrast, Trimalchio's friends are engrossed in deeper conversations (more on this later), but Encolpius and his friends are not involved; they remain observers of the banquet. In addition to the legal status, the intensity of the interactions is also decisive: Encolpius and his friends have no common past with Trimalchio and his friends; they do not know the same people and have not experienced anything together. Their interactions during the banquet remain rather superficial. Thus, it matters how long they have known each other and what they have in common.

---

20 Cf. Granovetter, "Strength of Weak Ties", 1360–1380; Burt, *Structural Holes*, 18–20.

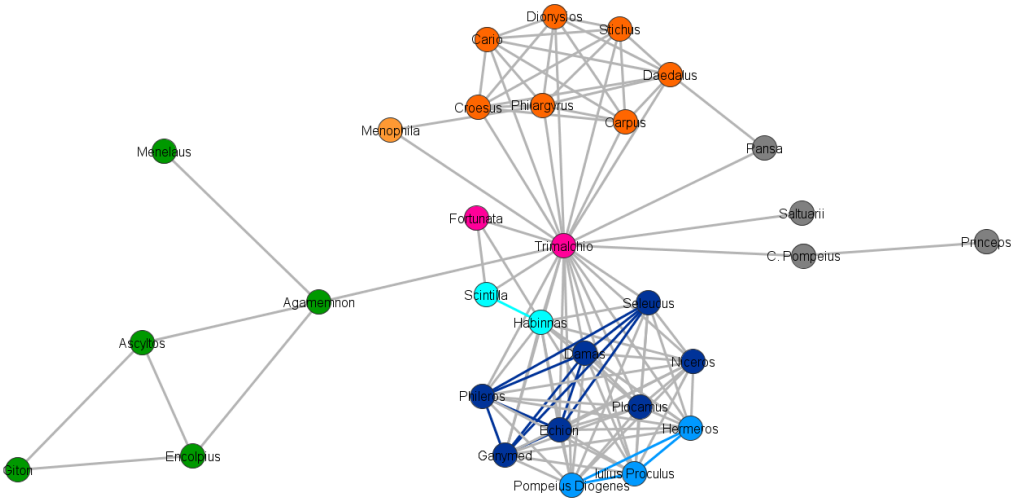

Figure 2. The nodes show the participants of Trimalchio's *cena* and the persons related to Trimalchio by testamentary dispositions. The different colors display their social or legal status (*servi, liberti, or cives*) and the quality of their relationship to Trimalchio (family members in pink, slaves in orange, friends in different shades of blue, external guests in green, and persons mentioned during the *cena* in relation with testamentary dispositions but not yet present in grey). The ties visualize the interaction between the individuals, whereby 'intensity' determines them as well as the legal status of the persons which limits their scopes. Here some of the ties are marked additionally with the color of the respective subgroup and thus, it is possible to visualize Petronius' narrative structure of Trimalchio's *amici*-cluster (see text below): Hermeros, C. Iulius, and C. Pompeius Diogenes in light blue, Echion, Ganymed, Damas, Seleucus, and Phileros in dark blue, Habinnas and Scintilla in turquoise.

Figure 2 focuses on Trimalchio's *amici* (displayed in different shades of blue). It illustrates the structuring of narration and Petronius' literary composition: Trimalchio's *amici* were all *liberti* who came from different parts of the *imperium Romanum*. They were brought as slaves to the Italian peninsula. In most of the cases, they were professionally successful and thus they had sufficient financial resources. But they did not come close to Trimalchio's wealth. Despite their wealth, they are denied actual social advancement. Trimalchio's guests can be subdivided in different subgroups. It can be assumed that Petronius' approach helps the reader to distinguish the different characters and keep an overview of Trimalchio's *amici*. To make these structures inside the *amici*-cluster visible in the graph (Figure 2), the ties linking the *amici* are shown in the color of the respective subgroup. One of the *liberti* is called Hermeros. We do not know what his job was, exactly, only that he disposed of financial resources comparable to those of Trimalchio; like the latter, he too was a *sevir*

Augustalis.[21] He talks to two men: the undertaker C. Iulius Proculus and his wealthy friend C. Pompeius Diogenes (nodes and ties in light blue).[22]

The other *liberti* – Damas, Seleucos, Phileros, Ganymed, Echion, Niceros, und Plocamus (nodes in dark blue) – are talking to each other about common friends, about gossip. Thus, they present their biographies in a kind of condensed self-communication. It is quite clear that they have known each other for many years. Nonetheless, in my opinion, their immense familiarity does not prove Jean Andreau's observation that all these men were former slaves in the *domus* of C. Pompeius, Trimalchio's erstwhile *patronus*.[23] Another smaller subgroup is composed of Echion, Ganymed, Damas, Seleucus and Phileros who are involved in a vigorous debate (ties in dark blue).[24] Ganymed criticizes his friends because of their aloof opinions and maybe because he is threatened by financial debt and societal decline. Again, Petronius creates structures within his narrative composition. And there is a further subgroup consisting of the couple Habinnas and Scintilla. These two arrived late for the *cena*.[25] Habinnas is – like Trimalchio and Hermeros – a *sevir Augustalis* and therefore probably also wealthy. It is mentioned that he is a stonemason and – later in the story – Trimalchio wants him to build his funerary monument.[26] It is likely that Scintilla and Fortunata know each other quite well (nodes and ties in turquois).

As already stated, during the *cena* Encolpius and his friends stayed in the background, listened to the conversations between Trimalchio and his friends.[27] Encolpius and his friends are first and foremost observers: they do not know the other guests from earlier gatherings, they have nothing or not enough in common with Trimalchio's *amici*. Nor do they fulfil their role of providing entertainment with their rhetorical talent. Here, both the intensity of the relationships as well as the social and legal status of the persons are decisive. In the case of the cluster of Trimalchio's friends, the literary composition of Petronius can be recognized. These men seem to be closely linked, whereby

---

21 Concerning Hermeros see Brown, *Character-Portrayal*, 44; Petron. 36–38; 57–59. Concerning Trimalchio's guests see Andreau, "Freedmen in the *Satyrica*", 120: "[…] Trimalchio's dinner party formed a single and unique *familia* […]."

22 Cf. Brown, *Character-Portrayal*, 55–56; Petron. 38.7; 38.10; 38.15–16.

23 Cf. Andreau, "Freedmen in the *Satyrica*," 120. According to the different *liberti* see Brown, *Character-Portrayal*, 57–69; Andreau, "Freedmen in the *Satyrica*," 117–119; Petron. 40.10–12; 21.2–4; 42.6–7; 43.1–2; 43.6–7; 44.15; 45.1–4; 63.1–10; 64.3–5.

24 Cf. Petron. 41.9–46.

25 Cf. Brown, *Character-Portrayal*, 65–69; Petron. 65–71.

26 Concerning Trimalchio's plans for his funeral monument see Petron. 71.5–12; Perkins, "Naming Power," 139–162; Hope, "At Home with the Dead," 147–151; Ramsey, "Freed Slave," 73; Roth, "An(other) Epitaph for Trimalchio," 422–425.

27 Cf. Petron. 33.5–8; Slater, "Reading the *Satyrica*," 23; Ramsey, "Freed Slave," 69; 81.

Encolpius and his friends were not welcomed or did not want to be integrated. The slaves who served food and drinks during the banquet were excluded from deeper interactions with the members of the other clusters because of their social and legal status. The analysis and visualization of the interpersonal relationships is necessary in order to then scrutinize and visualize the testamentary relationships and compare these forms of social relationships and interactions. In this way, Trimalchio's *mimus* and Petronius' social critique can be deciphered.

2.2 Trimalchio's testamentary relationships and his last will

2.2.1 Legal issues concerning last wills und the opening of a testament

In this paper, I intend to shed light, on the one hand, on Trimalchio's guests who come together in a bizarre *domus* enjoying an extraordinary meal. They are the audience for the opening of the host's last will. On the other hand, I also focus on testamentary relationships which means testamentary dispositions Trimalchio benefitted from as well as his own testament read out during the dinner.

First, however, it is necessary to clarify some legal issues concerning last wills in Rome. It is probable that Petronius took the *testamentum per aes et libram* as basis for all wills stated in the *Satyrica*, because it was the common form of testating in the 1st century A.D. Originally, with such a testament the testator's property was transferred to the *familiae emptor* in a symbolic act of purchase.[28] According to Trimalchio's will, it can be assumed that he has already completed this procedure: it was drawn up in front of five witnesses, the *libripens*, and the *familiae emptor*.[29] The persons mentioned in a last will (and those hoping to be

---

28 Cf. Gai. inst. 2.103–104; 2.97–98; Babusiaux, *Römisches Erbrecht*, 142; Jakab, "Inheritance," 498. The term *familiae emptor* is difficult to translate because the tasks associated with this function have changed over time. In general, the *familiae emptor* can be understood as a kind of estate administrator or executor, i.e. an intermediate person who purchased the inheritance symbolically and then transmitted the inheritance to heirs and legatees. Originally the *libripens* (scale-holder) probably actually weighed the uncoined copper which served as a means of payment. Later, especially in the case of wills the weighing became purely symbolic and the scale-holder functioned as another witness.

29 Cf. Babusiaux, *Römisches Erbrecht*, 139; Meyer, *Legitimacy and Law*, 161–162: „They [= the testator's friends who testified the last will] would add their seals to yours on whatever type of document was being constructed, showing to the world an

named) highly anticipated the moment of breaking the testament's seals and reading it out in public (or private).[30]

There was more than one possibility to open a will and make its contents public. In this context, Trimalchio's procedure must be interpreted: for one thing, breaking the testament's seals in public, e.g. in the presence of a praetor,was not unusual. Then again, it was also possible to read out a last will at the testator's *domus*, but we have no further information on which of these variants was more common or, perhaps, more traditional. We know that it was not unusual to talk about the content of a last will before it was opened.[31] But usually a testament was opened officially only after the testator's death. Having said this and remembering the bizarre setting of the *cena* which contradicts every norm, Trimalchio's dinner was not the appropriate occasion to open a will.[32] But this episode fits perfectly into Petronius' portrayal of Trimalchio's habitus with which he criticises the excessive importance of wills in Roman society.

2.2.2 Trimalchio as heir and legatee

But before having a closer look at Trimalchio as testator, his role as heir and legatee is worth mentioning in detail. Thus, Petronius depicts him as a typical member of the Roman sub-elite who not only benefited from testamentary depositions of his fellows economically, but also socially as well as symbolically. In general, this testamentary exchange was of paramount importance for any Roman aristocrat and an integral part of aristocratic habit because it honored friendship ties.

---

immediate public adherence to you. […] The *fides* of the sealers built a proud and self-satisfied rampart for a document that crumbled once those seals were broken, the *fides* leaking away through the breach." (cf. Sall. Cat. 16.2; Cic. Q. fr. 1.1.13).

30 According to E. Champlin (*Final Judgments*, 64–70) only little time passes between drawing up a last will and breaking the testament's seals (cf. BGU 1655; 2244; 326; 361; P. Coll. Youtie 64; P. Oxy. 2348; 3758; Suet. Claud. 44.1; App. civ. 1.105; Tac. ann. 14.29; Dig. 36.1,63; 32.102.1). But there exist enough examples showing the contrary, see e.g. Tac. ann. 3.16.5–7; 3.76; 17.8; 18.1; Suet. Aug. 17.1; Suet. Tib. 49.1; Suet. Vita Persi 3; Val. Max. 7.7.2–4; 7.8.2–3; 7.8.6; Sen. Clem. 1.15.4 = 3.13,4; 1.15.6 = 3.13.6; Plut. Ant. 58.4–8; Cass. Dio 50.3.3–5; 51.15.7.

31 Cf. Champlin, *Final Judgments*, 23; Mart. 9.48.1–3; 11.67; 12.40; 12.73; Lucian. dial. mort. 19 (9).3; Cic. Att. 14.3.2; 14.5; Val. Max. 7.6.8; 7.8.5; Cic. Phil. 2.4.1.

32 Severy-Hoven, "*Satyrica* of Petronius," 23: "If good company and simple meal were the paragons of virtue, then Trimalchio is a debauched mess."

To begin with, I want to mention the last will of Trimalchio's *patronus* C. Pompeius who made his slave co-heir besides the emperor:

> *"coheredem me Caesari fecit, et accepi patrimonium laticlavium."*
>
> "I was joint residuary legatee with Caesar, and came into an estate fit for a senator."[33]

To analyze this short passage in detail, I start with the emperor's roles when a Roman citizen died (Figure 3): first, the emperor can be regarded as supreme administrative officer who was responsible for the inheritance tax *(vicesima hereditatum)*; second, he could receive *bona caduca* and *bona vacantia*, and third – which seems in my opinion to be the most difficult and delicate role – he could be an heir or legatee.[34] As this is the role in which the the nameless emperor of the *Satyrica* is mentioned, it needs further explanation here. During the Roman Republic it was common for members of the aristocracy to consider their *amici* in last wills as an expression of *amicitia*. Since 27 B.C. and in spite of Augustus' *primus inter pares*-postulate, an equal status between *nobiles* and *princeps*, which was the basis for *amicitia*, did not exist any longer. Consequently, the habit of mentioning the *princeps* as heir or legatee in wills and thereby regarding him as an *amicus*, was no longer possible and rather obsolete. However, this paradox was not overcome: this tradition persisted at least during the 1st half of the 1st century A.D. This century, particularly, can be understood as a kind of transitional horizon during which traditions known from the late republic were either losing their significance and gradually given up or were given new meanings and could therefore continue in a modified form.

If the *princeps* appeared as beneficiary in such a testament he had to express self-restriction, especially if family members were disinherited or discriminated against with a smaller testamentary disposition. Otherwise, he ran the risk of appearing greedy or might even become involved in legal disputes. On the other hand, neither could the *princeps* reject the testamentary disposition completely as such a gesture would reflect badly on the testator and their *amicitia*. The

---

33 Petron. 76.2; cf. Bagnani, "Trimalchio," 85–87.

34 Cf. Rogers, "Roman Emperors," 140–158; Bund, "Erbrechtliche Geldquellen," 50–65; Champlin, *Final judgments*, 152, for more detailed information concerning the emperor as heir or co-heir see also Köstner, "Wenn Kaiser erben," 11–30. The term *bona caduca* refers to any thing which is left by testament to a person, but he/she does not take it for some reason. *Bona vacantia* is a legal concept associated with property that has no owner. In the imperial period, the *fiscus* collected the estates if no heir or heiress was appointed.

reciprocal interactions between *nobiles* and *princeps* thereby seem like a paradoxon within a paradoxic situation.

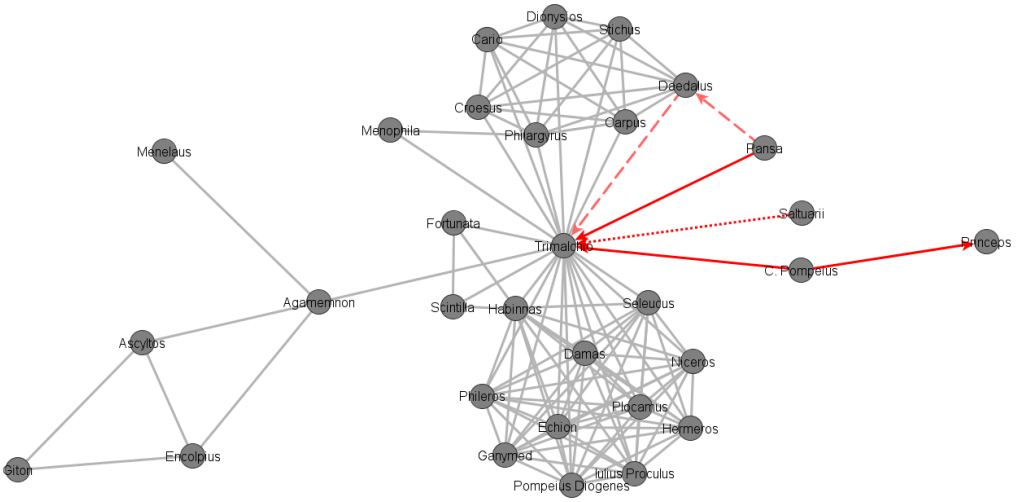

Figure 3. The nodes show the participants of Trimalchio's *cena* and the persons related to Trimalchio by testamentary dispositions. The ties visualize the interaction between the individuals, whereby 'intensity' determines them as well as the legal status of the persons which limits their scopes. Here some of the ties are marked additionally: Trimalchio's ties relating him with testators are marked in red, whereby a solid tie indicates a portion of inheritance or a legacy, a dotted tie means disinheritance, and dashed ties connect the persons involved in the same testament via the given inheritance.

In the case of C. Pompeius we can only speculate about his motivation in mentioning the emperor as his heir. But the combination of the *princeps* as heir and Pompeius' slave Trimalchio as co-heir might indicate that the testator was childless. A necessary condition to make Trimalchio his co-heir was to manumit him in his testament.[35] The act of *manumissio testamento* will be explained later in

35 Cf. Gai. inst. 2.186: "*Sed noster servus simul et liber et heres esse iuberi debet, id est hoc modo: 'Stichus servus meus liber heresque esto', vel 'heres liberque esto'*". – "A slave belonging to us must, however, be appointed heir and declared to be free at the same time, that is to say, in the following manner: 'Let Stichus, my slave, be free and my heir', or 'Let him be my heir and be free'." (for all passages of Gaius' *Institutiones* see Scott, Samuel P. 1932. "The Civil Law." Cincinnati: The Lawbook

detail. But the inheritance Trimalchio got from C. Pompeius formed the basis for his own property. Petronius terms the inheritance a *patrimonium laticlavium*, which indicates a considerable property, similar to a senator's fortune.[36]

The readers and the audience of the *Satyrica* come to know that Trimalchio also benefitted from a last will written by a man called Pansa who remains unknown to us:

> *[Trimalchio:] "'empticius an […] domi natus?' [Daedalus:] 'neutrum' inquit cocus 'sed testamento Pansae tibi relictus sum.'"*
>
> [Trimalchio:] "'Were you purchased or born on the estate?' [Daedalus:] 'Neither; I was left to you under Pansa's will.'"[37]

It can be assumed that Daedalus, one of the slaves working at the *cena*, was the legacy Trimalchio was offered by Pansa because of honoring their *amicitia* within his testament. In the following episode, Trimalchio was disinherited:

> *"iam etiam edicta aedilium recitabantur et saltuariorum testamenta, quibus Trimalchio cum elogio exheredabatur […]."*
>
> "We now had a further recitation of police notices, and some foresters' wills, in which Trimalchio was cut out in a codicil […]."[38]

Like an official gazette, a slave reports the current events on Trimalchio's estates during the dinner, as well as the obtained income and that Trimalchio was disinherited by his *saltuarii* (foresters). Martin Smith explains this passage by hypothesising that there existed a kind of prohibition which forbade the foresters from mentioning Trimalchio in their testaments.[39] Unfortunately, the legal status of these men remains unclear. If the *saltuarii* were slaves, they could not make a legally valid will but only an informal testament which was not legally valid at all. The *Satyrica* keeps silent about Trimalchio's reaction concerning the disinheritance. With these passages (Figure 3), Petronius creates a diverse as well as realistic portrait of Trimalchio in the role of a member of the

---

Exchange). Cf. Dig. 26.4.3.3; 50.16.120; Schmeling, "Commentary on the *Satyrica*", 319; Smith, *Petronii Arbitri Cena Trimalcionis*, 207.

36 Cf. Tac. ann. 1.75; Sen. epist. 27.5. Gareth Schmeling (*Commentary on the Satyrica*, 319) reads the phrase *patrimonium laticalavium* quite literally as portion of the inheritance of one million sesterces. In my opinion, Petronius wanted to stress the extremely high inheritance.

37 Petron. 47.12.

38 Petron. 53.9–10.

39 Cf. Smith, *Petronii Arbitri Cena Trimalcionis*, 144; Schmeling, *Commentary on the Satyrica*, 219; Plin. epist. 8.16.1–2.

Roman sub-elite. The grey nodes and ties that can be read from the text show testators, heirs, legataries and their connections to bequests. The testators – except Trimalchio – are of course not part of the *cena*, but they are indirectly present through the reference to their wills. This can be understood as a glimpse into Trimalchio's past. Inheritance and legacies work as a reward for *amicitia*- and *familia*-relationships that existed in the past between Trimalchio and C. Pompeius respectively Pansa. The relationship between Trimalchio and the *saltuarii* was terminated by these through the disinheritance.

2.2.3 Trimalchio's testament

> *"(1) […] 'amici', inquit 'et servi homines sunt et aeque unum lactem biberunt, etiam si illos malus fatus oppresserit. tamen me salvo cito aquam liberam gustabunt. ad summam, omnes illos in testamento meo manu mitto. (2) Philargyro etiam fundum lego et contubernalem suam, Carioni quoque insulam et vicesimam et lectum stratum. (3) nam Fortunatam meam heredem facio, et commendo illam omnibus amicis meis. et haec ideo omnia publico, ut familia mea iam nunc sic me amet tamquam mortuum'."*
>
> "(1) […] 'Ah, my friends, a slave is a man and drank his mother's milk like ourselves, even if cruel fate has trodden him down. Yes, and if I live they shall soon taste the water of freedom. (2) In fact I am setting them all free in my will. I am leaving a property and his good woman to Philargyrus as well, and to Cario a block of buildings, and his manumission fees, and a bed and bedding. (3) I am making Fortunata my heir, and I recommend her to all my friends. I am making all this known so that my slaves may love me now as if I were dead'."[40]

Trimalchio reads out his last will between acrobatic performances and exquisite food – a festive atmosphere which was neither the norm nor appropriate for such an occasion. He introduces his testamentary dispositions by awarding slaves – or at least his own slaves – the distinction of being seen as human (*et servi homines sunt*). Thus, he explains himself their *manumissio testamento*. Ulrike Roth regards these actions as "staged enactments of freedom".[41] Indeed, Trimalchio announced his intention to free all his slaves – *ad summam, omnes illos in testamento meo manu mitto* –, but this was in fact no longer possible since a law prohibiting this, the *lex Fufia Caninia*, was established

---

40 Petron. 71.1–3. In § 3 the Latin term *familia* is translated with "slaves" which does not fit well and therefore I would suggest "family" or "those close to" the *pater familias*. E.g. the translation of the *Satyrica* by Bracht Branham and Kinney ("Satyrica") uses the term "household"; cf. Smith, *Petronii Arbitri Cena Trimalcionis*, 195; Schmeling, *Commentary on the Satyrica*, 291–292.

41 Roth "Liberating the *Cena*", 615; cf. Roth, "Liberating the *Cena*", 616.

in 2 B.C.[42] This law intended to prevent a too liberal handling of testamentary manumissions.[43] On the one hand, the slaves being freed should be mentioned by name in the testament. On the other hand, only a fixed number of slaves could be freed. If a *patronus* owned between eleven and 30 slaves, he would be allowed to free one third; if he owned between 31 and 100 slaves, he would be allowed to free one quarter.[44] Due to the impresise numbers of slaves available from the text, it is not possible to determine the exact number of slaves Trimalchio possessed. What can be observed, however, is that eight slaves were working during the banquet. We know of two others: one is Menophila and another one who reported on the news of Trimalchio's estate (*villa*). The latter also mentioned several *saltuarii*, who may also have been slaves. Probably there were other slaves working on Trimalchio's estate. Probably, Trimalchio owned between eleven and 30 slaves. According to the *lex Fufia Caninia*, he was allowed to release a maximum of three slaves, which he did. It can be assumed that Petronius was sufficiently well informed in legal matters to pay attention to such details. Therefore, these manumissions remained within the legal framework.

Trimalchio manumitted Philargyrus and Cario, and maybe also Menophila who was not present at the *cena* (Figure 4). Additionally, Philargyrus received a plot of land and – as already mentioned – his lover and consort Menophila. From the text it cannot be determined with absolute certainty whether Menophila was released or whether she was given as a slave to Philagyrus. Cario got an *insula*, a bed, and the *vicesima*. This term refers to the five-percent-tax which had to be paid since republican times and which was reformed and introduced again by Augustus in order to aliment the newly created *aerarium militare*.[45] The tax amount depended on the slave's value at the moment of purchase. Usually, the person to be freed had to pay for it, except in those cases where the will included further regulations in a last will – like in Cario's case.[46] Unfortunately, we do not have further information about the *vicesima* that Philargyrus and Menophila had

---

42 Concerning the dating of the *lex Fufia Caninia* with the help of the eponymous consuls C. Fufius Geminus and L. Caninius Gallus see CIL 6.36809.

43 Cf. Gai. inst. 1.44; 2.239; Sirks, "Lex Fufia Caninia," 549–550.

44 Cf. Gai. inst. 1.42–45; Yavetz, *Kaiser Augustus*, 233–235; Sirks, "Lex Fufia Caninia," 549–551. The intention of *lex Fufia Caninia* was to avoid many slaves being manumitted by testament because this may have caused negative and far-reaching consequences for the testator's *familia*.

45 Cf. Liv. 7.16.7; 27.10.11; Caes. civ. 1.14.1; Cic. Att. 7.21.2; App. civ. 2.41; Cass. Dio 55.25.

46 Cf. Smith, *Petronii Arbitri Cena Trimalcionis*, 195; Müller and Ehlers, *Schelmenroman*, 517; Schmeling, *Commentary on the Satyrica*, 291–292; Ramsey, "Freed Slave," 73. Usually, the tax on testamentary manumissions had to be paid by the person concerned.

to pay. Trimalchio's interaction with his slaves displays him as as generous *patronus* and testator. It is his aim to create a positive *existimatio*.

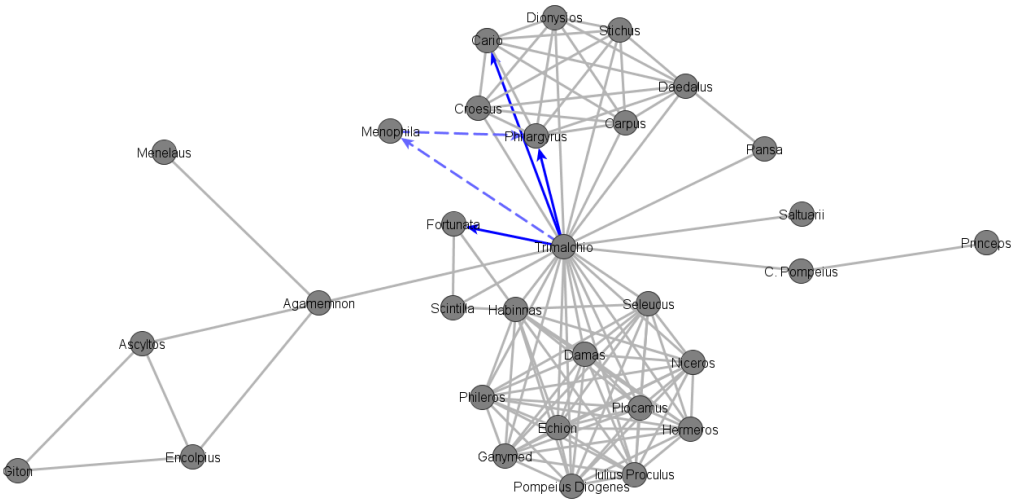

Figure 4. The nodes show the participants of Trimalchio's *cena* and the persons related to Trimalchio by testamentary dispositions. The ties visualize the interaction between the individuals, whereby 'intensity' determines them as well as the legal status of the persons which limits their scopes. Here some of the ties are marked additionally: Trimalchio's ties as testator relate him with heirs and legatees are marked in blue, whereby a solid tie indicates a portion of inheritance or a legacy. Dashed ties connect the persons involved in the same testament via the given inheritance.

Besides his slaves, Trimalchio also bequeaths his wife Fortunata, who is instated as the principal heiress of his property. Since usually the testator's children were preferred as heirs, we may assume that the couple had remained childless. Taking possession of the estate after the death of the testator, the heir or heiress had to fulfill several duties: he or she was responsible for the dispensation of the portions of inheritance and legacies. If there existed a testamentary disposition to this effect, the heir or heiress had to pay the *vicesima*. Additionally, the costs for the funeral monument and commemorative ceremonies had to be covered.[47] Moreover, Fortunata would become *sui iuris* after Trimalchio's death, that is: she became legally independent.

47 Cf. Petron. 71.8–9.

According to the text and graph (Figure 4), Trimalchio's guests were not considered in his will. This is not surprising for Encolpius and his friends, as their relationship with the host was rather superficial. But Trimalchio did not consider those whom he seemed to have known for many years, who had a similar biographical background and shared common values. Petronius draws Trimalchio as a man who deviates from social customs. Instead, besides his wife, some of his slaves are considered in his testament, i.e. they receive legacies and are manumitted. In the graph it can be quickly recognized what is not so easily practicable in the text: i. e. that testamentary and social connections are not always congruent. And this is the starting point for Petronius' *mimus* with Trimalchio as the main character.

But why does Trimalchio read out his last will at this moment at all? Afterwards, he stressed his intention to live on for another 30 years.[48] He answers this question himself: he wants to gain all the sympathy, love, and appreciation that is the result of his testamentary dispositions now and not after his death. Additionally, he intends to assure himself of the favors of his friends and family.[49] This was usually closely associated with the testator's intention to benefit from gifts and services given by the persons mentioned in a testament. Petronius takes the testamentary gift exchange *ad absurdum* and in this way criticizes the habitus of the testators, heirs and legatees, who already want to receive the appreciation that should actually be bestowed upon them after death or who greedily wait for the legacies probably intended for them. Trimalchio was not an exception in that he behaved as a typical member of the Roman elite. Actually, the testator had to choose the appropriate heir or heiress who could be his ideal successor as head of the family. But it should not be neglected that a testator was also interested in creating a positive image of himself (*existimatio*). On the one hand, for heirs, heiresses, and legatees, a last will was regarded as expression of *amicitia* and offered the opportunity to benefit in economic and social terms. On the other hand, to be mentioned in a last will was always related to uncertainty, because the testator could withdraw, disinherit, and change every single element of his testament before dying.[50]

---

48 Cf. Petron. 77.2: "*[…] et — quid vobis non dixerim — etiam nunc mi restare vitae annos triginta et menses quattuor et dies duos. […]*" – "[…] though I must not tell you this, that even now I had thirty years four months and two days left to live."

49 Cf. Perkins, "Naming Power," 158–159; Hope, "At Home with the Dead," 143: "Trimalchio wins favor, and hopes to gain continued good service from his household, by reading his will, but he would have many opportunities to change his mind if he were to live the further 30 years predicted by the stars."

50 Cf. Mart. 5.39; 12.37; Plin. epist. 2.20.10–11; 8.18.3; Tac. ann. 15.54.

3 Everything just fake news? Trimalchio's shifting interaction between seeming and being

It seems that Trimalchio had made a massive mistake which made his will legally invalid, viz. the wrong order in which the heirs are appointed *(institutio heredis)*. A Roman last will always began with the nomination of the heirs, with legatees, manumissions, and further dispositions following.[51] This was crucial because an inheritance was considered as a *successio in universum ius* and hence the heir was responsible for distributing the estate towards co-heirs and legatees, manumitting slaves, and implementing further dispositions.[52] Did Petronius not have any adequate knowledge about the regulations of the law of succession? Did he not know anything about the importance of a legally correct *institutio heredis*? If Petronius, who authored the *Satyrica*, was identical with the senator mentioned in Tacitus' *Annals*, then he would have known about the importance of the correct nomination of heirs even if he was not a lawyer. Do we have to consider the possibility of inaccuracy due to the literary composition Petronius created? I do not think so. The inclusion of said 'mistake' was Petronius' conscious decision, because the shifting interaction between fact and fake, between authenticity and illusion is of vital importance for the *Satyrica* and Trimalchio embodies it! This can be illustrated with the following passage and the graph (Figure 5):

---

51 Gai. inst 2.117: "*Sollemnis autem institutio haec est: 'Titus heres esto'; sed et illa iam conprobata uidetur: 'Titium heredem esse iubeo'; at illa non est conprobata: 'Titium heredem esse volo'; sed et illae a plerisque inprobatae sunt: 'Titium heredem instituto', item: 'heredem facio'.*" – "The regular appointment of an heir is as follows: 'Let Titius be my heir.' The following form at present seems to be approved, namely: 'I order that Titius be my heir.' This one, however, 'I desire Titius to be my heir' is not recognized as correct; and the following expressions, 'I appoint Titius my heir', and 'I make Titius my heir', are not admitted as valid by the greater number of authorities." Concerning the absolute compliance with the legal formalities according to the *institutio heredis* see Gai. inst. 2.116; Dig. 28.1.4; 28.5.32pr.; 28.5.34. For further information concerning the *institutio heredis* see Dig. 20.2.53.1; 28.5.67; 42.5,31pr.–2; 42.6.1.1; 50.16.138; 50.16.142; 50.17.7; 50.17.62; Gai. 2.206; 2.111; 2.158; 2.163; 2.167; 3.36; 3.78; 4.34. Concerning the testament's legal ineffectiveness and abrogation, see Gai. inst. 2.145; Dig. 28.1.12; 28.5.9,13; 28.5.79pr.; 49.15.5.1; 49.15.22pr. The heir or heiress was not permitted to be witness of the *institutio heredis* simultaneously (cf. Dig. 28.1.20pr.)

52 Dig. 50.17.62: "*Hereditas nihil aliud est, quam successio in universum ius quod defunctus habuerit.*" – "Inheritance is nothing more than succession to every right enjoyed by the deceased. " Cf. Gai. inst. 1.157; 1.176; 1.185; 1.189–190; 1.194; 2.153–155; 2.157–158; 2.162–163; 2.185–186; 3.154; 4.112; Dig. 28.5.31; 28.5.60pr.; 29.2.6pr.–1; 29.2.53.1; 41.1.19; Stern, "Testamentary Phenomenon," 413–428; Babusiaux, *Römisches Erbrecht*, 85; Hartmann, *Ordnung in Unordnung*, 127–129.

"gratias agere omnes indulgentiae coeperant domini, cum ille oblitus nugarum exemplar testamenti iussit afferri et totum a primo ad ultimum ingemescente familia recitavit."

"They all began to thank their master for his kindness, when he turned serious, and had a copy of the will brought in, which he read aloud from beginning to end, while the slaves moaned and groaned."[53]

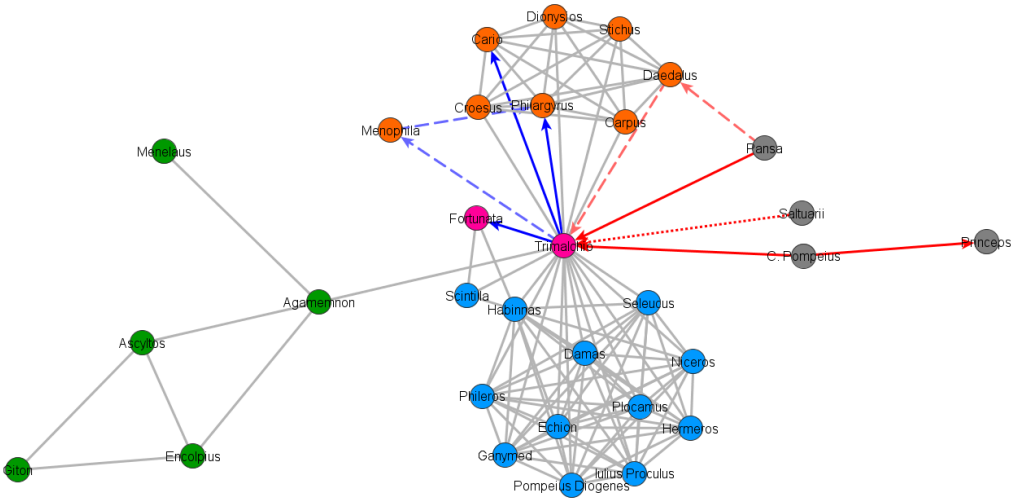

Figure 5. This graph combines information given in the previous graphs: The nodes show the participants of Trimalchio's *cena* and the persons related to Trimalchio by testamentary dispositions. The different colors display their social or legal status (*servi, liberti, or cives*) and the quality of their relationship to Trimalchio (family members in pink, slaves in orange, friends in light blue, external guests in green, and persons mentioned during the *cena* in relation with testamentary dispositions but not yet present in grey). The ties visualize the interaction between the individuals, whereby 'intensity' determines them as well as the legal status of the persons which limits their scopes. Here some of the ties are marked additionally: Trimalchio's ties as testator relate him with heirs and legatees are marked in dark blue, whereby a solid tie indicates a portion of inheritance or a legacy, and dashed ties connect the persons involved in the same testament via the given inheritance. Trimalchio's ties relating him with testators are marked in red, whereby a solid tie indicates a portion of inheritance or a legacy, a dotted tie means disinheritance and dashed ties connect the persons involved in the same testament via the given inheritance.

53 Petron. 71.4.

What did Petronius intend with Trimalchio's *mimus*? It is not possible to decide with any certainty whether or not the last will which Trimalchio read out afterwards was identical with the one he presented right off the bat. The beginning of the paragraph is of interest: those who were present – *omnes* – voice their *gratia* quite emotionally. Did they not notice that this testament was not legally binding at all? Lastly, even if they assume – just for one moment – that the last will was actually legally valid, who really had any reason to express deep gratitude towards Trimalchio? Usually, the testator had to mention *amici* and *familia* in his testament and in this context, he had to find the right balance between these groups. Concerning the *amici*, these men accompanied him throughout his life: they shared a broad base of common values (*morum similitudo*) and supported each other in various fields (e.g. financial or legal assistance). Their friendship had to be appreciated ultimately in the testator's last will. Anyway as as the graph shows, Trimalchio's friends, who were present during the *cena*, did not get anything.[54] Their mutual friendship was not represented or acknowledged in his last will, although such a habit was regarded as societal norm in Roman society. Moreover, it was rather hard for Habinnas, the stonemason: Trimalchio asked him to build his funeral monument. Usually, if somebody met such demands, he would get a legacy as expression of gratitude. The graph also shows that Trimalchio benefited from the inheritance of his *patronus* and a legacy of his friend Pansa, but did not himself keep up these practices. Finally, only Fortunata and the slaves being freed would have had any reason to express their gratitude towards Trimalchio, if his testament was legally valid! Beside his wife he considered some of his slaves in the will.

The graph shows, based on the text, that Trimalchio turned away from his own social group of *liberti*. However, the graph allows a rapid grasp of the different clusters into which the guests can be divided according to the intensity of their interactions and their social and legal status. Those who, according to social norms, could have hoped for an inheritance or a legacy, i.e. the *amici*, were left empty-handed. Trimalchio made his wife the main heiress and some of his slaves got legacies. This would represent a rejection of the social norms that were supposed to create cohesion. In fact, social interactions (e.g. financial and legal support, recovery and congratulations) should coincide with testamentary interactions. But this is not the case in the *cena Trimalchionis* and the graphs show it. Through this imbalance Petronius exercises social criticism. Petronius leaves the readership in the dark about Trimalchio's testament and its validity. All participants of the *cena* – guests and friends, wife and slaves – were part of a

54 Concerning *amici* as a burden in conjunction with last wills see Köstner, "Ein gefundenes Fressen," 191–221.

bizarre *mimus* which is deliberately shifting between seeming and being, and that includes exuberant and joyful expressions of thanks.

4 Bibliography

Andreau, Jean. 2009. "Freedmen in the *Satyrica*." In *Petronius, A Handbook*, edited by Jonathan Prag, Ian Repath, 114–124. Malden [Mass.]/Oxford/Chichester: Wiley-Blackwell.

Arrowsmith, William. 1966. "Luxury and Death in the *Satyricon*." *Arion* 5: 304–331.

Assmann, Aleida. 1993. "Zum Problem der Identität aus kulturwissenschaftlicher Sicht." *Leviathan* 21: 238–253.

Babusiaux, Ulrike. 2015. "Wege zur Rechtsgeschichte: Römisches Erbrecht." utb 4302. Köln/Weimar/Wien: Böhlau Verlag.

Bagnani, Gilbert. 1954a. "The House of Trimalchio." *American Journal of Philology* 75: 16–40.

Bagnani, Gilbert. 1954b. "Trimalchio." *Phoenix* 8: 77–91.

Baldwin, Barry. 1978. "Trimalchio's Domestic Staff." *Acta Classica* 21: 87–97.

Baldwin, Barry. 1993. "The Young Trimalchio." *Acta Classica* 36: 143–146.

Baldwin, Barry. 2001. "Notes on the Tacitean Petronius (Annals 16.18–20)." *Petronian Society Newsletter* 31: 15–18.

Bechet, Florica. 2016 "Fear and Irony in Petronius' *Satyricon*." In *Expressions of Fear from Antiquity to the Contemporary World, Papers of the March 30th 2013, National Colloquium, Department of Classical Philology, University of Bucharest/Romania,* edited by Maria-Luiza Dumitru Oancea, Ana-Cristina Halichias, Nicolae-Andrei Popa, 117–123. Newcastle: Bristol Classical Press.

Brown, Carl E. 1956. *Character-Portrayal in the cena Trimalchionis of Petronius.* PhD-Diss., Montreal.

Bund, Elmar 1978. "Erbrechtliche Geldquellen römischer Kaiser." In *Festschrift für Franz Wieacker zum 70. Geburtstag*, edited by Okko Behrends, Malte Dießelhorst, Herrmann Lange, Detlef Liebs, Joseph G. Wolf, Christian Wollschläger, 50–65. Göttingen: Vandenhoeck & Ruprecht.

Burt, Ronald. 1992. "Structural Holes: The Social Structure of Competition." Cambridge, Mass.: Harvard University Press.

Champlin, Edward. 1991. "Final Judgments: duty and emotion in Roman wills, 200 B.C.–A.D. 250." Los Angeles/Berkeley: University of California Press.

Courtney, Edward. 2001. "A Companion to Petronius." Oxford: Oxford University Press.

Granovetter, Mark. 1973. "The Strength of Weak Ties." *American Journal of Sociology* 78: 1360–1380.

Harrison, Stephen J. 1998. "Dividing the Dinner: Book Divisions in Petronius' *Cena Trimalchionis*." *Classical Quarterly* 92: 580–585.

Hartmann, Elke. 2016. "Ordnung in Unordnung, Kommunikation, Konsum und Konkurrenz in der stadtrömischen Gesellschaft der frühen Kaiserzeit." Stuttgart: Franz Steiner Verlag.

Hill, Timothy. 2004. "Ambitiosa Mors: Suicide and Self in Roman Thought and Literature." New York/London: Royal Holloway, University of London.

Holzberg, Niklas. ³2006. "Der antike Roman, Eine Einführung." Darmstadt: wbg.

Hope, Valerie M. 2009. "At Home with the Dead, Roman Funeral Traditions and Trimalchio's Tomb." In *Petronius, A Handbook*, edited by Jonathan Prag, Ian Repath, 140–160. Malden [Mass.]/Oxford/Chichester: Wiley-Blackwell.

Gowers, Emily. 2018. "Tasting the Roman World." In *Taste and the Ancient Senses, The Senses in Antiquity*, edited by Kelli C. Rudolph, 90–103. New York/London: Routledge.

Jakab, Éva. 2016. "Inheritance." In *The Oxford Handbook of Roman Law and Society*, edited by Paul J. du Plessis, Clifford Ando, Kaius Tuori, 498–509. Oxford: Oxford University Press.

Köstner, Elena. 2018a. "Wenn Kaiser erben: Eine Amalgamierung zwingender Gesten, ritualisierten Verhaltens und literarischer Topoi." *Diomedes* n.F. 8: 9–27.

Köstner, Elena. 2018b. "Ein gefundenes Fressen: Aufforderung zur Anthropophagie in fiktiven römischen Testamenten als Chiffre einer dystopischen Gesellschaft." *Historia* 67: 191–221.

Köstner, Elena. 2019. "Partizipation, Alterität und Alienität." In *Frauen in Kulten der römischen Kaiserzeit, Fallstudien zu Interdependenz und Gender*, Pietas 10, edited by Aliyah El Mansy, Elena Köstner, Christian U. Wohlthat, 14–23. Gutenberg: Computus Verlag.

Meyer, Elizabeth A. 2004. "Legitimacy and Law in the Roman World, Tabulae in Roman Belief and Practice." Cambridge: Cambridge University Press.

Murgatroyd, Tom. 2013. "Petronius' *Satyrica*." In *A Companion to the Neronian Age*, edited by Emma Buckley, Martin T. Dinter, 241–257. Malden [Mass.]/Oxford/Chichester: Blackwell Publishing.

Perkins, Judith. 2005. "Naming Power." In *Metaphor and Ancient Novel,* Ancient Narrative Suppl. 4. edited by Stephen Harrison, Michael Pachalis, Stavros Frangoulidis, 139–162. Groeningen: Barkhuis Publishing.

Perry, Ben E. 1967. "The Ancient Romances: A Literary-Historical Account of Their Origins." Sather Classical Lectures 37. Berkeley/Los Angeles: University of California Press.

Plass, Paul. 1995. "The Game of Death in Ancient Rome, Arena Sport and Political Suicide." Madison: University of Wisconsin Press.

Petronius. ³1983. "Satyrica – Schelmenroman." Lat.–Dt., translated and edited by Konrad Müller and Wilhelm Ehlers. München: Artemis Verlag.

Petronius. 1996. "Satyrica" edited and translated by Robert Bracht Branham and Daniel Kinney. Berkeley/Los Angeles: University of California Press.

Petronius. 2013. "Satyrgeschichten." Translated and edited by Otto Schönberger, Eva Schönberger. Würzburg: Königshausen und Neumann.

Ramsey, Teresa. 2012. "'Reading' the Freed Slave in the *Cena Trimalchionis*." In *Free at last! The Impact of Freed Slaves on the Roman Empire*, edited by Sinclair Bell, Teresa Ramsey, 66–87. London: Bloomsbury Academic.
Rogers, Robert S. 1947. "The Roman Emperors as Heirs and Legatees." *Transactions of the American Philological Association* 78: 140–158.
Roth, Ulrike. 2014. "An(other) Epitaph for Trimalchio: *Sat.* 30,2." *Classical Quarterly* 64: 422–425.
Roth, Ulrike. 2017. "Liberating the *Cena*." *Classical Quarterly* 66: 614–634.
Schmeling, Gareth. 2011. "A Commentary on the *Satyrica* of Petronius." Oxford: Oxford University Press.
Severy-Hoven, Beth. 2014. "The *Satyrica* of Petronius, An Intermediate Reader with Commentary and Guided Review." Oklahoma Series in Classical Culture 50. Norman: University of Oklahoma Press.
Sirks, Adriaan J. B. 2012. "The Purpose of the *Lex Fufia Caninia*." *Zeitschrift der Savigny-Stiftung für Rechtsgeschichte. Romanistische Abteilung* 129: 549–553.
Slater, Niall W. 2009. "Reading the *Satyrica*." In *Petronius, A Handbook*, edited by Jonathan Prag, Ian Repath, 16–31. Malden [Mass.]/Oxford/Chichester: Wiley-Blackwell.
Smith, Martin. 1975. "Petronii Arbitri *Cena Trimalcionis*." Oxford: Cleardon Press.
Stern, Yaakov. 2000. "The Testamentary Phenomenon in Ancient Rome." *Historia* 49: 413–428.
Völker, Thomas, and Rohmann, Dirk. 2011. "*Praenomen Petronii*: The Date and Author of the *Satyricon* Reconsidered." *Classical Quarterly* 61: 660–676.
Vout, Caroline. 2009. "The *Satyrica* and Neronian Culture." In *Petronius, A Handbook*, edited by Jonathan Prag, Ian Repath, 101–113. Malden [Mass.]/Oxford/Chichester: Wiley-Blackwell.
Wade Richardson, Thomas 1986. "Further on the Young Trimalchio." *Phoenix* 40: 201.
Walsh, Patrick G. 1970. "The Roman Novel, The *Satyricon* of Petronius and the *Metamorphoses* of Apuleius." Cambridge: Cambridge University Press.
Yavetz, Zvi. 2010. "Kaiser Augustus, Eine Biographie." Reinbek bei Hamburg: Rowohlt.

FERNÁNDEZ RIVA, GUSTAVO

Network Analysis of Medieval Manuscript Transmission. Basic Principles and Methods

Journal of Historical Network Research 3 (2019) 30-49.

Keywords

medieval studies, manuscripts, network analysis, shared manuscript transmission, Middle High German, digital humanities

Abstract

Manuscripts are one of the main sources for the study of medieval history and culture. Their features, production, circulation and transmission have been the subject of research from different disciplines and perspectives. This article will introduce an innovative way to investigate medieval manuscript transmission using network analysis. The computational study of networks has recently shown some great advancement, both as a visualization strategy and as a mathematical model to study complex phenomena, and can be very productively applied to medieval book history. Here we will focus on the theoretical and technical foundations to create a network of shared manuscript transmission. These

networks allow researchers to apply innovative exploratory visualization techniques and statistical methods. As a test sample, a network created to examine the shared manuscript transmission of texts written in German will be presented. The data for this research has been compiled from the online database *Handschriftencensus* and it has been processed and analyzed using *Python* and *Gephi*. The focus of the article are the theories, methods and strategies to create a network of shared manuscript transmission.

1 Introduction: Why a Network of Shared Manuscript Transmission*

Manuscripts are one of the most important sources to explore the medieval past. Scholars have studied their production, circulation and destruction; how they were read and used; how they interacted with oral discourse and with culture in general.[1] European medieval manuscripts are important as cultural heritage, as aesthetic objects, and as a material link to the Middle Ages. Even beyond their textual content, features like layout and script are valuable research areas that offer insight into history and culture.

Tens of thousands of medieval manuscripts are housed in various institutions across the world and their metadata stored in several digital databases. The availability of those databases could offer scholars the possibility to investigate medieval manuscripts from a quantitative and comparative perspective – what has seldom been done. Even before the overall digital availability of relevant databases, Neddermeyer[2] carried out a quantitative study in an attempt to better understand the transformation processes from

* **Acknowledgments:** Earlier versions of this paper were read at the *Digital Humanities Lunch*, organized by the Institute of Polish Language of the Polish Academy of Sciences in Krakow, on 15 March 2019 and at the conference *Visualisierung als Provokation? Netzwerkanalysen in Mediävistik und Altertumswissenschaften* held in Heidelberg on 3-4 April 2019.
I want to acknowledge my gratitude to Jürgen Wolf, Daniel Könitz, and Bernhard Runzheimer from *Handschriftencensus* for approving my use of their data, receiving me, answering my questions about the project and asking for my feedback on how to improve it. The work they do is incredible valuable for research in Medieval German Literature.
Corresponding author: Gustavo Fernández Riva. gustavo.fernandez.riva@uni-heidelberg.de.

1 Two valuable introductions to the field are: Raymond Clemens and Timothy Graham, *Introduction to Manuscript Studies* (Ithaca/London: Cornell University Press, 2007) and Erik Kwakkel, *Books Before Print* (Arc Humanities Press, 2018).

2 Uwe Neddermeyer, *Von der Handschrift zum gedruckten Buch. Schriftlichkeit und Leseinteresse im Mittelalter und in der frühen Neuzeit. Quantitative und qualitative Aspekte* (2 vols. Wiesbaden: Harrassowitz, 1998).

manuscripts to printed books. More recently, Buringh[3] used statistical methods to estimate how many manuscripts were produced in different places and times, how many currently survive, and other similar questions. These innovative and valuable researches, however, have not always been kindly received and remain exceptional cases.[4]

The present article introduces a quantitative model to investigate shared manuscript transmission using tools and method from the field of network analysis and takes advantage of the availability of digital manuscript catalogues. An approach similar to the one proposed here has been recently advanced by Zdenko Vozar,[5] who used an online manuscript database (*manuscriptorium.com*) to study a corpus of Hussite reform collection in order to demonstrate complex relations between authors and their "collecting". Using network analysis he was able to explore which authors appear in the same collections. This is, in its core, an implementation of the same method explained in this article, but applied to a smaller corpus and focusing on authors instead of texts. Other interesting projects are also currently working on how network analysis can be used to explore medieval manuscripts, although most of them are still very exploratory, focusing on very specific corpora, and with research questions that do not really include the analysis of shared manuscript transmission.[6]

The goal of this article is to set the theoretical foundations for the network analysis of shared manuscript transmission. This method enables scholars to ask, and propose answers to, certain important questions in the field of medieval manuscripts studies. However, before presenting the model it is important to

---

3 Eltjo Buringh, *Medieval Manuscript Production in the Latin West. Explorations with a Global Database* (Leiden: Brill, 2011).

4 Some shortcomings in the methodology of Neddermeyer's study are a point of harsh critique in the reviews: Günther Görz and Ursula Rautenberg, „Medienwechsel Bibliometrisch“, *IASL Online* (2001), https://www.iaslonline.lmu.de/index.php?vorgang_id=2334; Hanns Peter Neuheuser, „Rezension zu Uwe Neddermeyer: Von Der Handschrift...'', *Bibliothek* 25, no. 1 (2001): 110–12. Buringh's research is more solid from the mathematical perspective, although replication and more localized studies would be welcomed in order to further test the results.

5 Zdenko Vozár, „Metadata for the Middle Ages: A Network Analysis of Manuscriptorium.com“ (Paper presented at the Historical Network Research Conference, Masaryk University, Brno, Czech Republic, 2018).

6 Petra Mutlová has proposed an analysis of a corpus of texts from the Czech Reformation in order to test the hypothesis that the exchange of ideas among the Hussite reformers was governed by the laws of complex networks: Petra Mutlová, „Networks of Ideas in the Czech Reformation,“ Presentation at the *Historical Network Research Conference 2018*. Masarykova univerzita: Brno, 2018. Evina Steinova is working on early medieval copies of the *Etymologiae* of Isidore of Seville (~ 400 mss.), using networks to analyze innovations shared by manuscripts, e.g. a specific rewriting of one chapter: Evina Steinova, „Innovating Knowledge: Isidore's Etymologiae in the Carolingian Period,“ in *Mittelalter. Interdisziplinäre Forschung und Rezeptionsgeschichte*, 2 (2019): 12-15.

clarify what shared manuscript transmission is and why it is a relevant research object.

The concept of 'transmission' highlights that, from this perspective, manuscripts are regarded primarily as the medium upon which texts are recorded and 'transmitted' to readers. This means, that many relevant aspects of the manuscripts (layout, materials, etc.) will be left aside, in order to focus on their role as a medium for storing and communicating a textual content. From a different perspective, 'transmission' also means considering manuscripts as a form of communication between the time of their creation and the present – to interrogate the set of objects available nowadays, and try to infer some features about their production, circulation and destruction. 'Shared' transmission, refers to the fact that codices (i.e. physical books) usually contained more than just one text. There were many ways in which compilations could be achieved. Peter Gumbert establishes a distinction between

> the kind where several texts are contained in an object which physically is a single, homogeneous book, and the kind where several physical units, which originally were separate, were joined within the covers of one binding.[7]

This distinction is not always easy to make and the catalogues and databases do not always include this information in a machine readable way. In both cases, however, we can assume some sort of agency which brought together textual objects following some (vague or concrete) criteria. Even if the reasons behind a particular compilation were relatively simple and practical (availability, chance, etc.), it is sensible to presuppose that the compilation could not be completely random, and respected at least some limitations and fundamental principles. To test the validity of this claim of non-randomness in the compilation process is one of the goals of the network analysis proposed in this article.

Compilations are enabled and encouraged by the technology of the codex itself. In the previously dominating format, the roll, navigating the text was much more difficult, and the amount of content that could be included in one object was comparatively small. The codex allows to navigate the text easier, so that, for example, tables of content become feasible. Also, the amount of sheets that can be bound together can vary greatly from a single quire to hundreds. Finally, combining different previously separated quires in a single codex is relatively easy. In short: for many technological and cultural reasons, compilation was a common practice in the production of medieval manuscripts. Also, as big bound books are sturdy and valuable, they are more likely to

[7] Johann Peter Gumbert, „One Book with Many Texts: The Latin Tradition", in *Codices Miscellanearum. Brussels Van Hulthem Colloquium* (Brussels: Archives et bibliothèques de Belgique, 1999), 28.

survive the pass of time than unbounded booklets. As a consequence of these facts, current catalogues show a great amount of large codices and compilations.

Shared manuscript transmission is a fruitful area of research and offers valuable insight into medieval texts and culture.[8] There are mainly two complimentary approaches, which need to be carried out in conjunction, even when only focusing on one of them: the text-centered approach and the manuscript-centered approach. The first consists in analyzing how one text changes depending on the manuscript context.[9] For example, some textual variants might be explained as a way of adapting the work to the principles guiding a particular compilation. However, sometimes the insertion in a different textual environment alone changes the interpretation of the work, because it is considered as part of a new context. The complementary approach is to focus on one or more particular miscellany manuscripts in their entirety.[10] This kind of research has a long tradition in medieval philology and tries to understand the principles behind a particular compilation and the reasons that guided the persons responsible for creating it. The question for the structure of a miscellany manuscript goes beyond finding a conscious intention behind the grouping of texts. Even if the compiler(s) did not have a clear goal, there must have been practical and cultural criteria that determined which texts were selected. Studying the shared manuscript transmission is a way of understanding the availability and the interpretation of certain works in a given cultural context.

Detailed studies of shared manuscript transmission, focusing on particular texts or manuscripts, are valuable and needed, but this article proposes a different way to approach the issue: considering a big data-set instead of individual examples. In this way, it is possible to ask questions that address the

---

8 Relevant volumes addressing the problem of miscellanies from multiple perspectives and languages are: Stephen Nichols and Siegfried Wenzel, eds., *The Whole Book. Cultural Perspectives on Medieval Miscellany* (Ann Arbor: University of Michigan Press, 1996); Keith Busby, ed., *Codex and Context. Reading Old French Verse Narrative in Manuscript* (Amsterdam/New York: Brill, 2002); Lucie Dolezalova and Kimberly Rivers, *Medieval Manuscript Miscellanies: Composition, Authorship, Use* (Krems: Medium Aevum Quotidianum, 2013).

9 Two excellent examples of this procedure are: Diana Müller, *Textgemeinschaften: der ‚Gregorius' Hartmanns von Aue in mittelalterlichen Sammelhandschriften* (Goethe Universität, 2011); Margit Dahm-Kruse, *Die Sammlung Als Kontext. Formen Der Retextualisierung Und Kontextualisierung Mittelhochdeutscher Versnovellen in Kleinepischen Sammelhandschriften Am Beispiel von Konrads von Würzburg 'Herzmaere'* (Tübingen: Narr Francke Attempto, 2018).

10 Miscellany usually refers to codices composed by several heterogeneous texts. For example, a manuscript of a long epic poem that includes in the last extra folios a short narrative text would not normally be considered a miscellany, although it certainly is a case of shared manuscript transmission. I will use the term 'miscellany' in this article rather loosely to mean a codex that compiles many texts.

overall structure of shared manuscript transmission. This would allow the particular research to be more accurate and meaningful, as they can be assessed against the general background.

The methodology presented in this article is based upon the realization that shared manuscript transmission can be modeled as a network, thus enabling the application of a series of mathematical measurements and clarifying visualizations. Some of the statistical methods presented in the following analysis do not rely necessarily on the network model, but are a complement that allows the model to be even more productive.

2 Sources: The Handschriftencensus Online Database

This article focuses on the underlying methods and theories to create a network of shared manuscript transmission, but the data from the online catalogue *Handschriftencensus* (HSC) is used as a test sample. This online database is the result of years of effort from a varied group of German scholars. It began around 2006 and only recently (since 2017) it has become a funded project at the *Mainzer Akademie der Wissenschaften und Literatur*. The project gathers information about medieval and early modern manuscripts containing Middle High German texts. Currently it records around 26,000 manuscripts and fragments between approximately 750 and 1520. From these, however, only about a quarter are high quality entries with a complete description. In some cases, the content of many folios is not identified, which imposes limits to the representativity of the analysis. The most famous and important works and manuscripts are described in detail, but more marginal or obscure texts might still be missing from the database. In spite of these limitations, HSC is by far the most complete and best organized database for the subject and is undergoing an active process of improvement that will yield very positive results in the coming years.

By reusing the HSC, the analysis inherits many of the criteria and biases of its underlying data model. This means, for example, that information regarding time and place of composition is not recorded in a standardized way that would make it machine readable. That information could be very useful to ask certain questions about manuscripts transmission, but they will need to wait until the data model is improved and updated.[11] Also, the criteria used in the HSC to define and incorporate materials is also inherited in the analysis. This includes the definition of manuscript, which is not as self-evident as it might seem at first, as quires that belonged together might have been taken apart at

[11] In a conversation with the team of the HSC in May 2019, they reported that an important restructuring of their website and data model is on the way, which will include standardization of and time and place of composition.

some point in the history of the object, or originally independent books might have been combined. In this regard, HSC does not offer an own definition of manuscript and tends to rely on previous decisions of archives and catalogues. There are also a huge number of written documents not included in the database: single leafs or small leaflets with public and private administrative documents. Excluding them is also a reasonable choice, as these documents are a different kind of object that would require a specific analysis. These kind of selections and exclusions are inevitable in any data model created and all databases will have certain issues and biases. The important thing is to be aware of them during the analysis and to assess if they could generate problems in the results.

Another important feature of the database to consider when evaluating the results is the way the literary works are identified. The foundation for defining a text is the *Verfasserlexikon*, the most important reference work in the field. For this reason, many different texts are condensed in one. For example, dozens of different works by the author Der Stricker are listed as *Stricker: Kleinere Reimpaardichtungen*. This editorial decision is perfectly valid for a reference work, but distorts the analysis proposed here. The resulting network will be profoundly affected by these editorial decisions.

Another issue to consider is that even the best database has underlying choices and biases created during the preservation of the objects. In other words, the currently available manuscripts do not represent the actual manuscript production during the medieval period and the loss rate is not randomly distributed. For example, big, luxurious books have a higher change of surviving. However, it is not impossible to draw conclusions about the general picture of medieval manuscript transmission from the status quo.[12] As will be shown, the network of shared manuscript transmission might even give us some insight into the effects of being part of miscellany manuscripts for the survival of a text.

3 Construction of the Network[13]

The basic principle of the network of shared manuscript transmission is that two texts that appear in the same manuscript context are connected. Within this general principle, there is room for some variations. In the first place, what is considered 'manuscript context' may change for different kinds of research. In the example for this article, I consider manuscript context as (generally) a

[12] Carmen Cardelle de Hartmann, „Überlieferungsprozesse: Sammeln – Auswählen – Kanonisieren. Eine Einführung", *Mittellateinisches Jahrbuch* 53, no. 1 (2018): 5.

[13] Images of the network in .svg format to explore in high detail with a web browser are stored in Zenodo: https://zenodo.org/record/2576509 | DOI: 10.5281/zenodo.2576509

physical codex – and more accurately, as one manuscript entry in the HSC database. However, for different kinds of analysis the manuscript context could be defined as a particular scriptorium, or a particular region at a particular time period.

Of course, these different criteria could be useful for specific research questions, but the most basic model is the one presented here. In this model, each text is a node. When two texts appear in the same physical codex they are connected with an edge. To represent if some manuscripts appear more than once together, a weight attribute for the edge is implemented. Figure 1 shows a sample part of the whole network to explain how it works:

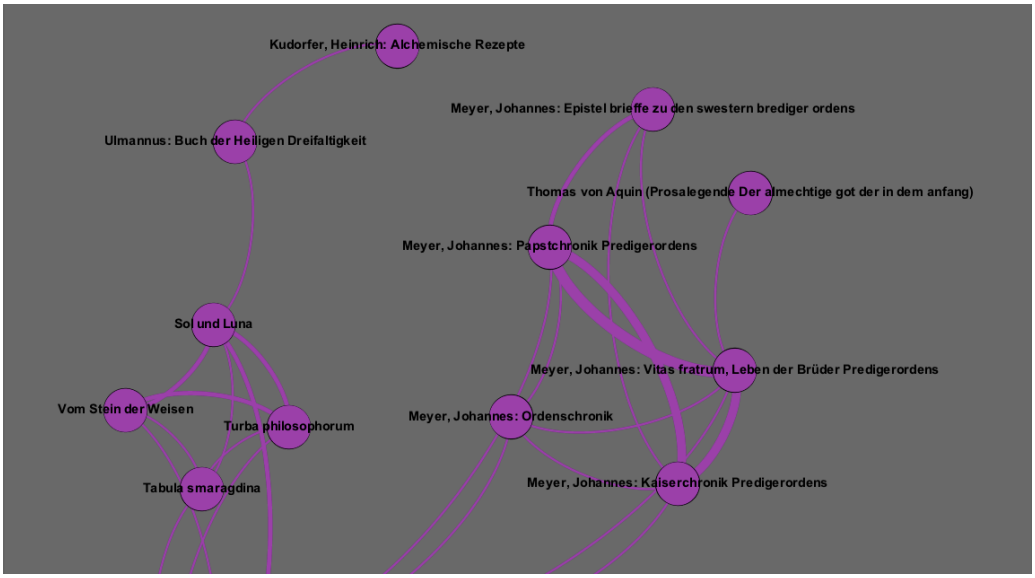

Figure 1. Excerpt of the network.[14]

In the example, one can see that *Alchemische Rezepte* by Heinrich Kudorfers appears in the same manuscript as Ulmannus' *Buch der heiligen Dreifaltigkeit*. The edge has a width of 1, which means that they only appear together in one manuscript. *Alchemische Rezepte* does not appear in the same manuscript context with any other work in the whole corpus, while the *Buch der heiligen Dreifaltigkeit* shares one manuscript with *Sol und Luna*. This work also shares manuscripts with *Vom Stein der Weisen*, *Turba philosophorum* and *Tabula smaragdina*. The many interconnections in this small cluster suggest that these four works must appear together in one manuscript (indeed: in Viena, Austrian National Library, Cod.

[14] Images of the network in .svg format to explore in high detail with a web browser are stored in Zenodo: https://zenodo.org/record/2576509, DOI: 10.5281/zenodo.2576509.

3001). As the width of the edges reflects the value of their weight attribute, it is possible to see that *Sol und Luna*, *Turba philosophorum* and *Vom Stein der Weisen* are attested together in more than one manuscript.

In this simple example, one can appreciate the most basic use of such a network as an exploratory tool. Understanding the shared manuscript transmission of this group of texts is easier with this network representation than navigating through the HSC database. This visualization allows scholars to understand how different texts relate to each other in a clear and simple way. This can also help discover connections that would be very hard to spot in a more traditional research environment. However, this exploratory use is just the tip of the iceberg of the possibilities of network analysis of manuscript transmission.[15]

To create the full network of shared manuscript transmission, the information from the website was stored in a *json* file with the following structure.[16]

> { 1: {'title': *Work Title*, 'manuscripts' : [*Ms1*, *Ms2*, *Ms3*] , 2 : {'title': *Work Title*, 'manuscripts' : [*Ms4*] , 3: {'title': *Work Title*, 'manuscripts' : [*Ms2*, *Ms4*, *Ms5*] , ...}

The HSC website does not provide, from the developers side, an API or other means of gathering the information in a structured way. However, the website allows webscraping with relative ease. The website includes a page with the index of all literary works in the database, which contains a link to the URL for each of them.[17] The first step to acquire the data is just to get a copy of all those URLs combined with the name of the texts. All these URL have a similar structure, ending in a number, which can be used as unique identifier for each text. Then a python program can iterate over that list, access each of the URLs, and retrieve the information about the manuscripts in which the work is attested. This is relatively easy as the manuscripts are listed in an *ol*-element with the attribute @class = 'signaturen'. The URL for manuscripts also have a unique identifier that can be used as id for each one of them.

Once the basic json file is created, a series of Python scripts were used to translate the data into the format required by the program chosen to create the network: *Gephi*.[18] Making a list of nodes is simple: the *script create-list-nodes.py* creates a CSV file with a row for each text in the original JSON file resulting from

---

15 In very convoluted parts of the network, a clear visualization can become difficult. In the future other programs and dynamic approaches, that only reveal selected part of the network should be used to improve what *Gephi* can offer.

16 This is true of the experiments that were used for this article, but I have recently replaced Json with XML to store the data.

17 http://www.handschriftencensus.de/werke.

18 Files and Python scripts used can be found on GitHub at the following URL: https://github.com/GusRiva/projects_data/tree/master/HSC

the webscraping, adding the title under the column *label* and the number of manuscripts as *rating*. Creating the list of edges is more complex. The scripts *create_list_manuscripts.py* and *create_list_manuscripts_with_works.py* reverse the original structure of the data: a new JSON file is created which lists the texts contained in each manuscript:

{*Ms1*: [*Txt1*, *Txt2*] , *Ms2* : [*Txt1, Txt3*] , *Ms3*: [*Txt2*, *Txt4*, *Txt5*] , ...}

Finally, the script *create_list_edges.py* writes the list of edges in a CSV file, each row indicating two nodes that need to be connected. For this, the Python package *itertools* is implemented in order to create all the size two combinations of the texts listed for each manuscript.

Gephi was the selected program to create the networks, because it yields very beautiful visualizations, has a multiplicity of algorithms to organize the layout of the network and offers the possibility to perform calculations of several features. Of course, other programs and tools could be used, like Neo4j, Python's *NetworkX* package or ORA-LITE. Those tools are more focused on mathematical analysis and less on visualisation and could be useful for future stages in the project, but, for now, the mathematical tools included in *Gephi* are adequate.

4 Analysis

There are many features of this created network that can be mathematically analyzed and offer important insight into the manuscripts transmission. In the following paragraphs, I will explain what these features are and why they are important, considering the network created with the HSC database as an example.

4.1 The Structure of Connected Components

In network analysis, a connected component is a subgraph in which any two vertices are connected to each other by paths. The number and size of connected components in a network of shared manuscript transmission reveals a great deal about the context in which those manuscripts were produced. A high number of connected components could mean that book and work tended to overlap, that most books contained one or few works in them and that miscellanies were not very common. It could also mean that the same groups of texts tended to be always transmitted together, that these groups were closed and well established and that there were strict limits to the possibilities of combining texts in the same codex. If, for the contrary, there are few or very big connected components, this means that compilation was common and there were no strict divisions due to,

for example, literary genre, that determined which works could be copied in the same book.

In the sample data from the HSC there is one huge connected component which makes up 76% of the nodes; a series of small connected components of 2 to 8 nodes (most with 2-4) which make up 6% of the total and many unconnected nodes which amount to 18%. This distribution can be seen in Figure 2. As this structure might be very typical for this kind of data and will be relevant for further analysis, it is useful to use specific names for each of these different 'zones' of the network and a geographical metaphor is highly appropriate. I propose to call the main connected component 'Continent', the small connected components 'Archipelagos' and the isolated nodes 'Islands'.[19]

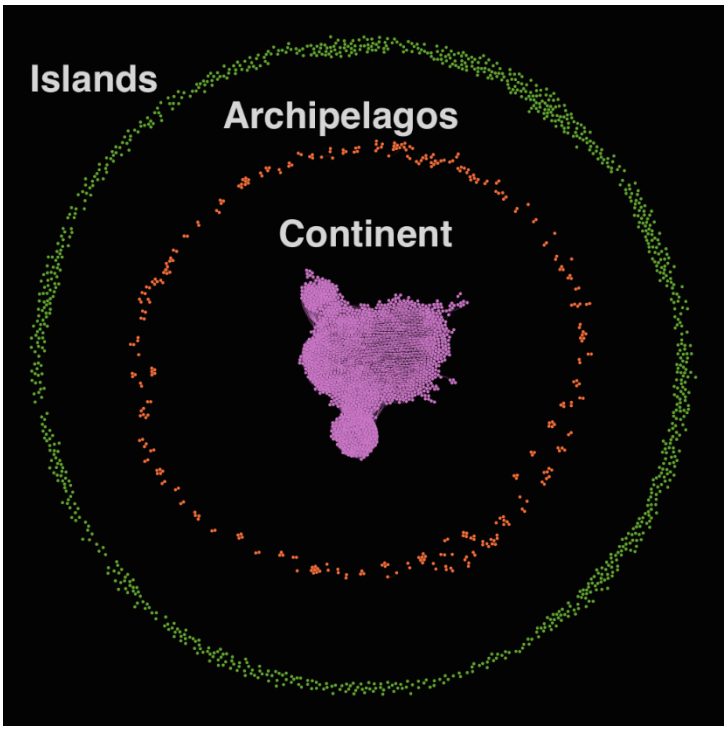

Figure 2. Full network with zones.

[19] The metaphor is not perfect, as archipelagos are actually collection of islands, while in this network islands can't be connected. However, I consider the names are very illustrative of the structure they try to explain if not taken the metaphor to the extreme.
The algorithm Force Atlas 2 contained in *Gephi* was used to structure the visualization. The islands and archipelagos were manually moved to their 'orbits' in the periphery of the image.

It is not hard to imagine that this structure might be repeated in other networks of shared manuscript transmission with similar features (French, Latin, Italian), however, it was not a priori to be expected. Considering that an important part of manuscripts in the database are fragments of books that might have originally contained more than one work, a tendency towards less connections in the network would be expected. However, there are so many miscellany manuscripts that they counteract the presence of fragments. The fact that there is only one big connected component including most works in the network suggests two things: 1- Compilation was the rule and not the exception. Most works appear at least some times in compilations. 2- There is no strict division of genres in the manuscripts (for example, religious and lay literature, prose and verse, etc.). There are at least some works that appear in different manuscript contexts and make such a big connected component possible.

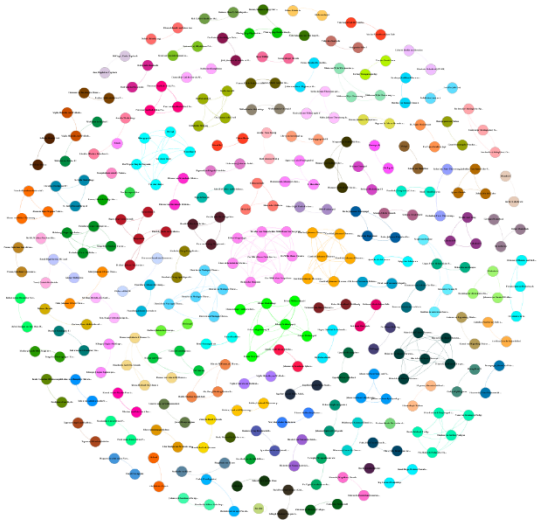

Figure 3. Archipelagos.

The most interesting analyses of such a network (for example, clustering and centrality, see below) focus exclusively on the continent, the biggest connected component, isolated from the rest and considered as a standalone network. However, a visualization of the archipelagos like the one offered in Figure 3, could be used for exploratory analysis.[20] The works in one of these small connected component must have, in most cases, a particular coherence and need to be understood as a particularly close group. In the sample data, 78% of all texts in this zone are also attested in only one manuscript. It could be

[20] The algorithm Fruchterman/Reingold contained in *Gephi* was used to structure the visualization.

argued that the analysis of any work included in one of these archipelagos needs to consider this shared manuscript transmission. As far as we know from the current evidence, the meaning of the individual texts in those groups depend on the other works that conformed their sole available context.

4.2 Degree

A node's degree is the number of links to other nodes. In a network of shared manuscript transmission, a high degree indicates a work which is most likely part of miscellany manuscripts. It would be expected that shorter works would tend to posses a higher degree, but this could not be tested on the dataset, as no information of length was included. Looking at the network there is, however, at least circumstantial evidence to assume that there is no real correlation between length and degree, as many important long works also have a high degree. In any case, degree is an important information to understand how a particular node fits within its manuscript context.

When considering degree, it is relevant to highlight the difference between 'islands' (degree = 0) and *unica* (works attested in only one manuscript). A text attested in many manuscripts, but always alone, is an island. A text attested in only one manuscript (*unicum*) but together with other works is not an island. However, trying to establish if there is some correlation between these two concepts in the data can be very insightful in order to understand the value of compilation for the survival of texts. In other words, if we find that most *unica* were actually attested alone, this means that works included in miscellany and other kinds of shared manuscripts have a higher chance of surviving. And indeed, in the dataset, 83% of islands are also *unica*, while only 40% of not islands are *unica* (and, as it's been mentioned before, 78% of archipelagos are *unica*). This interdependency of compilation and survival can be tested further considering if there is a correlation between degree and number of witnesses. When the Pearsons Correlation Coefficient is applied on the HSC data using degree and number of witnesses as variables, the results are r = 0.3935066925518164; p-value <0.001. [21] This suggests at least a weak correlation between the two variables, which would mean that works attested in compilations have a slightly higher chance of surviving. This is however a weak correlation, and it would be interesting to compare the results in other textual traditions.

[21] The Python function *pearsonr* from the S*ciPy* library was used to calculate this correlation coefficient. This function presupposes random chance as null-hypothesis (https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.pearsonr.html).

4.3 Clusters

One of the most fruitful consequences of modeling data as a network is the possibility to apply automatic community detection algorithms. These algorithms try to identify and differentiate clusters, i.e. groups of tightly interconnected nodes. These kind of clusters are relatively easy for humans to find in simple networks, but very complicated for complex networks. The community detection algorithms are also able to consider the weight of the edges, in order to give preference to the strong relationships over the weak ones. In this particular network, the nodes within the same cluster contain those texts that tend to be transmitted in the same manuscript context. In the network of the HSC data, it makes sense to isolate the continent to apply the community detection algorithm, as is shown in Figure 4. Each cluster detected is shown in a different color.[22]

Once clusters have been detected, it is worth asking if they can be explained; in other words, if there is a feature of the texts that explains why they are transmitted in the same manuscript contexts, or if it is just the result of chance. As the data has no labels for genre, nor place or time of composition, it is not possible to automatically compare if the clusters detected correlate with any of those attributes. However, a human inspection of the results suggests a strong overlap of communities and literary genres, as can be seen in Figure 5.[23] The correlation is not perfect as there are individual works or small groups of works that don't appear in the cluster expected according to their genre. A good example is the small group of *Minnereden* (late medieval texts in rhyming couplets, generally with little narrative content, about love) inside the purple community of mostly

[22] Depending of the variables used for the calculation the results may vary. In the example used here, standard parameters were used (Randomize/Use Weights/Resolution = 1.0). As a result, the modularity value is 0.654, and detects 15 communities. It would be possible to tweak the variables in order to detect more of less communities, but this number is appropriate for the analysis and offers a fair representation of the data.

[23] There are of course many different ways to classify the works written in Middle High German into genres. The objective here is not to propose a taxonomy of literary genres, but to showcase that the clusters in the network are not random and partially overlap with certain genres traditionally identified in literary history. A more detailed discussion on how medieval German literary genres are reflected in this particular network, as well as other specific issues that go beyond the scope of this article focused on methodology, will be carried out in a different paper.

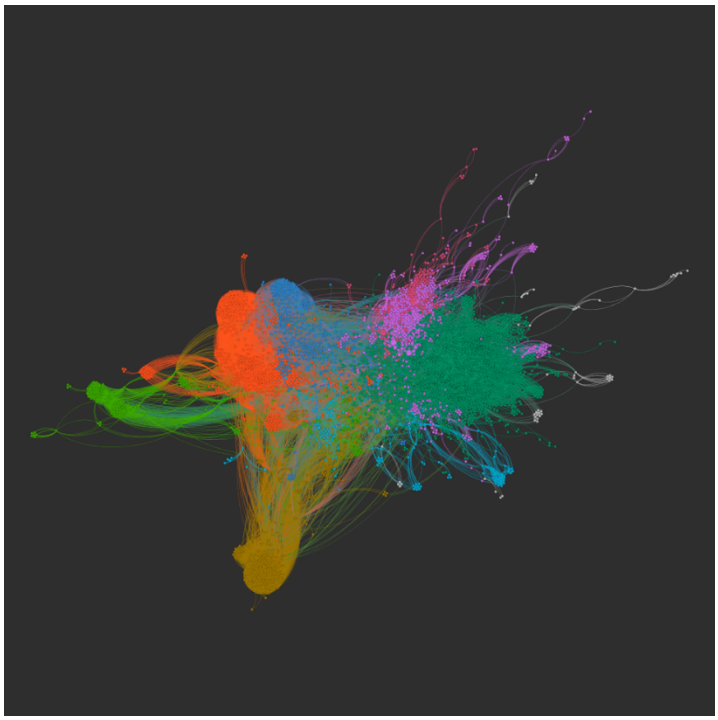

Figure 4. Clusters.

legal and sapiential literature, while most of the hundreds of *Minnereden* are either in the orange or light green clusters (see Figure 5). However, despite these exceptions, there is a clear tendency to group similar texts together. This suggest that the people responsible for creating medieval books applied some concept of genre when compiling different texts – a concept that corresponds, at least partially, with the modern classification of these works.

A virtue of the network model is that it allows to represent simultaneously that texts of the same genre tend to be transmitted together and that there is no strict division of genres. This means that at least some works can serve as nexus connecting the different clusters. The model enables the quantification of the connectivity and the clustering of the network and the identification of the works that perform as link between clusters, as will be shown in the next paragraph.

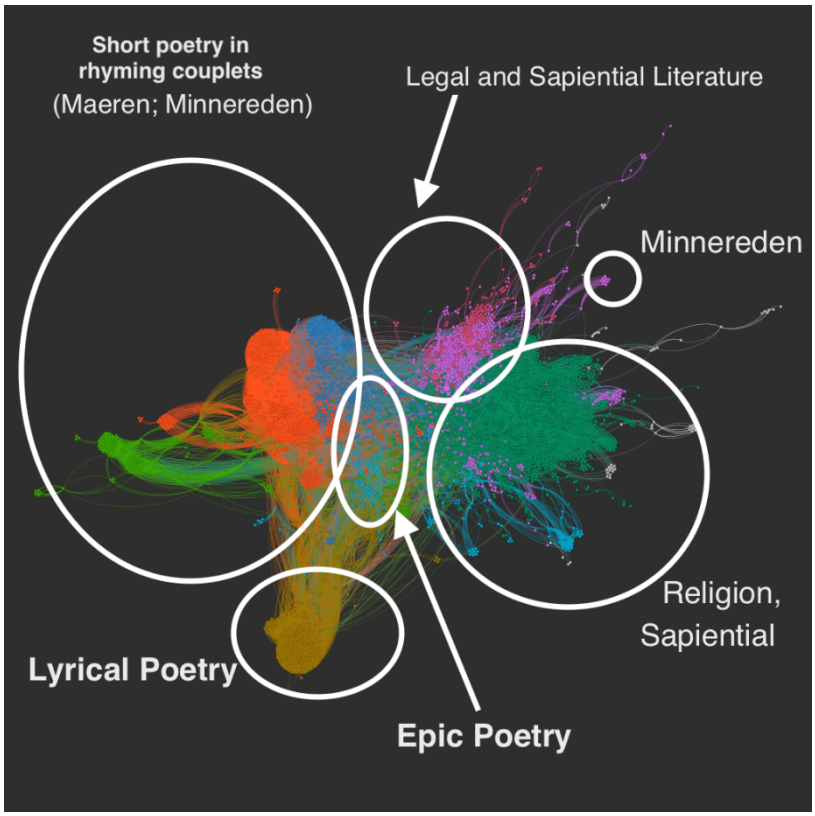

Figure 5. Clusters and genres.

4.4 Centrality

In the sample network, centrality measures only make sense when limited to the continent. There are many different measures of centrality that could bear valuable information, but it is necessary to understand how they might differ when modeling the phenomenon.[24] 'Eigenvector centrality' ranks the degree of a particular node and also considers the degree of the nodes to which it is connected. In this particular case, a high Eigenvector centrality would

[24] A general and informative discussion of network centrality can be found in: John Scott, *Social Network Analysis* (Los Angeles: SAGE, 2017), 95-106. There are many different concepts of centrality and different algorithms to calculate them. The two measurements implemented here, Eigenvector and betweenness, are common methods to calculate point centrality and represent two very different approaches. The first one focuses on a nodes' number and quality of connections; the second one, on its position in the graph. For a mathematical explanation see: Mark Newman, *Networks*. (Oxford: Oxford University Press, 2018), 159-176.

characterize works that fit particularly well in miscellany manuscripts. For this reason, Eigenvector centrality is a measurement of the compilation potential of a particular work and will tend to be high in short texts. 'Betweenness centrality' represents the frequency at which a node occurs on the shortest paths that connect every pair of points. In this sense, betweenness centrality is an excellent measure of what texts serve as nexus between different clusters of the network. Works with a high betweenness centrality are those which can easily be included in manuscripts with texts of different genres and help to create an interrelated network.

In the sample data the main results for both kind of centralities are similar (Figure 6 and Figure 7). In these Figures, nodes with a higher centrality value are bigger and red. Nodes with low centrality are smaller and yellow. The texts with highest Eigenvector and betweenness centrality are the mostly didactic poems of Freidank. These works are relatively short and fit any kind of manuscript context, regardless of genre, place and time of composition. In second place there is Cato, the german translation of the Disticha Catonis, also a didactic text, fundamental in the context of education during the Middle Ages. It also shares the feature of being able to be included in almost any manuscript context, as it is very famous and of a general didactic nature. It is also worth noting the two groups of texts with high Eigenvector centrality in the left part of Figure 6, which prove that high Eigenvector centrality means presence in big compilations. The upper group is mostly short narrative poetry in rhyming couplets (Versnovellen) which is usually transmitted in miscellany manuscripts. The lower group is lyrical poetry, that is mostly transmitted in song books.

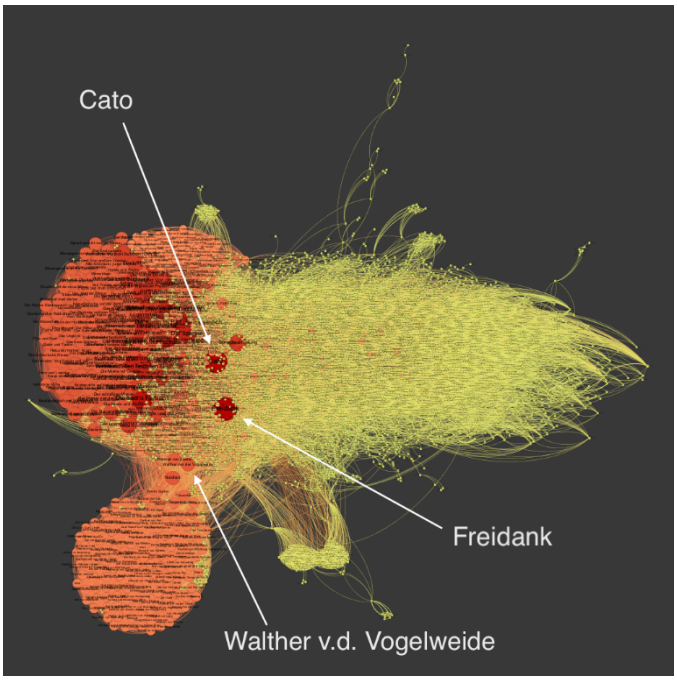

Figure 6. Eigenvector centrality.

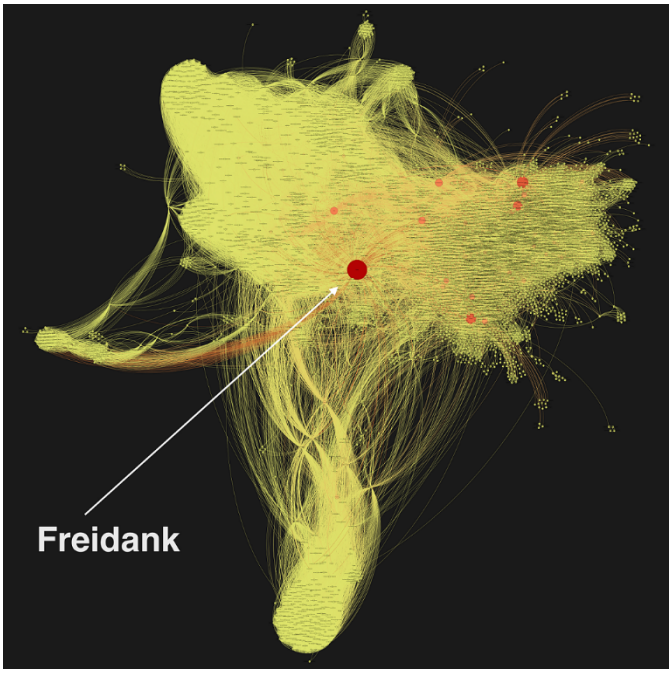

Figure 7. Betweenness centrality.

5 Conclusions

This paper displayed the basic principles and the advantages of modeling shared manuscript transmission as a network based on the particular example of medieval German manuscripts recorded in the HSC database. The model behind network theory permits not only a useful visualization for exploratory analysis, but also the implementation of different statistical tools and algorithms that shed light on the features of the underlying phenomena. Centrality measurements and community detection algorithms are the two main resources to assess how particular nodes or groups of nodes relate to the network as a whole. Other simple statistical methods (percentage of islands and archipelagos, percentage of unica) can complement the network analysis to create a better picture of the features of shared manuscript transmission.

In the future there are many possible ways to continue and improve this line of research. On the one hand, encoding metadata for genre as well as time and place of composition would allow to ask questions about clusters of nodes more efficiently. On the other hand, a comparative analysis of different manuscript traditions would be very fruitful. Discovering if manuscript transmissions in different languages, areas and times behave similarly would be very important to better understand the variation in the historical production and conservation of medieval manuscripts. Some measurement that don't reveal a lot applied on only one network (diameter, radius, average path) could be useful tools to compare different networks and assess their similarities and differences.

The use of network analysis is a promising strategy to investigate the shared manuscript transmission of medieval literature. Even considering the problems and biases in the available data, this model offers important insights into medieval textuality. This article is only a first attempt at implementation of the model. In the future, more detailed analysis of the particular network of German manuscripts are planned, as well as the creation of networks for textual transmission in other languages and for multilingual manuscripts. This perspective will hopefully complement other studies in the field and be a relevant tool to understand the practices and ideas that guided the creation of medieval manuscripts as well as their preservation and destruction.

6 Bibliography

Buringh, Eltjo. *Medieval Manuscript Production in the Latin West. Explorations with a Global Database*. Leiden: Brill, 2011.

Busby, Keith, ed. *Codex and Context. Reading Old French Verse Narrative in Manuscript*. Amsterdam/New York: Brill, 2002.

Clemens, Raymond, and Timothy Graham. *Introduction to Manuscript Studies*. Ithaca/London: Cornell University Press, 2007.

Dahm-Kruse, Margit. *Die Sammlung als Kontext. Formen der Retextualisierung und Kontextualisierung Mittelhochdeutscher Versnovellen in Kleinepischen Sammelhandschriften am Beispiel von Konrads von Würzburg 'Herzmaere'*. Tübingen: Narr Francke Attempto, 2018.

Dolezalova, Lucie, and Kimberly Rivers. *Medieval Manuscript Miscellanies: Composition, Authorship, Use*. Krems: Medium Aevum Quotidianum, 2013.

Görz, Günther, and Ursula Rautenberg. „Medienwechsel Bibliometrisch, Kurzrezension Zu Uwe Neddermeyer:..." *IASL Online*, 2001. https://www.iaslonline.lmu.de/index.php?vorgang_id=2334.

Gumbert, Johann Peter. "One Book with Many Texts: The Latin Tradition". In *Codices Miscellanearum. Brussels Van Hulthem Colloquium*, 27–36. Brussels: Archives et bibliothèques de Belgique, 1999.

Hartmann, Carmen Cardelle de. „Überlieferungsprozesse: Sammeln – Auswählen – Kanonisieren. Eine Einführung". *Mittellateinisches Jahrbuch* 53, no. 1 (2018): 1–10.

Kwakkel, Erik. *Books Before Print*. Arc Humanities Press, 2018.

Müller, Diana. *Textgemeinschaften : der Gregorius Hartmanns von Aue in mittelalterlichen Sammelhandschriften*. Goethe Universität, 2011. http://publikationen.ub.uni-frankfurt.de/opus4/frontdoor/index/index/year/2013/docId/30069.

Mutlová, Petra. "Networks of Ideas in the Czech Reformation". Presentation at the historical Network Research Conference 2018. Masarykova univerzita, Brno, 2018.

Neddermeyer, Uwe. *Von der Handschrift zum gedruckten Buch. Schriftlichkeit und Leseinteresse im Mittelalter und in der frühen Neuzeit. Quantitative und qualitative Aspekte*. 2 vols. Wiesbaden: Harrassowitz, 1998.

Neuheuser, Hanns Peter. „Rezension zu Uwe Neddermeyer: Von Der Handschrift..." *Bibliothek* 25, no. 1 (2001): 110–12.

Newman, Mark. *Networks*. Oxford: Oxford University Press, 2018.

Nichols, Stephen, and Siegfried Wenzel, eds. *The Whole Book. Cultural Perspectives on Medieval Miscellany*. Ann Arbor: University of Michigan Press, 1996.

Scott, John. *Social Network Analysis*. Los Angeles: SAGE, 2017.

Steinová, Evina. "Innovating Knowledge: Isidore's Etymologiae in the Carolingian Period". *Mittelalter. Interdisziplinäre Forschung und Rezeptionsgeschichte*, 2 (2019): 12-15.

Vozár, Zdenko. "Metadata for the Middle Ages: A Network Analysis of Manuscriptorium.com". Paper presented at the Historical Network Research Conference, Brno, 2018.

VALLERIANI, MATTEO; KRÄUTLI, FLORIAN; ZAMANI, MARYAM; TEJEDOR, ALEJANDRO; SANDER, CHRISTOPH; VOGL, MALTE; BERTRAM, SABINE; FUNKE, GESA; KANTZ, HOLGER

The Emergence of Epistemic Communities in the *Sphaera* Corpus: Mechanisms of Knowledge Evolution

Journal of Historical Network Research 3 (2019) 50-91.

Keywords

Early modern cosmology, epistemic communities, multiplex network analysis, semantic network, knowledge evolution

Abstract

The present work investigates the process of emergence of new epistemic communities. The research is based on semantic, content-related data extracted from a corpus of 359 printed editions, mainly of textbooks used to teach cosmology at European universities between 1472 and 1650. Epistemic communities are identified as families of editions, grouped according to their content, that eventually came to shape knowledge within and by way of the European educational framework. First, a method of classifying the textual content of the books is introduced. Second, a directed, multiplex network is constructed in five layers whose structures are defined specifically for the research question at hand. Then the network is analyzed, first by making use of

the aggregated graph—which accounts for the connectivity between books when any of the potential semantic relations are indistinctly considered—and second by showing the contribution of each layer to the emergence of new families of editions. Finally, we interpret the results within a historical framework and identify an epistemic community that represents continuity with the medieval tradition, plus two new scientific and diverging communities that originated in the cultural context of the Reformed countries, which appear in the 1530s. The characteristics of the identified epistemic communities are further analyzed in order to draw general inferences concerning mechanisms of emergence of epistemic communities and their identification in corpora of historical sources. The work concludes by describing future research endeavors related to the corpus, also based on new series of data.

1 Introduction[1]

The project *Sphaera: Knowledge System Evolution and the Shared Scientific Identity of Europe* (sphaera.mpiwg-berlin.mpg.de) aims to investigate how scientific knowledge evolved during the early modern period, how it transformed from natural philosophy to practice-oriented modern science, and how knowledge became homogeneous over time. The present work focuses on deepening our understanding of one specific aspect of such a process of knowledge evolution, namely the establishment of new epistemic communities that eventually shaped knowledge during the period covered by the corpus of historical sources selected for analysis.

The selection of historical sources is focused predominantly on university textbooks, mostly used in teaching at the faculties of liberal arts, namely in those educational institutions whose growing number and network dramatically shaped the shared scientific identity of the entire European

---

[1] **Acknowledgements:** The Sphaera project (headed by Matteo Valleriani) is supported by Department 1 of the Max Planck Institute for the History of Science and by the Berlin Center for Machine Learning (www.bzml.de) (01IS18037), funded by the Federal Ministry for Education and Research of Germany. This work was accomplished in collaboration with the research unit *Nonlinear Dynamics and Time Series Analysis* (headed by Holger Kantz) at the Max Planck Institute for the Physics of Complex Systems.
Authors: Corresponding author: Valleriani, Matteo: Max Planck Institute for the History of Science, Technische Universität Berlin, Tel Aviv University, e-mail: valleriani@mpiwg-berlin.mpg.de;
Bertram, Sabine; Funke, Gesa; Kräutli, Florian; Sander, Christoph; Vogl, Malte: Max Planck Institute for the History of Science;
Kantz, Holger; Tejedor, Alejandro; Zamani, Maryam: Max Planck Institute for the Physics of Complex Systems

continent. To further limit the field, only one of the ordinary disciplines that belong to the quadrivium is taken into consideration: astronomy. Within this field a further limitation has been applied through the choice of a specific treatise around which the corpus of sources was built: the *Tractatus de sphaera* by Johannes de Sacrobosco.

To achieve a consistent corpus of historical sources and, thereby, a corpus that allows for reliable and representative historical conclusions, only the printed editions that are related to Sacrobosco's *De sphaera* are investigated here; the manuscript tradition is ignored, as no census of these sources is extant. As the first printed edition of *De sphaera* is dated to 1472, and because the relevance of this work in the frame of university teaching rapidly declined around 1650, the entire project is limited to a timespan of around 180 years. Moreover, as will be shown in the next section, the investigation reaches forty-one cities located all over the European continent. In the frame of such a corpus, an epistemic community, therefore, is materially represented by a subgroup of editions and books that belong to the corpus. They are a community when, because of their scientific content and their circulation, they impacted and diversified the educational paths of astronomy and cosmology during the early modern period in Europe.

First, we describe the corpus of historical sources selected for analysis. Then, by introducing the concept of a "text part" and the process of the "atomization" of historical sources, we describe a method of extracting and organizing data to accomplish the semantic analysis of early modern textual sources, whose texts are usually not yet machine readable. In the next section, we use the data to build a five-layer network and furnish the data structure. At that point we analyze the temporal influence of each book as it emerges from the data structure and discuss how long we can assume print-events influenced successive events in the frame of the corpus. Analysis of the topology and structure of the network will then illustrate the emergence of epistemic communities and their characteristics. Finally, we interpret the results from a historical perspective. In the conclusions, we cite further data and announce plans for our future research.[2]

---

[2] For a justification of this kind of approach to writing history, see also Matteo Valleriani, "Maths is revolutionising the study of history – here's how," *The Conversation* https://theconversation.com/maths-is-revolutionising-the-study-of-history-heres-how-85710 (2018).

2 The Corpus

The corpus is constituted of 359 different editions that contain the text of Sacrobosco, all printed between 1472 and 1650. The corpus is collected in a database—CorpusTracer—accessible through the project website[3] The dataset is modeled according to the formal ontology CIDOC-CRM and the FRBRoo extension for bibliographic records.[4] As mentioned above, the editions were produced in forty-one different cities on the European continent (Figure 1).[5]

The *Tractatus de sphaera* of Johannes de Sacrobosco is an introduction to geocentric cosmology written in the framework of the quadrivium for teaching at the University of Paris about halfway through the thirteenth century. It became a standard text for teaching all over Europe as the number of universities and their corresponding European network grew. Sacrobosco, the lecturer in Paris who wrote the tract, became (over the centuries) identified with this specific knowledge and for the style and design of exposition that he conceived for his book. The corpus here is pivoted around this text in order to investigate which other texts were connected to it and, finally, the dynamics of appearance and disappearance of these connected texts. A text is considered connected to the original text of Sacrobosco if it appears in the same printed book.[6]

---

3 https://sphaera.mpiwg-berlin.mpg.de. Through the database, each historical source is provided with a permanent PID number. When such historical sources are mentioned in the following, they are referred to only by the PIDs.

4 We used the Erlangen OWL implementation of CIDOC-CRM and FRBRoo to represent the data in RDF (http://erlangen-crm.org). For more information, see Florian Kräutli and Matteo Valleriani, "CorpusTracer: A CIDOC Database for Tracing Knowledge Networks," *Digital Scholarship in the Humanities* (2017).

5 One edition of a commentary on Sacrobosco's treatise moreover was published in what is now Mexico City. See, http://hdl.handle.net/21.11103/sphaera.101292.

6 Scholarly attention to the edition history around Sacrobosco's treatise has grown in recent years. For an overview of the literature as well as an introduction to the entire project, see Matteo Valleriani, "The Tracts on The Sphere. Knowledge Restructured over a Network," in *Structures of Practical Knowledge*, ed. Matteo Valleriani (Dordrecht: Springer, 2017), 421–73. For a critical edition of Sacrobosco's treatise, see Lynn Thorndike, *The Sphere of Sacrobosco and its Commentators* (Chicago: The University of Chicago Press, 1949). See also, Olaf Pedersen, "In Quest of Sacrobosco," *Journal for the History of Astronomy* 16, no. 3 (1985): 175–220; Corinna Ludwig, "Die Karriere eines Bestsellers. Untersuchungen zur Entstehung und Rezeption der Sphaera des Johannes de Sacrobosco," *Concilium medii aevi* 13 (2010): 153–85.

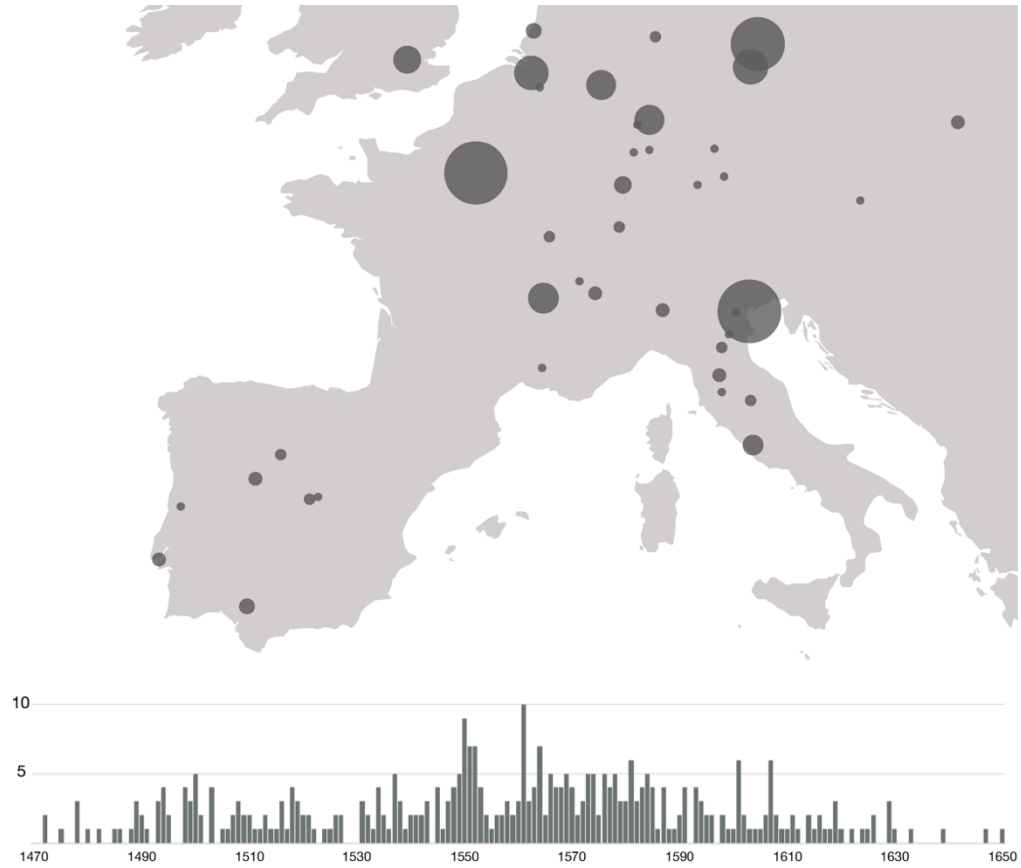

Figure 1. Geotemporal distribution of the production of the treatises belonging to the corpus considered here. The visualization is made by using Palladio at http://hdlab.stanford.edu/palladio-app.

The geographical distribution concerned with the production of these commentaries covers the entire continent, from Krakow to Lisbon and from London to Rome. Nevertheless, the production was not equally distributed: if only those centers of production are considered where at least ten different editions were printed, only nine cities remain (Figure 2). The two most relevant centers were Venice and Paris, both hubs of the transnational European market for printed books.[7] Wittenberg, in the third position, is all the more relevant if

[7] For a comprehensive overview of the economy of the printed book in the early modern period, see Angela Nuovo, *The Book Trade in the Italian Renaissance* (Leiden: Brill, 2013). For a more specific investigation concerned with the academic book market related to medicine, see Ian MacLean, *Learning and the Market Place: Essays in the History of the Early Modern Book* (Leiden: Brill, 2009).

one considers that it entered the academic book market as late as 1531, fifty-one years after the first printed edition of *De sphaera*. Antwerp deserves special mention too; its position at number five is due to production that, though it began in 1543, was prolific only between 1560 and 1585, when production of these editions was at its peak across the continent.

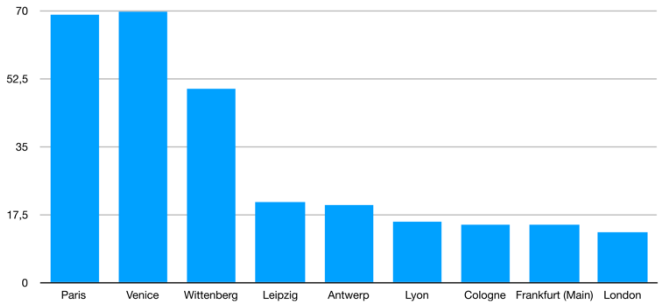

Figure 2. The top nine places where early modern printed commentaries on the *Sphaera* of Johannes de Sacrobosco were produced.

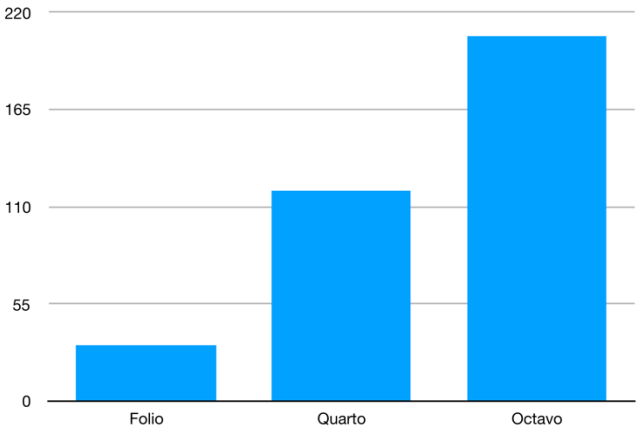

Figure 3. Book formats of the early modern printed commentaries on the *Sphaera* of Johannes de Sacrobosco.

The books of the corpus were mostly destined for the student market. This is reflected in the predominant formats of the editions (listed here in order of decreasing size and price): *folio*, *quarto*, and *octavo* (Figure 3).[8] The *in-octavo* books dominate the material identity of the corpus. Moreover, the *folio* format was mostly produced only during the first fifty years of the history of *Sphaera* editions.[9]

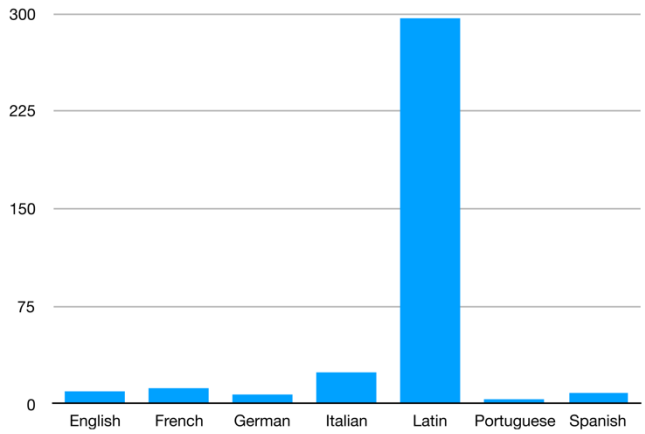

Figure 4. Languages in which the editions of the early modern printed commentaries on the *Sphaera* of Johannes de Sacrobosco were printed.

Finally, it is worth considering the languages of the corpus. The dominance of Latin over other languages is the clearest indicator of the function of these books in university teaching (Figure 4).[10] This does not necessarily imply that treatises compiled in different languages—in many cases one-to-one translations of books published in Latin—were not used for teaching, but probably not at the universities.[11] Other kinds of educational

---

8 Two editions are in *sextodecimo* format.

9 For an extensive description of the corpus of the early modern commentaries on *De sphaera*, see Matteo Valleriani, "Prolegomena to the Study of Early Modern Commentators on Johannes de Sacrobosco's Tractatus de sphaera," in *De sphaera of Johannes de Sacrobosco in the Early Modern Period: The Authors of the Commentaries*, ed. Matteo Valleriani (Dordrecht: Springer Nature, In press).

10 Richard J. Oosterhoff, "A Book, a Pen, and the «Sphere:» Reading Sacrobosco in the Renaissance," *History of Universities* 28, no. 2 (2015): 1–54.

11 Kathleen M. Crowther et al., "The Book Everybody Read: Vernacular Translations of Sacrobosco's Sphere in the Sixteenth Century," *Journal for the History of Astronomy* 46, no. 1 (2015): 4–28.

institutions (in Portugal, for instance) used both manuscripts and printed books that were not written in Latin, as Henrique Leitão has shown.[12] It is interesting to note that, in spite of the fact that the majority of editions produced in local languages and dialects were in Italian, the first Italian edition did not appear on the market before 1537, at which point editions had already been produced in Portuguese (first edition: 1509), German (first edition: 1516), and French (first edition: between 1525 and 1529) with a printed version of the medieval commentary of Nicole Oresme.

3 The Semantic Analysis of the Textual Element of the Corpus

To investigate a long-term knowledge transformation process on the basis of a collection of 359 historical sources, it is necessary to identify elements—atoms of knowledge—that unequivocally characterize the knowledge represented by each historical source, in turn represented by a material object: the book. At the same time, such atoms have to allow for a comparison between the knowledge of different contemporary sources if we are to detect the dynamics of transformation. To identify such atoms, we first distinguished among different "representations" of knowledge in historical sources such as books: texts, illustrations, and tables. In what follows we will consider only the textual element.[13]

By means of electronic copies of all sources, the texts were carefully atomized into "text parts." A text part is a textual passage that cannot be formally smaller than a paragraph and covers a well-defined subject with completeness. A text part in the corpus of Sacrobosco's *De sphaera*, for instance, might be the *Theoricae novae planetarum* of Georg von Peuerbach,[14] as this text began being printed together with the *Sphaera* as early as 1482 and had been reprinted together with the *Sphaera* seventeen times by 1537. If literary compositions—ordinarily printed in scientific books beginning in the sixteenth century—are considered, a text part can be much more modest in length. A

---

12 Henrique Leitão, ed. *Sphaera Mundi: A Ciência na Aula de Esfera. Manuscriptos científicos do Colégio de Santo Antão nas colecções da BNP* (Lisboa: Biblioteca Nacional de Portugal, 2008); "Um Mundo Novo e una Nova Ciência," in *360º · Ciência Descoberta, Catálogo da Exposição*, ed. Henrique Leitão (Lisboa: Fundação Calouste Gulbenkian, 2013), 16–39.

13 The ongoing investigation concerned with the scientific illustrations and tables extracted from the corpus, as well as the intended future use of these data, are briefly discussed in the last section of the present work.

14 For Georg von Peuerbach's role in the frame of the corpus of *De sphaera*, see http://hdl.handle.net/21.11103/sphaera.100965.

representative example might be the short *carmen* written by Donato Villalta and dedicated to the scholar Pierio Valeriano,[15] printed for the first time in 1537[16] and then reprinted another thirty-two times. Another example of text part—which can be seen as both a literary composition and a scientific contribution—is the famous letter to Simon Grynaeus, written by Philipp Melanchthon[17] in defense of astrology as a teaching subject in the Reformed countries. The letter was printed, together with Sacrobosco's text, for the first time in 1531[18] and then another sixty-four times.

Atoms of knowledge such as text parts are useful not only to identify a source but also to compare among one another, because such atoms re-occur systematically. Only the re-occurrence of such atoms is considered here: we represent such re-occurrences in the form of a network and then we analyze it. By considering only re-occurring parts, the total number of books analyzed during the last three years in this study is 350 and their publication period ranges from 1472 to 1647 (175 years).

In the following, we first introduce the taxonomy of text parts specifically conceived to investigate the corpus, which allows us to analyze each single source.

---

15 For Pierio Valeriano's role in the frame of the corpus of *De sphaera*, see http://hdl.handle.net/21.11103/sphaera.100963.

16 Donato Villalta's *carmen* was printed for the first time in http://hdl.handle.net/21.11103/sphaera.101194.

17 For Philipp Melanchthon's role in the frame of the corpus *De sphaera*, see http://hdl.handle.net/21.11103/sphaera.101002.

18 Philipp Melanchthon's letter to Grynaeus was printed for the first time in http://hdl.handle.net/21.11103/sphaera.100138.

3.1 The Taxonomy of the Parts and the Methods of Scientific Production

We distinguish between two different types of text parts, "original part" and "adaption," where "adaption" is further distinguished into "annotation" and "translation."[19]

Original part

Original parts can be both paratexts and content-related texts. In both cases they played the role of reference text, though in different ways.

As content-related text parts, namely as scientific texts, they were rarely updated or significantly changed. Their role as reference texts becomes evident either through the fact that printers were publishing them in uncommented form or together with commentaries written on the same original fundamental text. This second option includes the usual early modern commentary-like book in which the original text and the commentary are printed on the same page but kept clearly distinct through the layout. Many such texts were produced a long time before the date of publication of the books—for instance, the treatise of Sacrobosco itself is an original text part written in the thirteenth century. This means that, in spite of the age of the text, it was still considered a legitimate scientific contribution. Because of this characteristic, original parts are interpreted as the scientific milestones in the time period under investigation.

Paratexts are a type of text whose presence in printed books became common over the course of the sixteenth century. They were therefore always contemporary creations. A paratext could serve as a scientific introduction or a social or institutional contextualization—a role for instance played by a dedication to a patron. In the first case, no difference between content-related texts and paratexts emerges. In the second case, they are considered reference texts because they indicate the level of prestige of an entire edition. As will be shown in what follows, however, this particular kind of original part played a marginal role in the knowledge transformation process, as most of these text parts did not experience any diffusion.

---

[19] The textual analysis made use of the category "fragment," too. In particular, we identified fragments of adaptions and translations of fragments. These data are however not used in the present work.

Adaption

Text parts classified as adaptions may be translations or what is usually known as a scientific commentary. "Adaption" is an inclusive category needed to capture different kinds of connections among books (see below, layers se14, se15, and se16) in reference to both commentary parts (Category: "Annotation" below) and translated parts (Category: "Translation" below).

Annotation

Text parts classified as "Annotations" are commentary texts. They have to be seen as dependent on an original part and as expressing the authority of that part. Commentary was the ordinary means of keeping a scientific debate alive during the early modern period. Because of the tendency to "carry" the original part unchanged, commentaries are texts that could easily convey innovations in science—innovations whose scientific credibility was based, among other things, on the fact that they were expressed in conjunction with an old and authoritative text. Nevertheless, commentaries themselves could rise to the status of "standards" almost as authoritative as those original parts. It is not rare, for instance, to find late medieval commentaries on the *Sphaera* of Sacrobosco, such as Pierre d'Ailly's,[20] re-published many times among the early modern editions. Moreover, such standard commentaries sometimes became the object of second-order commentaries, an aspect that we capture in layer se17 as expressed in the next section.

Translation

Text parts classified as "Translations" are translations of any part from one language to another. Due to historical realities, most of the texts of origin are in Latin and, correspondingly, most of the translations were adapted from Latin into the other languages present in the corpus.

As this taxonomy clearly shows, the historical sources constituting the corpus are analyzed by the methods of production of scientific knowledge rather than by the content of the single parts or their association with specific scientific fields, such as mathematical astronomy, astrology, or medicine.[21]

---

[20] For Pierre d'Ailly's role in the frame of the corpus of *De sphaera*, see http://hdl.handle.net/21.11103/sphaera.100741.

[21] We consider the methods of production of scientific knowledge to be fundamental in recognizing the processes of emergence of epistemic communities, as the results of this work clearly show. Further content-related taxonomies will be added in the future in order to be able to interpret these results from the perspective of the transformation of scientific knowledge.

In the next section we set up the multiplex network on the basis of the data describing the re-occurrence of text parts.

4 The Network and its Layers

The text-part analysis applied to the editions of the corpus results in the identification of a total of 563 text parts. Their identification is based on the principle of first appearance along the chronological line. These text parts are subdivided into 444 original parts and 119 (part) adaptions. As our goal is to build a longitudinal network, from this point on we consider only those text parts that were reprinted and re-published at least once, at least one year after the first appearance. By applying these criteria, 239 text parts remain, meaning that 324 text parts were published either only once or more than once but in the same year. Focusing on the remaining 239 text parts, their total number of re-occurrences (in the total timespan of 175 years considered here) is 1,653.[22]

A further consideration should be made here concerning the paratexts. These constitute 251 text parts of the original 444. Their total number of re-occurrences is 623. Nevertheless, most of these re-occurrences take place in the context of the so-called re-issuances of printed books. A re-issuance is when the same publisher or printer re-published (re-issued into the market) exactly the same book several times in several different years. In these cases, the books were printed all at once and put on the market in different successive years by producing only a new title page with a different year of publication on it. The role of re-issuances in the general context of circulation of knowledge is a recognized subject, but this aspect cannot be taken into consideration here because of lack of data.[23] However, if we consider only the paratexts that were

---

22 In the corpus we found 28 text parts that we were unable to identify in terms of authorship. This amounts to only ca. 5% of all 563 text parts. These anonymous parts are assigned to the author handle "Anonymous," each disambiguated by the year in which the respective part assigned to this specific "Anonymous" appeared for the first time within our corpus. This leads to twenty-three authors with handles like "Anonymous_1488" or "Anonymous_1508." In three cases it seems highly probable that one "Anonymous" authored more than one part; when two parts seem to depend on and are followed by each other in the book(s), these parts (eight in total) have been assigned to only one "Anonymous," as in the example of "Anonymous_1564." In three cases, however, different anonymous text parts (eight in total) may have appeared in the same year(s) (1488, 1538, and 1543) for the first time in our corpus but are very likely not the product of one single author. In these cases, they have been distinguished by adding "a" and "b" to their handle (e.g., "Anonymous_1488a" and "Anonymous_1488b").

23 To detect re-issuances, it is necessary to first extract the fingerprints of the books. Fingerprints are codes extracted through a standard system from the material books as

republished by different publishers and/or printers—in which case those text parts undoubtedly geographically and temporally moved along the network—then their number amounts to only thirty-five text parts; nineteen of them are dedication letters like Melanchton's letter to Grynaeus, three are *proemia* and therefore also on the edge between literary and scientific compositions, and a total of twelve are pure literary compositions (three *carmina*, four epigrams, one *hexastichon*, and four sonnets). The number of publishers and/or printers involved in the circulation of pure literary paratexts is nineteen, while their total number in the corpus is 206. In addition, about 85% of the cases when a literary paratext circulated happened during the twenty years between 1530 and 1550—a very small window compared to the entire interval considered here. All these figures imply that in the following argument, the role of genuinely literary paratexts is marginal.[24]

4.1 The Semantic and the Structure of the Layers

As our goal is to understand the emergence of epistemic communities, we conceived a graphic connectivity structure that enables us to relate such new epistemic communities to specific forms of production of scientific knowledge. In particular, we want to know whether new epistemic communities were established because of the historical realization of one or more of the following options, each concerned with the production of new historical sources and related to the appearance of new text parts: a) production and publication of new original texts, b) publication of old texts that were however either new to the corpus or to the general scientific context of the period, c) production and publication of new commentaries, d) production and publication of new translations, e) publication of new combinations of text parts. With this dataset at hand, we built a longitudinal network constituted of five layers. Each graph is defined on the basis of one specific kind of relationship, where all relationships involve 239 text parts and their total 1,653 re-occurrences. The structure of the layers therefore is as follows:

Layer *se13* - *Same Original Part*: Two books are in relation to each other if they contain exactly the same original part, for instance the same dedication letter or the same treatise in the same language and by the same author.

---

preserved nowadays in libraries and archives. Fingerprints are expressions of the printing procedure. The extraction of fingerprints from the sources of the *Sphaera* corpus is ongoing.

[24] The identification of the paratexts in the corpus was executed by Irina Tautschnig in the institutional collaboration between the *Sphaera* Project and the Project NOSCEMUS - *Nova scientia*. Early Modern Scientific Literature and Latin (https://www.uibk.ac.at/projects/noscemus).

Layer *se14* - *Same Adaption*: Two books are in relation to each other if they contain exactly the same part and this text part is an adaption, for instance a commentary on the *Tractatus* of Sacrobosco. For instance, the two books http://hdl.handle.net/21.11103/sphaera.101112
and http://hdl.handle.net/21.11103/sphaera.101056 are in relation to each other because they both contain Élie Vinet's[25] commentary on the *Sphere* of Sacrobosco.

Layer *se15* - *Translated Same Original Part*: Two books are related to each other when they both contain a translation of the same original part. The translations do not have to be into the same language.

Layer *se16* - *Annotated Same Original Part*: Two books are related to each other if they both contain commentaries that are not the same but are on the same original part, as for instance the commentary of Francesco Capuano, published in the source book http://hdl.handle.net/21.11103/sphaera.100047, and the commentary of Francesco Giuntini, published in the target book http://hdl.handle.net/21.11103/sphaera.101101; both commentaries are written on the same original part, namely the *Theorica novae planetarum* of Peuerbach.

Layer *se17* - *Annotated Same Adaption*: Two books are related to each other if they both contain commentaries that are not the same but are on the same "adaption," which is in turn a commentary on or a translation of an original text part. For instance, the source book http://hdl.handle.net/21.11103 /sphaera.101114 is related to the target book http://hdl.handle.net/21.11103/ sphaera.100656 because they respectively contain Francesco Giuntini's commentary and Alberto Hero's commentary on Élie Vinet's adaption of Sacrobosco's S*phaera*, the latter being an original part.[26]

The nodes in each layer are a subset of the printed books (Figure 5).[27] These are connected to each other according to the relations defined above. The relations among books are as numerous as their parts allow. This means that if two books have more than one related part, then we assume that there are as

---

25 For Élie Vinet's role in the frame of the corpus of *De sphaera*, see http://hdl.handle.net/21.11103/sphaera.100903.

26 If two parts that are the same "Annotation on a Part Adaption" are present in two editions, then the corresponding relation between the two editions is listed in layer se14, as it falls under the category "same adaption."

27 The decision to use books as nodes of the graphs is justified by the fact that this will allow us to correlate these graphs with other graphs expressing relations of social and material nature by means of metadata extracted from the books and through the analysis of the books as material objects. See also the last section below.

many links between these two nodes as there are part-based relations. The drawback of this way of representing links lies in the fact that, if we wanted to describe the links by an adjacency matrix, we should do this on the level of parts and not of books. However, we never explicitly use the parts adjacency matrix or a weighted version of the adjacency matrix of books and thus avoid this complication.

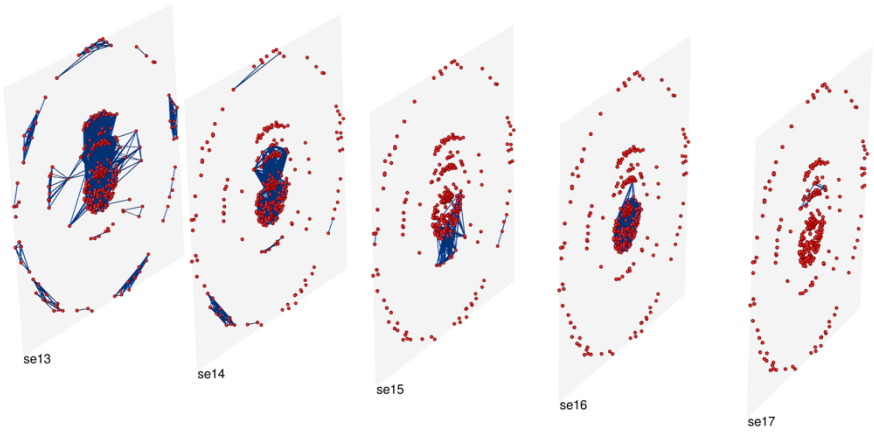

Figure 5. Visualization of the multi-layer network by means of muxViz (muxviz.net).

The network we consider is a multiplex network: its nodes are connected in different layers that describe various types of edges, but cross-links between layers are not considered. A multiplex network is hence a special case of multi-layer network.[28] This allows us a) to keep and handle relations between books

---

28 For an introduction to multi-layer networks as well as a formal definition of the aggregated graph, see Mikko Kivelä et al., "Multilayer networks," *Journal of Complex Networks* 2, no. 3 (2014): 203–71; G. Bianconi, *Multilayer Networks: Structure and Function* (Oxford: Oxford University Press, 2018); Alberto Aleta and Yamir Moreno, "Multilayer networks in a nutshell," *Annual Review of Condensed Matter Physics* 10 (2019): 45–62. For an introduction to multiplex networks, see E. Cozzo et al., *Multiplex Networks: Basic Formalism and Structural Properties*, Springerbriefs in Complexity (Cham: Springer Nature, 2018). For the utility of the application of a multi-layer-network approach to historical studies, see Charles van den Heuvel, "Mapping Knowledge Exchange in Early Modern Europe Intellectual and Technological Geographies and Network Representations," *International Journal of Humanities and Arts Computing* 9, no. 1 (2015): 95–114. For an illuminating example on how a dataset extracted from historical sources can be systematized in terms of multi-layer networks, see Ingeborg van Vugt, "Using Multi-Layered Networks to Disclose Books in the

according to their parts differently in the different layers of the model, and b) to avoid assigning weights in advance as the number of links between pairs of books is instead considered.[29]

5 How Knowledge is Produced over Time

As described in section 4, the different types of semantic relationships yield different connectivity structures, which can be represented as distinct graphs. Each of these five graphs consists of a set of nodes (representing a subset of books from the corpus), links (depicting pairs of books sharing at least a part relevant to the examined semantic relation), and weights attached to those links (representing the number of parts shared between each pair of connected books).[30] It is important to note that these graphs are directed, with directionality imposed by the chronological ordering of book publication. Thus, links are always directed from older (source) to newer (target) books. The analysis also includes the so-called aggregated graph (single layer), which accounts for the connectivity between books when any of the potential semantic relations are indistinctly considered. Therefore, the aggregated graph includes all the semantic pairwise relations between books in the corpus. As a reference we include some basic descriptors (number of nodes, number of links, and total weight) of the different graphs mentioned (Table 1).

Because of the long period of time between the first and last publications of the corpus, we first approach the interesting question of the temporal length of the influence of an event of the past (such as the production of a book) on successive events. In this respect, we first assess the distribution of link ages, L_{age}, within each of the different graphs. L_{age} is simply computed as the difference between the year of publication of the target and source books connected by a link. In Figure 6 we present the distribution of L_{age} for the

Republic of Letters," *Journal of Historical Network Research* 1 (2017): 25–51. See also *The Structure and Dynamics of Scholarly Networks Between the Dutch Republic and the Grand Duchy of Tuscany in the 17th Century (PhD Thesis)* (Amsterdam: Amsterdam School of Historical Studies, University of Amsterdam, 2019).

29 The creation of links between books is based on SPARQL queries to the *Sphaera* database. A resulting edge CSV file and the metadata for all books are published in https://doi.org/10.20375/0000-000c-1f68-e. Based on the link information, the post-processing of the network of layers is detailed in two Jupyter Notebooks, accessible at https://gitlab.gwdg.de/MPIWG/Department-I/sphaera/sphaera-semantic-data. A link to an interactive view of the Notebooks is provided to allow a reproduction of the post-processing steps.

30 We refer the reader to S. Boccaletti et al., "Complex Networks: Structure and Dynamics," *Physics Report* 424, no. 4–5 (2006): 175–308; Mark Newman, *Networks: An Introduction* (Oxford: Oxford University Press, 2010).

graphs corresponding to each of the semantic layers and for the aggregated graph. We also summarize some relevant descriptors for L_{age} in Table 2.

Layer	Nodes	Links	Weights
se13 (same original)	321	5681	13401
se14 (same adaption)	199	2173	3163
se15 (same original translated)	43	341	342
se16 (annotated same original)	183	15326	20874
Se17 (annotated same Adaption)	8	15	15
Aggregated graph	350	20293	37795

Table 1. Number of nodes, links, and total weight in each layer and in the aggregated network.

We observe that the vast majority of links are under ninety years old, which can be explained due to the higher production of books in the central part of the time period 1530–1580 (e.g., a book published exactly in the middle of the time period can be at most the source or target of a link with L_{age} =88 years). In fact, we compare the percentage of links with ages greater than ninety years in the aggregated graph to a reference scenario in which every book is connected to all other books published afterwards (e.g., from the perspective of the semantic relation se13, this reference scenario corresponds to a corpus where all books share at least one original part). The connectivity structure between books in this reference scenario translates into a fully connected directed graph, given the chronological ordering constraint. Note that the connectivity structure of the reference graph is only a function of the publication timing of the various books in the corpus, and therefore its structure encodes the variable production rates reported and shown in Figure 1. Indeed, by analyzing this reference scenario, we find that only 9.15% of the links have an age greater than ninety years. We want to note that the percentages shown in Table 2 for the reference scenario do not constitute a higher bound in terms of percentage, but they serve to give some intuition about how production rates affect L_{age}.

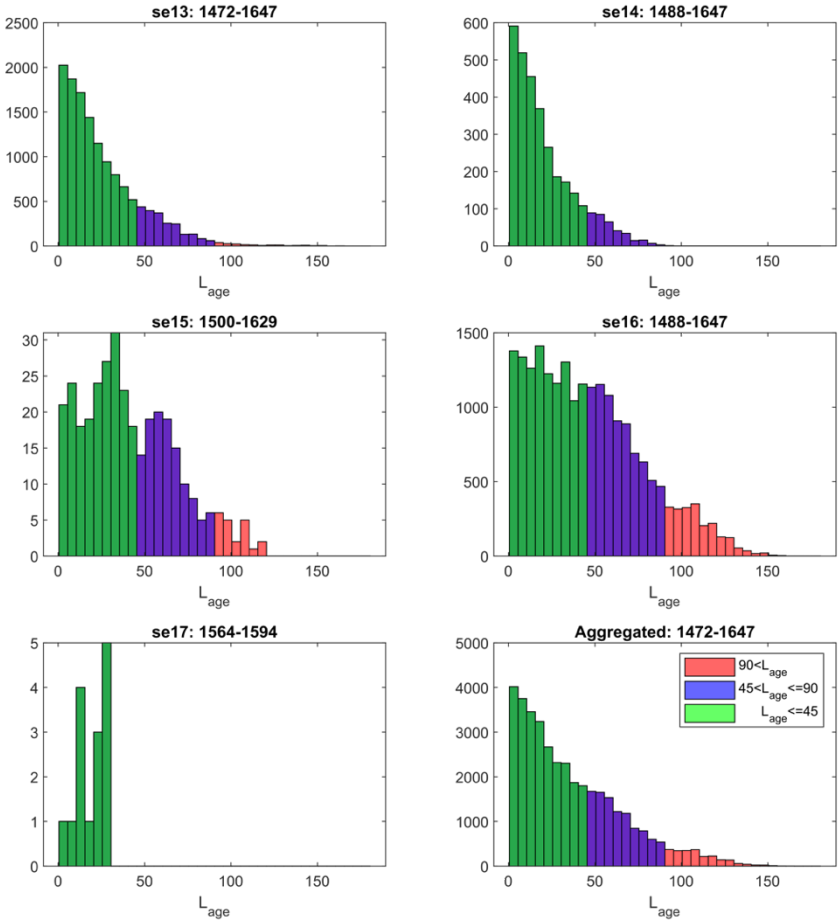

Figure 6. Histograms of link ages for each layer and for the aggregated graph.

We further observe that the two graphs that show a relatively older population of links are the graphs corresponding to layer se15 (same original translated) and se16 (annotated same original), an aspect that will be discussed in section 5.2.

Layer	Period	L_{age}	$\sigma(L_{age})$	Lage ≤ 45	45 < L_{age} ≤ 90	90 < L_{age}
se13	1472–1647	25.56	21.99	83 %	15.75 %	1.25 %
se14	1488–1647	20.89	14.47	88.75 %	11.22 %	0.03 %
se15	1500–1629	41.99	27.03	59.94 %	33.92 %	6.14 %
se16	1488–1647	46.05	31.48	54.01 %	35.75 %	10.24 %
se17	1564–1594	19.80	8.59	100 %	0 %	0 %
Aggr.	1472–1647	36.63	29.40	67.27 %	26.57 %	6.16 %
Reference	1472–1647	43.19	31.50	58.88 %	31.97 %	9.15 %

Table 2. Link Age statistics.

Given the reasonable values of L_{age} shown in Table 2, and to avoid arbitrary thresholds, we include all the links extracted from the analysis of the parts as explained in section 4. We further argue that this approach is the most suitable to study the structure of knowledge underlying the corpus.

5.1 Emergence of Edition Families and Influential Editions within the Corpus

In the following, we describe a method for investigating whether different epistemic communities can be identified in the corpus along its timeline and what their characteristics are. An epistemic community is identified by a family of editions.

We first assess the number of connected components in the aggregated graph. For undirected networks, a connected component is a set of nodes, so that a path (sequence of links) between any pair of those nodes exists. For directed networks, as the matter at hand, the so-called weakly connected components can be equivalently defined by ignoring the directionality of the links. The interpretation of the internal network structure of weakly connected components is not straightforward in our case, since the temporal ordering of books is a crucial property. However, the emergence of different connected components is particularly relevant in the analysis of the aggregated graph, when interpreted in terms of books belonging to different components. Thus, if any given pair of books are known to belong to two different components, we can immediately infer that those two books do not share any semantic relation (from those included in section 4.1). Our analysis reveals the emergence of 14 connected components (Figure 7), although the network is clearly dominated

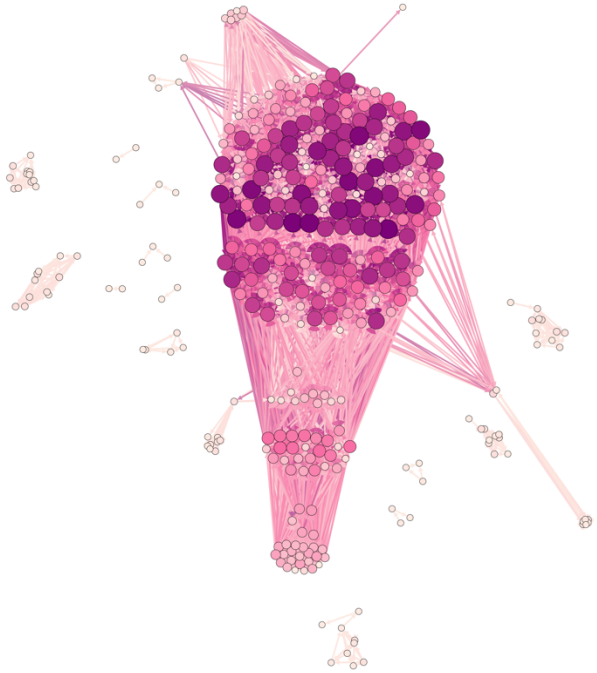

Figure 7. Network's components. The network is constituted of one large component and thirteen small ones.

by the largest component, which includes 274 out of the 350 books (compared with the twelve books forming the next component in terms of size). Due to this fact, the analysis distinguishes between the books that belong to the largest connected component versus those which belong to any of the other components.

Next, we assess the influence of the different books in the corpus. One of the simplest and most intuitive metrics to quantify the influence of a given book within the corpus is the percentage of books published afterwards to which that given book connects. From the network perspective, this is equivalent to what we define as the normalized node out-degree. The out-degree of a node in a directed graph is simply defined as the number of links departing from that node (i.e., book pairwise relations in which the given book is the source). We show the computed book out-degree as a function of the book publication year for the aggregated network (black circles represent

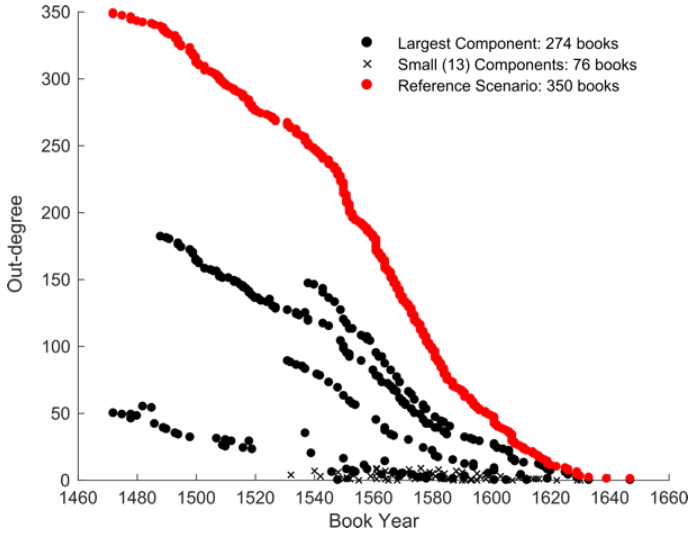

Figure 8. Book out-degree as a function of publication time for the aggregated graph (black) and the reference scenario (red).

books in the largest connected components and black crosses are used for books belonging to any other connected component)[31] in Figure 8.

We also display in the same figure the values of book out-degree for the above-mentioned reference scenario (red) (i.e., each book is connected to every book published thereafter), which corresponds to the end-member connectivity structure where all the books are as influential as they can potentially be, given their time of publication.

The first obvious point that becomes apparent from Figure 8 is that the book out-degree as an absolute number (e.g., the total number of books to which a given book connects) is not a good metric for book influence, since it is by definition a decreasing function of time due to the chronological ordering of book publication (i.e., a link cannot be established from a book published at a given time to a book published earlier). Therefore, we define the normalized book out-degree as the ratio of the number of links departing from a node to the number of nodes corresponding to books published afterwards (it

[31] Editions that belong to other components are considered in the following for the normalization procedure. Below in this section, we show the reason why these seventy-six editions do not enter the scheme described in section 4 and, in the last sections, we discuss how they can be integrated in future analysis and interpretation and what their historical meaning might be.

corresponds graphically to the point-wise ratio of black and red points in Figure 8).

The normalized book out-degree as a function of time of publication is shown in a different plot (Figure 9), revealing the emergence of four time periods characterized by the presence of a specific number of families of editions:

1) The early period (approx. 1472–1488): The first editions that appear in the record are characterized by a relatively low value of normalized book out-degree, meaning that their content was reproduced or adapted by a small percentage of books published afterwards (~15%).

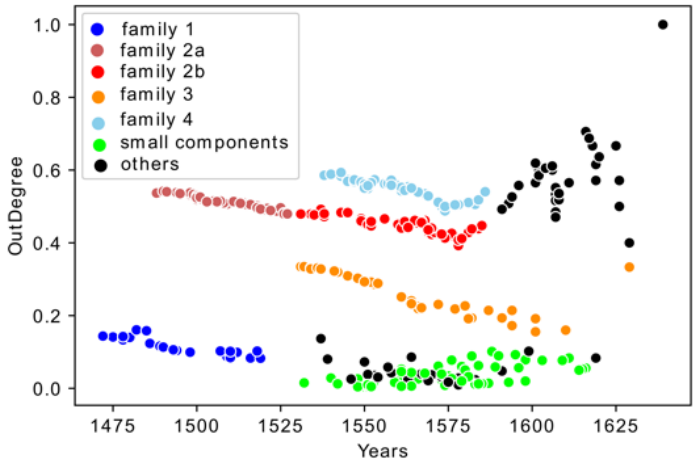

Figure 9. Normalized book out-degree as a function of publication time for the aggregated graph.

2) The second period (approx. 1488–1531): A new edition was published in 1488,[32] which is significantly more influential than the previous editions, as shown by the increase in the normalized book out-degree from 15% to 55%. After this publication two families of books (branches) are distinctly depicted: (i) Family 1: a first family of books that mostly follows the content in the books published in the early period as indicated by the lower branch with normalized book out-degree values around 15–10% (similar to those for the books in the early period); (ii) Family 2a: a second family of books whose content is related to the book published in 1488 as inferred from a similar

[32] This 1488 edition is http://hdl.handle.net/21.11103/sphaera.100822.

values (branch) of the normalized book out-degree in the range of 55–48%. Note that this family became clearly dominant, that is, most of the books published in this period are associated with this family (as shown by a higher density of points in this branch). The appearance of a dominant branch can be interpreted as the emergence of a period characterized by knowledge convergence, namely an epistemic community.

3) The divergence period (approx. 1531–1600): Several new editions with significant changes appeared during this period, resulting in the divergence of content in the corpus as shown by the emergence of several competing families of editions, shown as branches in Figure 9. We highlight the coexistence of four families during this period: (i) Family 2b: there exists a family of books that continues the dominant tradition in the previous period, as shown by the branch of points that continues the trend previously existing in Family 2a with values of the normalized book out-degree in the range of 48–40%; (ii) Family 3: a new edition was published in 1531,[33] which introduced changes that reduced the normalized book out-degree from 48% to 34%. These changes, though not very popular in the bigger picture (as shown by the above-mentioned reduction in the normalized out-degree), were reproduced in several subsequent editions, as shown by the emergence of the branch of points in the normalized book out-degree range of 34–18%. (iii) Family 4: a new edition was published in 1538.[34] The changes adopted in this new book increased the normalized out-degree from 48% to 59%. The emergence of a branch of points which exhibits similar values of normalized book out-degree suggests that those books form a family of books with similar content; (iv) Family 5: there is a large set of books that were published after 1532, which have relatively low value of normalized book out-degree (below 10%). Family 5 does not exhibit a clear branch structure when all its books are considered. However, when we distinguish between books belonging to the largest connected component (circles) and those belonging to different (small) components, a clearer pattern emerges. The subset of books in Family 5 within the largest connected component form a branch structure, which shows a trend compatible with that exhibited by books in Family 1 (second period). On the other hand, the books that belong to Family 5 and that are part of the smaller components show more heterogenous, although always small, values of normalized book out-degree. These low values are expected due to the reduced size of each of the connected components. The internal variability of the out-degree within the family can be attributed to their heterogeneity in terms of the semantic content, indicating that these books, although catalogued in the same family, are actually quite

---

[33] This 1531 edition is http://hdl.handle.net/21.11103/sphaera.100138.

[34] This 1538 edition is http://hdl.handle.net/21.11103/sphaera.101106.

different from one another, their main commonality being their relatively low influence on future books (low normalized book out-degree).

4) Final period (1600–1647): The significant decrease in the rate of book production in this period, together with finite effects, make this period difficult to interpret.

In order to better contextualize the results obtained from the analysis of the normalized book out-degree, we present a series of plots (Figs. 10, 11, 12) that show the normalized book out-degree as a function of time of publication, where the points are colored according to the normalized book in-degree (defined for each book as the percentage of books published beforehand that connect to that given book) (Figure 10), city of publication (Figure 11), and book format (Figure 12). Several interesting remarks can be made from this analysis:

1) The early period (approx. 1472–1488): Most of the books in this period were published in Venice and all of them were in quarto format.

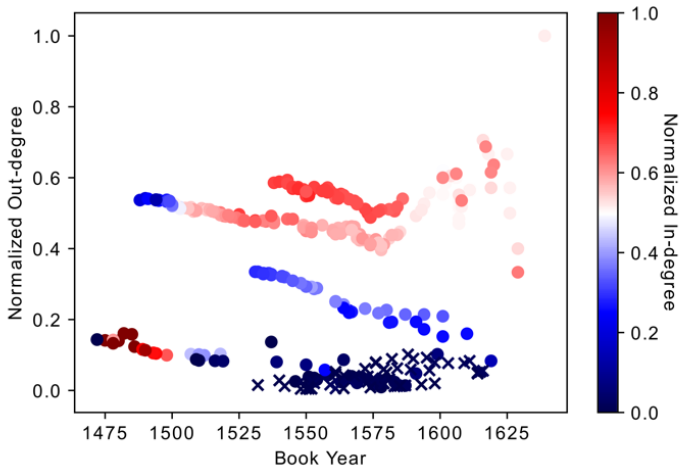

Figure 10. Normalized book out-degree as a function of book publication year. The points are colored according to the normalized book in-degree. Circles identify editions that belong to the biggest connected component and cross symbols represent books in the small components.

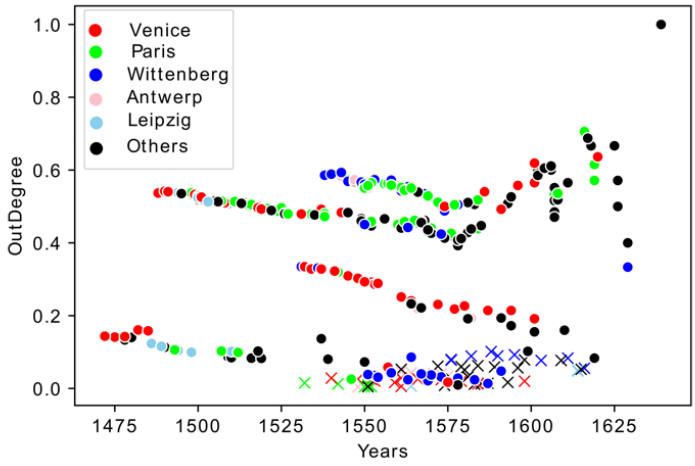

Figure 11. Normalized book out-degree as a function of book publication place. The points are colored according to the city where each book was printed. Circles identify editions that belong to the biggest connected component and cross symbols represent books in the small components.

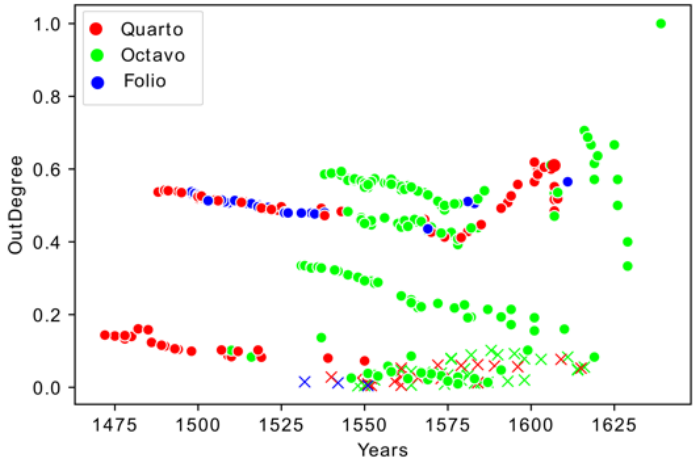

Figure 12. Normalized book out-degree as a function of book publication year. The points are colored according to the book format. Circles identify editions that belong to the biggest connected component and cross symbols represent books in the small components.

2) The second period (approx. 1488–1531): (i) Family 1 is also mostly characterized by *quarto* format. (ii) Family 2: The first editions that triggered this new branch were published in Venice in *quarto* format. These early

editions within Family 2 are also characterized by a low value of normalized book in-degree (i.e., a low amount of information/parts shared with previous books), which supports the argument that a significant amount of new information was included in these editions. Interestingly, the books belonging to this family were published in different locations, but a clear predominance is shown by Paris, where another format, the *folio*, can also be found.

3) The divergence period (approx. 1531–1600): The first striking observation is that the divergence period coincides with the massive adoption of the *octavo* format. We highlight that both Family 3 and Family 4 were triggered by two distinct new editions, both published in Wittenberg. We also observe the predominance of Venice as the city where most of the subsequent books belonging to Family 3 were published. Regarding the normalized book in-degree, we observe that both families 2a and 4 carry high values, meaning that they are significantly connected to previous books, while books within families 3 and particularly 5 show very low values of normalized book in-degree, indicating that those books introduced a fair amount of innovation and removed traditional parts. As mentioned, seventy-six books that appear in Family 5 belong to smaller components. As a matter of fact, these books constitute a peculiar subgroup of books within the corpus. These books are considered to be strongly influenced by the text of reference, namely the *Tractatus de sphaera* of Sacrobosco, but they *do not contain it* and do not comment directly on it. They are considered to be influenced by it because they discuss the same subjects, either all of them or the majority of them. Moreover, they discuss them by following either the same or a very similar order. Finally, they largely make use of the same visual apparatus.[35] Nevertheless, they do often contain different scientific arguments and different views, though on the same subjects. These books therefore represent the first strong departure from the tradition of textbooks associated with Sacrobosco's treatise. They are, in other terms, at the boundaries of the corpus from a content-related point of view and therefore represent a category of books that will be taken into consideration for further analysis in the future, as discussed in the final section.

During the previous analysis we have pointed out specific books of particular relevance, since they were the seed for the convergence/divergence of knowledge triggering the emergence of different epistemic communities.

---

35 Owen Gingerich, "Sacrobosco Illustrated," in *Between Demonstration and Imagination. Essays in the History of Science and Philosophy Presented to John D. North*, ed. Lodi Nauta and Arjo Vanderjagt (Leiden, Boston, Köln: Brill, 1999); Kathleen M. Crowther and Peter Barker, "Training the Intelligent Eye: Understanding Illustrations in Early Modern Astronomy Texts," *Isis* 104, no. 3 (2013): 429–70.

But of all these books, we want to highlight three particularly disruptive editions:

1) The 1488 Venice edition: This book, which we used to define the beginning of Family 2, broke with the tradition of the early period of the printed corpus (as shown by the low value of normalized book in-degree), introducing new knowledge that became tradition over time, and exhibiting semantic connections with more than 50% of all the books in the corpus.

2) The 1531 Wittenberg edition: This book, which we use to define the beginning of the divergence period (Family 3), is also highly disruptive since it broke with the dominant tradition by introducing new content that clearly diverged from previous editions (as shown by the low value of normalized book in-degree). Although the new knowledge in this book did not replace the previous tradition, it remained relatively influential (it connects to 34% of books published afterwards) in a period where several distinct book families co-existed.

3) The 1538 Wittenberg edition: This book, which established the emergence of Family 4, does not seem particularly disruptive at first sight as its high value of normalized in-degree indicates. Nevertheless, the high value of normalized out-degree suggests an interpretation according to which this edition exerted a strong influence. As discussed in the next section, in fact, its relevance in the corpus and, in particular, its innovative character become more apparent when families 3 and 4 are considered together.

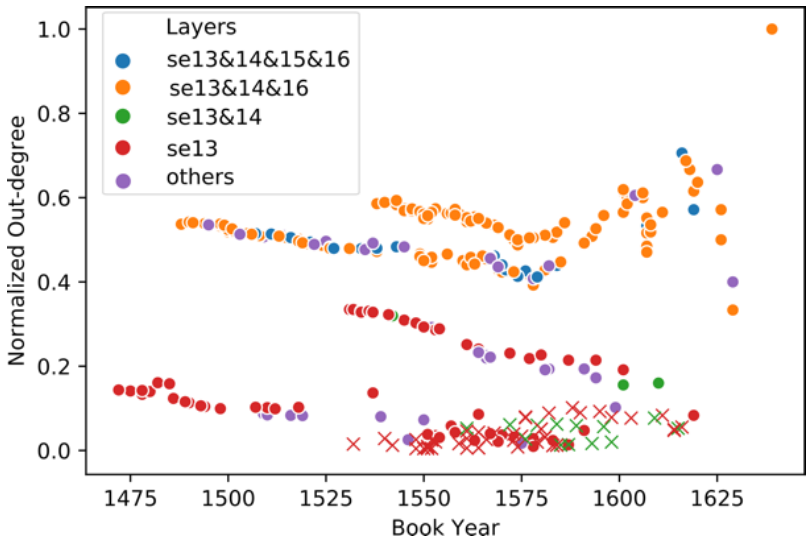

Figure 13. Composition of the families in function of the layers of the network. Circles identify editions that belong to the biggest connected component and cross symbols represent books in the small components.

Lastly, we examine the role of each of the semantic relations defined in section 4 in shaping the book families. To do so, the contribution of each layer to the final aggregated graph is investigated in order to assess which of the layers control the different families (emerging branches) in the normalized out-degree graph (Figure 13). In particular, families 2 and 4 are more dominated by a composition of layers se13 (same original part), se14 (same adaption), and se16 (annotated same original part). Families 1 and 3, on the other hand, are clearly shaped almost exclusively by layer se13. Cross symbols, finally, correspond to the books that do not belong to the main component and that, from a content-related point of view, further depart from the Tractatus of Sacrobosco.

5.2 Interpretation

The average age of the links and especially the low number of links eliminated when the assumption of influence is limited to ninety years are important factors in a very fundamental question of historical research, namely for how long it can be assumed that an event in the past has influenced a successive event. Obviously, this question can only be answered in the frame of a specific historical context. In this case, therefore, it can be said that scientific knowledge (externally represented by means of *Sphaera* editions between the end of the fifteenth and the half of the seventeenth century in Western Europe) reached a maximal age, the age before being forgotten, of about ninety years. This finally implies that longer knowledge traditions were possible only through re-instantiation of the same knowledge—in this case through the process of re-publishing.

Furthermore, the relative older age of links in layer se15 (same original translated) compared to layer se13 (same original part) could indicate that translations used a well-established (i.e., older) source-book, increasing the influence of some original parts in time. Regarding layer se16, the relational connections used to establish connectivity in this layer could explain the potential older age of its links. In particular, a link is established in layer se16 when two books contain commentaries on the same original part. This allows for a scenario in which two books distant in time are not connected by direct influence, but by re-publication of an original part in the context of subsequent commentaries published in between (*temporal evolution* of an original part).

As for the interpretation of the process of emergence of families as representatives of epistemic communities, we focus especially on families 2, 3,

and 4.[36] As the plots (Figures. 10, 11, 12) show, there are three branches (Families 2a and 2b, Family 3, and Family 4), each distinguished by a relatively stable, slightly decreasing normalized out-degree.

The books collected in families 3 and 4 seem relatively similar in several regards. Both branches begin with similar editions published in Wittenberg by the same publisher: Joseph Klug. These editions, as well as the subsequent books in these two families, contain a limited number of short text parts. These parts are distributed differently over the books under consideration, but re-occur frequently; so these books are similar with regard to their content but can be seen as "samplers" of a rather limited set of text parts (compared to the overall number of parts), often combined slightly differently in the various editions. Most of the text parts that appear in the books from which the new families originate are indeed new *in the corpus*. Namely, they appear here for the very first time. In many cases however they actually originate in works from earlier decades or even centuries.

The background for the selection of parts can only be speculated upon, but one scenario seems most likely: these collective volumes were intended mainly for teaching purposes and were closely related to the educational endeavor of Philipp Melanchthon and his circle in Wittenberg and Protestant Germany in the 1530s. Almost all books under consideration for the two families include the above-mentioned dedication letter by Philipp Melanchthon himself, safeguarding the use of natural astrology and cosmology within the Christian educational context.[37]

The major difference between the books collected in families 4 and 3 is that those of Family 4 tend to contain more parts and are thus longer books. Nonetheless, with regard to many text parts, books of both families overlap to

---

[36] The interpretation of families 2, 3, and 4 is based on the editions published in the frame of the first thirty years of each family's life. A full historical analysis of the scientific trends and epistemic communities, based on the results of the present work, will be accomplished in the future.

[37] Isabelle Pantin, "La lettre de Melanchthon à Simon Grynaeus: Avatars d'une défense de l'astrologie," in *Divination et controverse religieuse en France au XVIe siècle*, Cahiers V. L. Saulnier, Collection de l'Ecole Normale Supérieure de Jeunes Filles (Paris: Ecole Normale Supérieure de Jeunes Filles, 1987), 85–101; Sebastian Lalla, "Über den Nutzen der Astrologie: Melanchthons Vorwort zum „Liber de sphaera"," in *Gedenken und Rezeption: 100 Jahre Melanchthonhaus*, ed. Günther Frank (Heidelberg: Verlag Regionalkultur, 2003), 147–60; Karin Reich and Eberhard Knobloch, "Melanchthons Vorreden zu Sacroboscos «Spahera» (1531) und zum «Computus ecclesiasticus»," *Beiträge zur Astronomiegeschichte* 7 (2004): 13–44. See also, Claudia Brosseder, *Im Bann der Sterne: Caspar Peucer, Philipp Melanchthon und andere Wittenberger Astrologen* (Berlin: Akademie Verlag, 2004).

a high degree. This means that the text parts of the Family 3 editions are mostly also included in the editions of Family 4—which later also partially spread over Family 2. In particular, and in chronological order, the 1531 edition that opens Family 3 contains four text parts: a) the above-mentioned letter by Melanchthon, b) the original treatise by Sacrobosco, c) a short epigram also by Melanchthon, and d) a chapter from the famous work in astronomy by Johannes Regiomontanus: his *Epitome* on Ptolemy's *Almagest* (published for the first time in 1496), a work that elaborates on Ptolemy's astronomy by combining it with fifteenth-century mathematical astronomy. Melanchthon's letter and Regiomontanus's *Epitome* are the text parts that make this family turn out to be a new epistemic community within the corpus. In the first thirty years after the beginning of this family, we encounter eighteen books. In these books, the *Epitome* was republished seventeen times and Melanchthon's letter eleven times.

Looking at the text parts of the 1538 edition, by means of which Family 4 began, it is surprising that this family created a branch by itself. In fact, the 1538 edition republishes three of the four text parts that appear in the 1531 edition in exactly the same way. This aspect contributes to about half of the difference between the in-degree value of Family 4 (1538 edition) and Family 3 (1531 edition). To fully understand such value, however, a closer look at the composition of the 1538 edition is due. The first change that can be recognized in Family 4 is related to Sacrobosco's *Tractatus*. While this was contained in the 1531 edition as an original part, therefore repeating the late medieval text, the 1538 edition contains an expanded version of the treatise that was published in this edition for the first time. This is not an explicit commentary in the usual terms, but the result of an anonymous intervention in the original medieval text itself. Following our taxonomy, however, this text is categorized as an anonymous commentary on Sacrobosco's *Tractatus*. This in turn implies that it is formally captured by the semantic of layer se16, whose higher number of links and weights contributed for a bit over half of the difference between the in-degree value of Family 4 (1538 edition) and Family 3 (1531 edition) as well.[38]

This early modern expanded version of Sacrobosco's treatise, which was published under the name of Sacrobosco himself, experienced considerable

---

[38] This result therefore shows that, to achieve a more precise determination of the in- and out-degree values, a further category should be included that is able to distinguish more clearly between explicit commentaries and other sorts of interventions on the texts for all text parts. Apart from the obvious difficulty that could emerge while distinguishing between literary-stylistic interventions—due for instance to the humanistic imperative to emend medieval Latin on one side, and scientific interventions on the other—this information can be systematically collected only on the basis of a textual analysis executed on electronic transcriptions. No technology is available to produce such transcriptions at the moment.

success and, as it turns out, is one of the main reasons for the constitution of Family 4. If only the first thirty years of Family 4 are considered, we encounter thirty-two books, twenty-two of which contain such a variation of Sacrobosco's *Tractatus*. Considering that this text part was re-published a total number of twenty-six times in the total corpus, this text can be almost uniquely associated with this family. Besides these four parts, the 1538 edition also contains a) Sacrobosco's treatise on *computus*,[39] b) a *Cisiojanus*,[40] and c) a chapter of a late medieval Latin translation, made by John of Seville, of a work on mathematical astronomy originally written in the year 833 by the Arab scholar al-Farghani, a work that entered Western culture under the title *Liber de aggregatione stellarum*. This text part was published in the 1538 edition for the first time in the corpus and was re-published twenty-three times until 1568. The treatise on *computus* and the *Cisiojanus* are published in this edition for the first time as well and were always re-published together. Within the same time interval, their re-occurrences amount to twelve in Family 4, while their total amount in the corpus until 1650 is twenty.

Families 3 and 4 represent new epistemic communities in the history of the corpus. There is a series of reasons for this. The first is the fact that new text parts, namely parts that were not yet present in the corpus of printed treatises, appeared for the first time. The second is related to the behavior of their re-occurrences; they were not only successful but were often especially successful in the frame of the family itself. They were successful because the absolute number of their re-occurrences was often high and, additionally, they remained strongly present within the respective families. Considering these aspects together, it implies that the establishment of the families as new epistemic communities was due to the fact that the new text parts re-appeared together. In other words, they formed bundles of atoms of knowledge represented by text parts. The appearance of a new text part is an innovation in the corpus but not necessarily a knowledge innovation, as many of these texts

---

[39] Treatises on *computus* or *computus ecclesiasticus* were textbooks by means of which late medieval students learned to calculate the date of Easter for successive years and, with it, could assign a date to all movable feasts and complete the liturgic calendar. *Computus* was a widespread study in the late medieval period and many different treatises circulated on the topic. For Sacrobosco's treatise, entitled *De anni ratione* during the early modern period, see Jennifer Moreton, "John of Sacrobosco and the Calendar," *Periodicals Archive Online* 25 (1994): 229–44.

[40] A *Cisiojanus* is a short text, written in the form of a poem, intended to be learned by heart. Its apparently nonsensical verses allowed the students to remember the rules to calculate the dates of the movable feasts of the Christian liturgic calendar. For more information, see Rolf Max Kully, "Cisiojanus. Studien zur mnemonischen Literatur anhand des spätmittelalterlichen Kalendergedichts," *Schweizerisches Archiv für Volkskunde* 70 (1974): 93–123.

were actually already centuries old. The fact that a new trend emerged because of a new combination of texts (rather than new texts) implies that novelty in science emerged on a higher level, namely at the level of the shared scientific identity based on the study of a new combination of text parts. These families of editions indeed represent processes of the circulation of scientific knowledge in specific temporal and geographical areas—knowledge acquired by university students. This also shows that innovation of scientific knowledge, as far as concerns this corpus and the educational pattern in cosmology, was brought about more by the publishers than by the authors. The publishers were ultimately responsible for the composition of their books.

Returning to the structural and bibliographical similarities of the books belonging to both branches, a few more observations are noteworthy. First, and as already mentioned, these books exhibit the success of books printed in a smaller format, namely in *octavo*. This tendency to "convert" *Sphaera* volumes from *folio* into *octavo* format has been observed in previous scholarship, but is borne out here not only with more rigor but also in a specific historical context and in a quantified manner.[41] Moreover, on a more political and confessional note, books of these branches testify to a "bridge" from Protestant Wittenberg to the Republic of Venice, Paris, and Antwerp. Those places of book production were all officially Catholic at the time of the emergence of these new communities. As has been observed in existing scholarship, Melanchthon's humanist approach in particular was valued highly among certain humanist and Catholic circles in Italy.[42] This affinity might have compelled or enabled the cooperation of printers and publishers north and south of the Alps or might at least have triggered printers to copy the Wittenberg edition(s) as they felt the demand for this type of publication among their own clients and peers.

A final relevant aspect concerning families 3 and 4 is related to the printer of the books that establish both families—a fact that ultimately explains why families 3 and 4 can be considered together and why the high value of normalized in-degree of Family 4 should actually be balanced by the low normalized in-degree value of Family 3. As mentioned, the books were both

---

41 Owen Gingerich, "Five Centuries of Astronomical Textbooks and Their Role in Teaching," in *The Teaching of astronomy*, ed. J. M. Pasachoff and J. R. Percy (Cambridge: Cambridge University Press, 1990), 189–211; Isabelle Pantin, "Borrowers and Innovators in the Printing History of Sacrobosco: The Case of the "in-octavo" Tradition," in *De sphaera of Johannes de Sacrobosco in the Early Modern Period: The Authors of the Commentaries*, ed. Matteo Valleriani (Dordrecht: Springer Nature, In press).

42 Christoph Sander, "Johannes de Sacrobosco und die Sphaera-Tradition in der katholischen Zensur der Frühen Neuzeit," *NTM Zeitschrift für Geschichte der Wissenschaften, Technik und Medizin* 26, no. 4 (2018): 437–74.

printed by Joseph Klug. Klug began offering his services in Wittenberg in 1523, when the center of the Protestant Reformation was attracting numerous printers. He began working for the Reformers in 1525 by publishing the first editions of three works of Martin Luther. He became a relevant printer especially for the production of the *Geystliche gesanck Buchleyn*, a collection of chants edited directly by Martin Luther. It remains unclear how close Klug was with the Reformers on a personal level, but he was later put in charge of publishing several other particularly important theological works by Philipp Melanchthon. Until now, it was completely unknown that Klug was at the vanguard of producing extremely influential university textbooks as well.[43]

Turning now to Family 2, the books belonging to this family are very different from those just analyzed. As this family begins much earlier, in 1488, the books belonging to its first phase are representative of the passage from the manuscript tradition to the print, a point that can be at least partially demonstrated by comparing the books published during the first thirty years of Family 2 with the so-called medieval *Corpus astronomicum*.[44] Focusing on the characteristics of the printed editions of Family 2, two observations seem to corroborate this strong connection to a manuscript culture. Some of the earliest editions of this family are printed in *folio* and contain many long and complete works, such as the long and hitherto neglected commentary of Francesco Capuano on the *Theoricae novae* of Peuerbach.[45] This very much resembles the appearance and content of late medieval "cumulative" manuscripts in the field of cosmology.

In strong contrast to the two branches corresponding to families 3 and 4, the first phase of Family 2 hardly contains books in *octavo* format, though this format had been circulating since 1495 thanks to the publication of the first of

---

43 Unfortunately, the activity of Joseph Klug has not been as investigated by book historians as the subject deserves. For a short biographical sketch, see Hans Volz, "Die Wittenberger Gesangbuchdrucker Joseph Klug und Hans Lufft," *Jahrbuch für Liturgik und Hymnologie*, no. 4 (1958): 129–33. For Joseph Klug's activity in the frame of the corpus *De sphaera*, see http://hdl.handle.net/21.11103/sphaera.100802. On print culture in early modern Wittenberg, see Stefan Oehmig, ed. *Buchdruck und Buchkultur im Wittenberg der Reformationszeit* (Leipzig: Evangelische Verlagsanstalt GmbH, 2015).

44 For the medieval *Corpus astronomicum*, see O. Pedersen, "The Corpus Astronomicum and the Traditions of Mediaeval Latin Astronomy," *Copernicana*, no. 13 (1975): 57–96. The manuscript tradition obviously began in the thirteenth century when the *Tractatus* was first written. Hundreds of manuscripts containing the *Tractatus* and other text parts have come down to us, but as there is no census and no closer reading of them, no punctual analysis can be accomplished at this stage.

45 For an edition that belongs to Family 2 and that contains Capuano's commentary, see for instance the 1499-published treatise http://hdl.handle.net/21.11103/sphaera.100273.

the Aldine, by Aldo Manuzio in Venice. These editions are in *quarto* and *folio*. Those formats were less used by students than by scholars, teachers, and collectors, as they were more expensive. These editions, moreover, also have no clear geographical center or distribution. They were published widely all-over central Europe, from Rome to Cologne, and from Salamanca to Krakow. Also, in contrast to the books of families 3 and 4, those of Family 2 do not have an immediate "shared identity" with regard to their content and their authors. What does seem to connect them is their individuality on the one hand and their success on the other. This means that we find very different sets of editions belonging to this family—for example, a *folio* volume from Paris re-published three times,[46] or a set of similar *folio* volumes containing, among other things, either the commentary on the *Sphaera* by Francesco Capuano di Manfredonia or the commentary of the *Sphaera* by Jacques Lefévre d'Étaples (both printed primarily in Paris and Venice),[47] or the edition of Sacrobosco's treatise both introduced and commented upon by Wenzel Faber, usually entitled *Opus sphaericum* or *Opusculum spericum* and published in Cologne, Strasbourg, and Leipzig in *quarto* format as well.[48] These three sets of editions are not only rather peculiar (each in its own way) and different among themselves, but also mutually successful, as they all saw multiple editions that belong to the same family.

A common feature of the editions of Family 2, therefore, seems to be their attempt to re-structure and confirm the established cosmological knowledge—represented by Sacrobosco's treatise—in the path of tradition. The Paris editions, beginning in 1498, do so by adding a number of (often medieval) reference works and a few commentaries on the *Sphaera*. The second set does so mostly by combining the two rather contemporary commentaries by Capuano and d'Étaples with many more, often medieval works (some of which had already appeared in the Paris *folio* editions) beginning only one year later,

---

46 The Paris *folio* volume is published twice in 1498:
http://hdl.handle.net/21.11103/sphaera.100038 and
http://hdl.handle.net/21.11103/sphaera.100274 and then, for instance, again in 1508:
http://hdl.handle.net/21.11103/sphaera.100642.

47 This set of editions, characterized by very different titles but very similar content, is particularly large. In chronological order, some of these *folio* editions are: (Venice 1499):
http://hdl.handle.net/21.11103/sphaera.100273,
(Venice 1508) http://hdl.handle.net/21.11103/sphaera.100915,
(Paris 1511) http://hdl.handle.net/21.11103/sphaera.100919,
(Paris 1516) http://hdl.handle.net/21.11103/sphaera.100990.

48 Editions of Wenzel Faber's commentary are numerous. See for instance the following:
(Leipzig [1495] http://hdl.handle.net/21.11103/sphaera.100886, (Leipzig 1499)
http://hdl.handle.net/21.11103/sphaera.100888,
and (Cologne 1508) http://hdl.handle.net/21.11103/sphaera.100183.

in 1499 in Venice.[49] Faber's commentary in turn was printed as a monograph and not together with other commentaries, as early as 1495 (in Leipzig). His work seems to mirror the attempt to pave the way toward the emergence of a commentary style more tailored to teaching purposes, especially in universities in German territories.[50]

On a formal and statistical level, it is persuasive to argue for structural differences between families 3 and 4 in comparison to Family 2. Books in families 3 and 4 tend to combine and re-combine a limited set of text parts: while in Family 3 and Family 4 we find twenty-six and forty-nine text parts, re-combined to a total of 177 and 419 times respectively, Family 2 is represented by 128 text parts recombined so as to let them appear 411 times. This gives the impression of a relatively stable content profile built around a constellation of a small number of text parts or atoms of knowledge for the first two families, while the content profile, the shared identity, of Family 2 can only be established if a large number of text parts is considered.

To summarize, we would interpret Family 2 as the continuation, in a new medium, of the late medieval tradition, though this came at a high cost, namely the necessity to vary as much as possible the offering of new text parts, be they original parts or adaptions, while remaining at the closest possible proximity to the original medieval treatise. This implies continuity and great variation at the same time. Families 3 and 4, instead, show the establishment of new epistemic communities that slightly depart from the tradition represented by Family 2 and that were established by means of a more efficient mechanism, as this involved smaller formats and, above all, because they were compilations of a more limited number of text parts.[51]

Apparently, this result was achieved through the two following steps, which occurred respectively in 1531 and 1538. The first, highly disruptive, was

---

49 The two commentaries by Francesco Capuano and Jacques Lefèvre d'Étaples were first published in 1499, in the same edition (http://hdl.handle.net/21.11103/sphaera.100021). d'Étaples's commentary was first published in 1494. (http://hdl.handle.net/21.11103/sphaera.101126)

50 Family 2 remains stable along the timeline. However, beginning in 1543 we see vernacular translations enter it as well, and later on even translations that include text parts typical for families 3 and 4, indicating an increasingly large component and, therefore, a wider and perhaps faster circulation of knowledge.

51 The hypothesis could also be formulated at this stage that the degree of variation of parts that characterizes the families was also dependent on the print runs of the editions. Unfortunately, such dependence cannot be investigated because systematic data concerning the print runs are missing. But it could be speculated that smaller print runs are associated to higher variation of text parts.

the insertion of a compilation where three parts out of four were new to the corpus. Thus, both the parts and their combination were novel. The second step built upon the first and enriched the compilation with new parts. Through analysis of the single layers of the network, therefore, we are now able to analyze this double step more closely. As mentioned, the more disruptive changes (Family 3) are fully represented by layer se13 (Figure 13), namely by a graph of books connected to each other because they contain the same original (in this case, new) text parts. The second step (Family 4), however, is achieved by mixing this characteristic with those indicated by layers se14 and se16, namely by either re-publishing exactly the same commentaries or commentaries on the same (small number of) original parts. This means that, once the fundamental change was accomplished, to become influential in European educational paths the editions had to increase their degrees of variation similarly to the behavior of the editions of Family 2.[52] As the high value of normalized out-degree of Family 4 shows (being the highest among the families), in this way Joseph Klug built up the most influential new epistemic community. This particular circumstance clearly describes the mechanisms the Reformers used to influence the scientific educational paths of Europe.

The investigation, based on the different methods of production of scientific knowledge, represented here by the taxonomy of the text parts and the semantic structures of the layers, offers the opportunity to disclose the most fundamental of the mechanisms of emergence of new epistemic communities. The emergence, establishment, and disappearance of such new epistemic communities, namely communities that display new knowledge, are processes that illustrate how knowledge evolves over time, in this case during the early modern period.

---

[52] The huge *folio* editions contained in Family 2 might have inspired the printers of the editions contained in Family 4. Although these printers (esp. Klug) made a completely different choice regarding the actual text parts compared to those of Family 2, they nonetheless might have observed that the *folio* volumes of Paris and Venice proved successful and thus applied their compositional pattern (esp. the inclusion of many text parts and the combination of mediaeval original parts with contemporary commentaries) to a new selection of text parts and a new book format.

6 Discussion

On the basis of the data used for the present work, further analyses will be performed to assess the maximum time of influence of editions to address (1) whether there is a characteristic expiration time for each link, in the sense that each editions has a maximum lifetime in terms of influence, (2) how link influence depends on book production rates, (3) how link lifetime depends on the semantic layers, and (4) whether and how non-semantic factors (e.g., publisher, city of production, book format) affect link lifetimes.

A further analysis will include a new graph able to formally capture the small components. This graph will connect those books that, as a result of this analysis, turned out to be particularly distant from the content-related tradition as determined by the content of the work of reference: Sacrobosco's treatise. This will allow us to compare the results of this work, concerned with the core of the knowledge system pivoted around Sacrobosco's *Tractatus*, with those achieved by looking at what might turn out to be the beginning of a new, even more disruptive family.

More fundamentally, the project will continue first and foremost through the release of further data, producing a higher number of layers of the network. These in turn will generate connections enabling modeling that will disclose which of these layers are relevant for the historical argument.

On the level of semantic atoms to identify each single historical source and to allow the comparison among them, we are extracting and analyzing illustrations and numerical tables. We consider these kinds of "knowledge atoms" as ontologically different from text parts. In spite of the fact that texts, images, and tables are all connected to each other in each source, the same text part, in its re-occurrences, could be enriched by unique illustrations. Illustrations are carriers of knowledge; they will therefore be considered to be a specific form of commentary. Numerical tables in the frame of astronomy and cosmology did not convey only observational knowledge. More often, they are representative of computational methods that were not made explicit in the texts and become apparent only through the analysis of the numbers listed in the tables. While the content in reference to geocentric cosmology might have remained constant, algorithms for the necessary computations might have evolved and changed over time. Meanwhile, ca. 20,000 illustrations and 11,000 tables have been extracted from the sources of the corpus. Further work is ongoing to cluster this data and, accordingly, to prepare new graphs concerned with the diffusion of visual material and of computational tables. After this work is concluded we will have the ability to cross the new data with

the metadata and thereby to establish new layers expressing the diffusion and circulation of visual knowledge as well as of computational algorithms in the sources and to compare them with the behavior of the text parts.[53]

Furthermore, a dataset is being completed that includes aspects of social and material nature that can be extracted from the printed books directly. This will allow us to create nine further graphs to represent collaborations among authors, printers, and publishers of the editions, each according to a specific semantic.[54] Finally, we will a) investigate the correlations between layers expressing semantic behaviors and those closely related to the social and material aspects of book production and b) measure the hierarchical structure and study the driving forces that might make the structure of the network converge to hierarchy.[55]

Another exciting avenue of research will be studying dynamical processes on the multilayer networks to model the spread of knowledge in this historical period. Pioneering studies on diffusion[56] and the dynamics of the spread of disease[57] in multilayer networks have shown a priori unexpected behavior in the dynamical response of systems, which emerge due to the coexistence of paths between nodes of different natures, in the sense that those paths integrate the connectivity of the various layers. More recently, it has been shown that when multilayer networks include directed graphs[58] the dynamic enriches even more, wherein diffusion dynamics can exhibit optimality (i.e., the system can achieve maximum spreading rates). Thus, given the multilayer structure and directionality of the network extracted from the corpus,

---

53 The identification of the scientific illustrations as well as of the numerical tables and their clustering according to different levels of "sameness" is being executed in the frame of the Berlin Center for Machine Learning, of which the *Sphaera* Project is also part. For more information, see https://www.bzml.de.

54 Jürgen Renn et al., "Netzwerke als Wissensspeicher," in *Die Zukunft der Wissensspeicher. Forschen, Sammeln und Vermitteln im 21. Jahrhundert*, ed. Jürgen Mittelstraß and Ulrich Rüdiger (München: UVK Verlagsgesellschaft, 2016), 35–79.

55 Maryam Zamani and T. Vicsek, "Glassy Nature of Hierarchical Organizations," *Scientific Reports* 7, no. 1382 (2017); Maryam Zamani, L. Camargo-Forero, and T. Vicsek, "Stability of Glassy Hierarchical Networks," *New Journal of Physics* 20, no. 023025 (2018).

56 S. Gómez et al., "Diffusion Dynamics on Multiplex Networks," *Physical Review Letters* 110, no. 028701 (2013).

57 Manlio De Domenico et al., "The Physics of Spreading Processes in Multilayer Networks," *Nature Physics* 12 (2016): 901–06; Guilherme Ferraz de Arruda, Francisco A. Rodriguez, and Yamir Moreno, "Fundamentals of Spreading Processes in Single and Multilayer Complex Networks," *Physics Reports* 756, no. 1 (2018): 1–59.

58 Alejandro Tejedor et al., "Diffusion Dynamics and Optimal Coupling in Multiplex Networks with Directed Layers," *Physical Review X* 8, no. 031071 (2018).

questions of interest include: (1) how the time-evolving structure of book connectivity is characterized in terms of its potential to spread information, (2) whether the period with the highest book production rates corresponds to the connectivity structure that allows the fastest spread of knowledge, and (3) whether there are key books that might not be influential from the point of view of topological influence (e.g., normalized book out-degree) but are critical in the spreading of information across different communities (e.g., geographical areas). Finally, from the data analysis point of view, it will be interesting to study the corpus according to a phylogenetic tree, as is the practice in biology for the evolution and interrelation of species. More generally, we intend first to introduce a similarity measure between items of the corpus in order to visualize and quantitatively analyze changes of the contents over time and, on a more speculative level, to investigate employing models used in evolutionary biology to describe the process of evolution of knowledge.

7 Authors' contributions

Data collection: S. Bertram, G. Funke, C. Sander, M. Valleriani

Data repository and curation: F. Kräutli

Dataset creation: F. Kräutli, M. Vogl

Data analysis: A. Tejedor, M. Vogl, M. Zamani

Historical interpretation: C. Sander, M. Valleriani

Results discussion: H. Kantz, F. Kräutli, C. Sander, A. Tejedor, M. Valleriani, M. Vogl, M. Zamani

Writing: C. Sander, A. Tejedor, M. Valleriani

8 Bibliography

Aleta, Alberto, and Yamir Moreno. "Multilayer networks in a nutshell." *Annual Review of Condensed Matter Physics* 10 (2019): 45–62.

Bianconi, G. *Multilayer Networks: Structure and Function.* Oxford: Oxford University Press, 2018.

Boccaletti, S., V. Latora, Y. Moreno, M. Chavez, and D.-U. Hwang. "Complex Networks: Structure and Dynamics." *Physics Report* 424, no. 4–5 (2006): 175–308.

Brosseder, Claudia. *Im Bann der Sterne: Caspar Peucer, Philipp Melanchthon und andere Wittenberger Astrologen.* Berlin: Akademie Verlag, 2004.

Cozzo, E., Guilherme Ferraz de Arruda, Francisco A. Rodriguez, and Y. Moreno. *Multiplex Networks: Basic Formalism and Structural Properties.* Springerbriefs in Complexity. Cham: Springer Nature, 2018.

Crowther, Kathleen M., and Peter Barker. "Training the Intelligent Eye: Understanding Illustrations in Early Modern Astronomy Texts." *Isis* 104, no. 3 (2013): 429–70.

Crowther, Kathleen M., Ashley Nicole McCray, Leila McNeill, Amy Rodgers, and Blair Stein. "The Book Everybody Read: Vernacular Translations of Sacrobosco's Sphere in the Sixteenth Century." *Journal for the History of Astronomy* 46, no. 1 (2015): 4–28.

De Domenico, Manlio, Clara Granell, Mason A. Porter, and Alex Arenas. "The Physics of Spreading Processes in Multilayer Networks." *Nature Physics* 12 (2016): 901–06.

Ferraz de Arruda, Guilherme, Francisco A. Rodriguez, and Yamir Moreno. "Fundamentals of Spreading Processes in Single and Multilayer Complex Networks." *Physics Reports* 756, no. 1 (2018): 1–59.

Gingerich, Owen. "Five Centuries of Astronomical Textbooks and Their Role in Teaching." In *The Teaching of Astronomy*, edited by J. M. Pasachoff and J. R. Percy, 189–211. Cambridge: Cambridge University Press, 1990.

———. "Sacrobosco Illustrated." In *Between Demonstration and Imagination. Essays in the History of Science and Philosophy Presented to John D. North*, edited by Lodi Nauta and Arjo Vanderjagt. Leiden, Boston, Köln: Brill, 1999.

Gómez, S., A. Díaz-Guilera, J. Gómez-Gardeñes, C.J. Pérez-Vicente, Y. Moreno, and Alex Arenas. "Diffusion Dynamics on Multiplex Networks." Physical Review Letters 110, no. 028701 (2013).

Kivelä, Mikko, Alex Arenas, Marc Berthelemy, Jampes P. Gleeson, Yamir Moreno, and Mason A. Porter. "Multilayer networks." *Journal of Complex Networks* 2, no. 3 (2014): 203–71.

Kräutli, Florian, and Matteo Valleriani. "CorpusTracer: A CIDOC Database for Tracing Knowledge Networks." *Digital Scholarship in the Humanities* (2017).

Kully, Rolf Max. "Cisiojanus. Studien zur mnemonischen Literatur anhand des spätmittelalterlichen Kalendergedichts." *Schweizerisches Archiv für Volkskunde* 70 (1974): 93–123.

Lalla, Sebastian. "Über den Nutzen der Astrologie: Melanchthons Vorwort zum „Liber de sphaera“." In *Gedenken und Rezeption: 100 Jahre Melanchthonhaus*, edited by Günther Frank, 147–60. Heidelberg: Verlag Regionalkultur, 2003.

Leitão, Henrique, ed. *Sphaera Mundi: A Ciência na Aula de Esfera. Manuscriptos científicos do Colégio de Santo Antão nas colecções da BNP*. Lisboa: Biblioteca Nacional de Portugal, 2008.

———. "Um Mundo Novo e una Nova Ciência." In *360º · Ciência Descoberta, Catálogo da Exposição*, edited by Henrique Leitão, 16–39. Lisboa: Fundação Calouste Gulbenkian, 2013.

Ludwig, Corinna. "Die Karriere eines Bestsellers. Untersuchungen zur Entstehung und Rezeption der Sphaera des Johannes de Sacrobosco." *Concilium medii aevi* 13 (2010): 153–85.

MacLean, Ian. *Learning and the Market Place: Essays in the History of the Early Modern Book.* Leiden: Brill, 2009.

Moreton, Jennifer. "John of Sacrobosco and the Calendar." *Periodicals Archive Online* 25 (1994): 229–44.

Newman, Mark. *Networks: An Introduction.* Oxford: Oxford University Press, 2010.

Nuovo, Angela. *The Book Trade in the Italian Renaissance.* Leiden: Brill, 2013.

Oehmig, Stefan, ed. *Buchdruck und Buchkultur im Wittenberg der Reformationszeit*. Leipzig: Evangelische Verlagsanstalt GmbH, 2015.

Oosterhoff, Richard J. "A Book, a Pen, and the «Sphere:» Reading Sacrobosco in the Renaissance." *History of Universities* 28, no. 2 (2015): 1–54.

Pantin, Isabelle. "La lettre de Melanchthon à Simon Grynaeus: Avatars d'une défense de l'astrologie." In *Divination et controverse religieuse en France au XVIe siècle*. Cahiers V. L. Saulnier, Collection de l'Ecole Normale Supérieure de Jeunes Filles, 85–101. Paris: Ecole Normale Supérieure de Jeunes Filles, 1987.

———. "Borrowers and Innovators in the Printing History of Sacrobosco: The Case of the "in-octavo" Tradition." In *De sphaera of Johannes de Sacrobosco in the Early Modern Period: The Authors of the Commentaries*, edited by Matteo Valleriani. Dordrecht: Springer Nature, In press.

Pedersen, O. "The Corpus Astronomicum and the Traditions of Mediaeval Latin Astronomy." *Copernicana*, no. 13 (1975): 57–96.

Pedersen, Olaf. "In Quest of Sacrobosco." *Journal for the History of Astronomy* 16, no. 3 (1985): 175–220.

Reich, Karin, and Eberhard Knobloch. "Melanchthons Vorreden zu Sacroboscos «Spahera» (1531) und zum «Computus ecclesiasticus»." *Beiträge zur Astronomiegeschichte* 7 (2004): 13–44.

Renn, Jürgen, Dirk Wintergrün, Roberto Lalli, Manfred Laubicher, and Matteo Valleriani. "Netzwerke als Wissensspeicher." In *Die Zukunft der Wissensspeicher. Forschen, Sammeln und Vermitteln im 21. Jahrhundert*, edited by Jürgen Mittelstraß and Ulrich Rüdiger, 35–79. München: UVK Verlagsgesellschaft, 2016.

Sander, Christoph. "Johannes de Sacrobosco und die Sphaera-Tradition in der katholischen Zensur der Frühen Neuzeit." *NTM Zeitschrift für Geschichte der Wissenschaften, Technik und Medizin* 26, no. 4 (2018): 437–74.

Tejedor, Alejandro, Anthony Longjas, Efi Foufoula-Georgiou, Tryphon T. Georhiou, and Yamir Moreno. "Diffusion Dynamics and Optimal Coupling in Multiplex Networks with Directed Layers." *Physical Review X* 8, no. 031071 (2018).

Thorndike, Lynn. *The Sphere of Sacrobosco and its Commentators.* Chicago: The University of Chicago Press, 1949.

Valleriani, Matteo. "The Tracts on The Sphere. Knowledge Restructured over a Network." In *Structures of Practical Knowledge*, edited by Matteo Valleriani, 421–73. Dordrecht: Springer, 2017.

———. "Maths is revolutionising the study of history – here's how." *The Conversation* https://theconversation.com/maths-is-revolutionising-the-study-of-history-heres-how-85710 (2018).

———. "Prolegomena to the Study of Early Modern Commentators on Johannes de Sacrobosco's Tractatus de sphaera." In *De sphaera of Johannes de Sacrobosco in the Early Modern Period: The Authors of the Commentaries*, edited by Matteo Valleriani. Dordrecht: Springer Nature, In press.

van den Heuvel, Charles. "Mapping Knowledge Exchange in Early Modern Europe Intellectual and Technological Geographies and Network Representations." *International Journal of Humanities and Arts Computing* 9, no. 1 (2015): 95–114.

van Vugt, Ingeborg. "Using Multi-Layered Networks to Disclose Books in the Republic of Letters." *Journal of Historical Network Research* 1 (2017): 25–51.

———. *The Structure and Dynamics of Scholarly Networks Between the Dutch Republic and the Grand Duchy of Tuscany in the 17th Century (PhD Thesis)*. Amsterdam: Amsterdam School of Historical Studies, University of Amsterdam, 2019.

Volz, Hans. "Die Wittenberger Gesangbuchdrucker Joseph Klug und Hans Lufft." *Jahrbuch für Liturgik und Hymnologie*, no. 4 (1958): 129–33.

Zamani, Maryam, L. Camargo-Forero, and T. Vicsek. "Stability of Glassy Hierarchical Networks." *New Journal of Physics* 20, no. 023025 (2018).

Zamani, Maryam, and T. Vicsek. "Glassy Nature of Hierarchical Organizations." *Scientific Reports* 7, no. 1382 (2017).

Breure, Abraham S.H.; Heiberger, Raphael H.

Reconstructing science networks from the past. Eponyms between malacological authors in the mid-19th century

Journal of Historical Network Research 3 (2019) 92-117.

Keywords

Eponyms; History of Malacology; Historical Social Networks; Elite; Exponential Random Graph Models

Abstract

Reconstructing scientific networks from the past can be a difficult process. In this paper, we argue that eponyms are a promising way to explore historic relationships between natural scientists using taxonomy. Our empirical case is the emerging community of malacologists in the 19th century. Along the lines of pivotal concepts of social network analysis we interpret eponyms as immaterial goods that resemble the properties of regular social contacts. Utilising Exponential Random Graph Models reveals that the social exchange underlying eponyms follows similar rules as other social relationships such as friendships or collaborations. It is generally characterized by network endogenous structures and homophily. Interestingly, the productivity of authors seems to be well recognised among contemporary researchers and increases the probability of a tie within the network significantly. In addition, we observe an epistemological divide in the malacological research community. Thus even in the 19th century, at a time when science was just emerging as a differentiated social system, epistemological distinctions have been a defining concept for scientific contacts.

eISSN 2535-8863
DOI 10.25517/jhnr.v3i1.52

1 Introduction*

Collaboration lies at the heart of the scientific endeavour and has received a lot of attention from scholars of various backgrounds for many decades.[1] The relationships that connect scientists are often represented as networks and allow other researchers to derive distinct patterns of disciplines, e.g. how many collaborators a typical scholar has or the underlying routines of the division of labour within a field.[2] Those recurrent patterns of scientific relationships form "invisible colleges"[3] resembling local encounters of leading scholars and their followers, forming intellectual networks across ages and driving academic progress since a long time.[4]

On a micro-level, studies reveal how the formation process of scientific contacts takes place in detail.[5] Yet, most of the explained variance of why people collaborate with each other can be assigned to classic demographic characteristics, starting with varying patterns of collaboration by scholars' age.[6] Another important aspect lies in the geographic proximity that increases the probability to do research together.[7] It is also often argued that informal social networks and collaboration in general increases the productivity of a

* **Acknowledgments:** We are grateful to Marten Düring and Martin Stark for exchanging ideas on an initial outline for this paper and Richard Heidler for his valuable comments. Also, we thank Jonathan Ablett for his linguistic advice. This work was partially funded by the German Excellence Initiative.

Corresponding author: Raphael Heiko Heiberger, Universtität Stuttgart, Seidenstraße 36 70174 Stuttgart

1 Beaver, Donald. 2001. Reflections on scientific collaboration (and its study): past, present, and future*. *Scientrometrics* 52: 365–377; Beaver, Donald, and R. Rosen. 1979. Studies in scientific collaboration: Part II. Scientific co-authorship, research productivity and visibility in the French scientific elite, 1799–1830. *Scientometrics* 1: 133–149. doi:10.1007/BF02016966; Merton, Robert K. 1973. *The Sociology of Science*. Chicago: The University of Chicago Press.

2 Newman, Mark. 2004. Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences* 101: 5200–5205. doi:10.1073/pnas.0307545100.

3 Bakker, Hans. 2017. Scientific Networks and Invisible Colleges. *The Blackwell Encyclopedia of Sociology*. London: Blackwell. doi:10.1002/9781405165518.wbeoss051.pub2

4 Collins, Randall. 2002. *The Sociology of Philosophies: A Global Theory of Intellectual Change*. Cambridge, Mass.: Belknap Press of Harvard University Press.

5 Genuth, Joel, Ivan Chompalov, and Wesley Shrum. 2000. How Experiments Begin: The Formation of Scientific Collaborations. *Minerva* 38: 311–348.

6 Wang, Wei, Shuo Yu, Teshome Megersa Bekele, Xiangjie Kong, and Feng Xia. 2017. Scientific collaboration patterns vary with scholars' academic ages. *Scientometrics* 112: 329–343. doi:10.1007/s11192-017-2388-9.

7 Ponds, Roderik, Frank van Oort, and Koen Frenken. 2007. The geographical and institutional proximity of research collaboration. *Papers in Regional Science* 86: 423–443. doi:10.1111/j.1435-5957.2007.00126.x.

researcher.[8] Finally, epistemological boundaries play a huge role[9], which create by design many more opportunities for research collaboration *within* one community than between scientists from different fields.

Despite the importance in understanding the composition of research teams and the abundance of studies[10], there are only few historical studies dating back earlier than 1900 due to a variety of data issues like missing documentation or archives, emergence of many disciplines later on, a semi-professional science system, and many more. In this paper, we argue that within biological sciences and therein eponyms provide a great opportunity to study historical social contacts in science. Given the old and rich archival systems established fairly early on in these taxonomical disciplines, we are able to examine many of the personal characteristics we previously cited to be of high relevance for networks of scholars: age, geography, productivity, and affiliation to a certain research community.

In order to test the influence of those characteristics on eponyms, we first provide some background on taxonomy and eponyms in zoological science. After describing the data and methods used in this paper, we address typical questions of research collaboration, e.g. who are the most important authors of that epoch and if an elitist core is identifiable. Building on those descriptive patterns, we run Exponential Random Graph Models[11] to detect homophily in regard to personal characteristics, i.e. to test if one of, or probably even *the*, most guiding principle[12] in social relationships also applies in the social process of eponyms between malacologists. Finally, we discuss our results and possible directions for future research, especially in how eponyms could help scholars to

---

8 Bozeman, Barry, and Elizabeth Corley. 2004. Scientists' collaborating strategies: implications for scientific and technical human capital. Research Policy 33: 599–616. doi:10.1016/j.respol.2004.01.008. Villanueva-Felez, Africa, Jordi Molas-Gallart, and Alejandro Escribá-Esteve. 2013. Measuring Personal Networks and Their Relationship with Scientific Production. *Minerva* 51: 465–483. doi:10.1007/s11024-013-9239-5.

9 Knorr Cetina, Karin. 2009. *Epistemic Cultures: How the Science make Knowledge*. Harvard University Press.

10 Stokols, Daniel, Kara L. Hall, Brandie K. Taylor, and Richard P. Moser. 2008. The Science of Team Science. *American Journal of Preventive Medicine* 35: S77–S89. doi:10.1016/j.amepre.2008.05.002.

11 Harris, Jenine. 2014. *An Introduction to Exponential Random Graph Modeling*. 2455 Teller Road, Thousand Oaks California 91320 United States: SAGE Publications, Inc. doi:10.4135/9781452270135; Robins, Garry, Pip Pattison, Yuval Kalish, and Dean Lusher. 2007. An introduction to exponential random graph (p*) models for social networks. *Social Networks* 29: 173–191. doi:10.1016/j.socnet.2006.08.002.

12 McPherson, Miller, Lynn Smith-Lovin, and James M Cook. 2001. Birds of a Feather: Homophily in Social Networks. *Annual Review of Sociology* 27: 415–444. doi:10.1146/annurev.soc.27.1.415.

get a better understanding of the emerging days of professional scientific research.

2 Eponyms as scientific contacts of the past

The role of historical science networks in biological sciences has received at least some attention.[13] However, historical studies in malacology have focused almost exclusively on biographies, bibliographies and lists of new taxa described by individual malacologists. A regularly updated list of these data is available[14] and as such is a great resource. In some biographical works contact networks have been reconstructed.[15] However, neither in-depth studies on contact networks of individuals nor studies of coherent networks have been published (cf. Audibert and Breure, 2017).

Malacology can be seen as an example of a rich field for analysing social contacts represented by eponyms.[16] Superficial data on contacts between malacologists is scattered throughout the literature. Archival studies have been limited to biographical data, and the correspondence archives of malacologists are scarce and ill-explored. Correspondence archives are usually limited to

13 E.g. Marples, A., and V. R. M. Pickering. 2016. Patron's review: Exploring cultures of collecting in the early modern world. *Archives of Natural History* 43: 1–20. doi:10.3366/anh.2016.0342.

14 Coan, Eugene V., and Alan R. Kabat. 2018. *2,400 years of malacology*. American Malacological Society.

15 E.g. van der Bijl, Bram, Robert Moolenbeek, and Goud Jeroen. 2010. *Matheus Marinus Schepman (1847-1919) and his contributions to malacology*. Leiden: Netherlands Malacological Society; Breure, Abraham S.H., and Wim Backhuys. 2017. Sauveur Abel Aubert Petit de la Saussaye (1792–1870), his malacological work and taxa, with notes on his correspondence. *Archiv für Molluskenkunde International Journal of Malacology* 146: 71–96. doi:10.1127/arch.moll/146/071-096; Breure, Abraham S.H., and Wim Backhuys. 2017. Science networks in action: the collaboration between J.G. Hidalgo and H. Crosse, and the creation of 'Moluscos del Viaje al Pacifico, Univalvos terrestres.' *Iberus* 35: 11–30; Mierzwa-Szymkowiak, D., and Abraham S. H. Breure. 2017. Inside and outside the Neotropics: three Polish naturalists during the late nineteenth and early twentieth centuries. *Archives of Natural History* 44: 151–158. doi:10.3366/anh.2017.0423.

16 Breure, Abraham S.H. 2017. Reconstructing historical egocentric social networks in malacology: is there a link between eponyms and contacts of an author? *Folia conchyliologica*: 3–12.

professionals[17], while those of amateurs are seldom preserved.[18] Preliminary studies of correspondence have shown that a three-fold distinction may be made: (a) the exchange of ideas, (b) the exchange of material (i.e. dry shells or preserved molluscs), and (c) the exchange of formal knowledge (i.e. reprints). Special attention is given to eponymy (dedication by a taxonomist of a new species to a certain person), as this may have played a role in the building of trust during the establishment of the social relationship. Eponyms are used in taxonomy when an author describes a new taxon (usually a new species) for which he uses the name of a person, following the rules of latinisation as given in the International Code on Zoological Nomenclature (ICZN). Eponyms can be given to anyone, but are usually either someone who collected material for study (field collectors) or colleagues (cabinet collectors, authors). Recently the hypothesis was developed that eponyms may serve as a proxy for contact[19], and this has been researched using archival sources and data from literature.[20] Although each author has his 'personal profile' when giving eponyms to others, the case studies hitherto explored show consistently two main target groups for eponyms: field collectors who supplied the material which could be used to describe new species, and cabinet collectors or fellow authors with whom there was contact as evidenced by correspondence. Some examples may help to illustrate this process. The first one relates to Arthur Morelet (1806-1892), who received material collected in Angola by the botanist Friedrich Welwitsch (1806-1872). He identified the material and found several new species, of which he named eight after Welwitsch.[21] Another case study concerns Hippolyte Crosse (1826-1898), director of the French malacological journal at that time, who also had a collection. Breure showed that usually the first eponym was given around the time of the first contact, evidenced by the correspondence archive of Crosse.[22]

While this was all centred on individuals, the science network within the community of malacologists is virtually unexplored. This community consists of persons performing one or more of the following roles: field collector, cabinet collector, and author. This preliminary analysis focusses on the latter role, i.e. the malacological author writing taxonomical papers, and takes into account

17 Breure, Abraham S.H., and Cédric Audibert. 2017a. 'Mon cher Directeur': an inventory of the correspondence addressed to Hippolyte Crosse during his years as director of the 'Journal de conchyliologie.' *Folia conchyliologica*: 3–108.

18 For an exception see: Breure, Abraham S.H. 2015. The malacological handwritings in the autograph collection of the Ph. Dautzenberg archives, Brussels. *Folia conchyliologica*: 1–111.

19 Breure, *Reconstructing historical egocentric social networks in malacology*.

20 Breure, *The malacological handwritings in the autograph collection of the Ph. Dautzenberg archives*; Breure, *Reconstructing historical egocentric social networks in malacology*.

21 Breure, Abraham S.H., Cédric Audibert, and Jonathan D. Ablett. 2018. *Pierre Marie Arthur Morelet (1809-1892) and his contributions to malacology*. Nederlandse Malacologische Vereniging.

22 Breure, *Reconstructing historical egocentric social networks in malacology*, Figure 2.

that two (sub)communities may be distinguished: authors dealing with fossil shells (palaeontologists), and those dealing with Recent shells. The distinction between these two groups is, however, not complete and a partial overlap exists. The aim of this paper is to present a first analysis of relations between malacological authors during the period 1850-1870. How was the community of authors structured during that period? Where was the core of malacological activities situated? Was there an 'elite' of malacological authors? We will address these questions by looking at the amount of active relationships of authors per country, whether these relationships were nationally or internationally oriented, and, more generally, whether the eponyms are structured in a similar way as "regular" social contacts like friendships or collaborations.

3 Methods: Social Network Analysis and Exponential Random Graph Models

As source of data for this analysis the publication of Ruhoff was used, covering the period 1850-1870. [23] Data on authors have been extracted from this paper, listing the number of publications during this period, the number of pages (for the elite authors; see below), the number of co-authored publications, and the number of co-authors involved. The number of pages from co-authored publications is divided between the co-authors. In total 701 authors are listed in Ruhoff's paper, of which 490 published new species. All species listed in her Index to Species were checked for possible eponyms against the authors included and against Coan and Kabat[24] to exclude eponyms that had been given posthumously (eponyms published in the year after the person's death are, however, still counted due to possible time lag in publication). The data on the authors are summarised in the supplementary information for this article.[25]

For each eponym (1) the publishing author ('source') and (2) the author named in the taxon ('target'). The interactions between authors are divided into (3) eponyms, exchange of material (when the manuscript name of an author has been introduced in a work of a third author), or a joint publication. Further (4) the number of eponyms, exchanges, or co-authored papers, (5) the year of the first eponym within the period 1850-1870, (6) ibidem the last year, (7) the country where the source was residing according to current political-administrative borders, and (8) ibidem for the target. Some authors relocated

---

23 Ruhoff, F.A. 1980. Index to the species of Mollusca introduced from 1850 to 1870. *Smithsonian Contributions to Zoology*: 1–640.

24 Coan and Kabat, *2,400 years of malacology*.

25 This and other supplementary data is available in a Figshare repository: doi:10.6084/m9.figshare.10322114.

during this period, and when this is known the year of relocation is taken into account; otherwise the country of residence where the person lived for the majority of time during this period was chosen. Eponyms derived from first names (e.g., *arthuri*, *ceciliae*, *sophiae*) are excluded. If the eponym could be applicable for more than one person with that surname, care was taken to check the original source or to take contextual information into consideration. Authors known to have published (mainly) on fossils are indicated with 'Palaeontologist'. A summary of relations of source nodes at national scale and across boundaries is given in Supplementary Information S1; transdisciplinary relations are summarised in S2. Geographically the following aggregations have been made: European – all countries west of Russia and Turkey; Americas – countries of North and South America, and the Caribbean; 3A – countries in Africa, Asia (including Russia), and Australia.

Although it is understood that some authors may be underrepresented due to the period chosen (especially those authors active during the years immediately before 1850 and after 1870), these limits have been chosen due to practical reasons. To take this into account, the age of the author in 1850 (if known) has been recorded. The selection of productive authors ('elite') was done in two steps: first a ranking was made on the total number of publications during the period analysed; secondly authors were selected who contributed to 80% of the total publications and a final ranking was made using their total number of pages published during the period (derived from Ruhoff or from WorldCat).[26]

In addition to descriptive network characteristics, we are analysing possible effects of homophily in malacologists' eponyms. For this purpose, endogenous parameters that are well-known to structure networks (triangles etc.) have to be controlled in order to reveal signals of nodal or dyadic attributes. This is most often done in Exponential Random Graph Models (ERGM)[27], which are stochastic representations of empirical networks. The goal of an ERGM is to explain the global structure of a network with few local parameters. In doing so, it resembles a multivariate model in which endogenous network parameters can be considered, which most often exhibit the largest effects on the constitution of a network. To avoid the problem of multicollinearity - which is by definition always present in a network due to interdependence of its parts - we simulate in ERGMs a large number of random graphs to compute average network statistics and compare those with the empirical network.

Nevertheless, the general mechanics of an ERGM are very much alike to a logistic regression, the binary outcome variable for a network model being

[26] The dataset was analysed using Cytoscape 3.5.1 (www.cytoscape.org; Shannon et al. 2003) and RStudio (2018).

[27] Harris, *An Introduction to Exponential Random Graph Modeling*; Robins *et al*., *An introduction to exponential random graph (p*) models for social networks*.

"having a tie (or not)". Formally, we estimate the probability P of a specific realisation of a network x out of a set of all possible networks X with n vertices: $P(X = x) = exp\,(\theta z(x))/K(\theta)$, with $z(x)$ as network or actor (dyadic) characteristics, θ coefficients, and K as a normalising constant. Yet unlike a deterministic logistic regression, an ERGM estimates the probability of observing a specific network x by exploring its deviation from a large number of random networks, in order to circumvent the problem of multicollinearity. The algorithm converges if the coefficients θ of the network characteristics $z(x)$ generate graphs which are reasonable close to the empirical realisation.[28] Hence, θ can be interpreted as the log-odds of an individual tie. In so doing, the change statistic z is increasing or decreasing the probability of a tie in the specific network x by θ than it would be expected by chance alone (and which we approximate by large quantity of simulated random graphs).

Most of the effects in which social scientists are interested in are the attributes of social entities, mostly size and homophily. Given its composition, ERGMs allow us to test if specific nodal or dyadic attributes influence ties' probability in a certain graph significantly net of endogenous network effects. For instance, we can directly test whether homophily in regard to gender, country of birth or discipline is important for interactions at a conference. In addition, we can also model if the presence or absence of a tie depends on a nodal attribute, i.e. the likelihood of interactions increases (or decreases) with an attribute. These attributes can also be dyadic terms and refer to the status or qualities of an edge. It is also important to note that in order to reduce complexity and improve the convergence of the ERGMs we do not consider direction in the ERGMs and also include authors with more than 5 relationships to concentrate on leading scholars forming the "invisible college" of emerging malacology. This does not alter, however, the exploration of the structural effects of homophily and productivity in regard to being part of the malacological network of eponyms.

4 Mapping the field of historic malacology

In overview, the network shows a rather densely connected 476 nodes, with two heavily linked areas, whereby palaeontological authors gather mostly in one cluster (Figure 1. Further descriptives are also provided in Table 1). We explore this network by its authors' attributes.

[28] Cf. further details, for instance, Harris, *An Introduction to Exponential Random Graph Modeling*.

Geography

During the period 1850-1870 a total of 458 malacological authors were active and which could be included in the dataset, of which 83 (18%) were non-European. Of these authors 178 were assigned as palaeontologists, of which 118 gave eponyms to others or exchanged material. In total there were 1822 relationships during the study period, 1578 (87%) by European authors, 219 (12%) by authors from the Americas, the rest from other parts of the world. Within Europe, the countries with the most active authors in terms of relationships were France, Germany, the United Kingdom, and Switzerland (respectively 41%, 20%, 16%, 8% of the European total); see also Supplementary Information S3. Relationships with a palaeontological author as source were 673 (37%), the rest were from authors devoted to recent species or partly describing fossil species. The split between national and international contacts is 52/48% (respectively 53/47% for palaeontologists, and 51/49% for other authors). Countries with relatively high percentages of national contacts were the United States (73%), France (68%), and the United Kingdom (53%).

Network Properties	
Number of Nodes	476
Number of Edges	1822
Average Path Length	3.26
Average Cluster Coefficient	0.13
Modularity	0.41

Table 1. Network descriptives.

Communities

Within the total group, two 'communities' may be recognised: Recent and palaeontological authors, respectively. 'Recent authors' study molluscs that are still extant, while the 'palaeontologists' group studies fossils. There is only a small overlap between the two groups, and authors have been attributed to the group where most of their publications are related to. Of the 1149 relations of the Recent authors group, 1007 (88%) were within this community. For the palaeontological authors this was 443 of a total of 673 (66%). Between the two communities respectively 230 and 142 were initiated by palaeontological and

Recent authors. This is underlined by the high modularity of the network (cf. Table 1), which stems from the compartmentalisation of the malacological research community.[29]

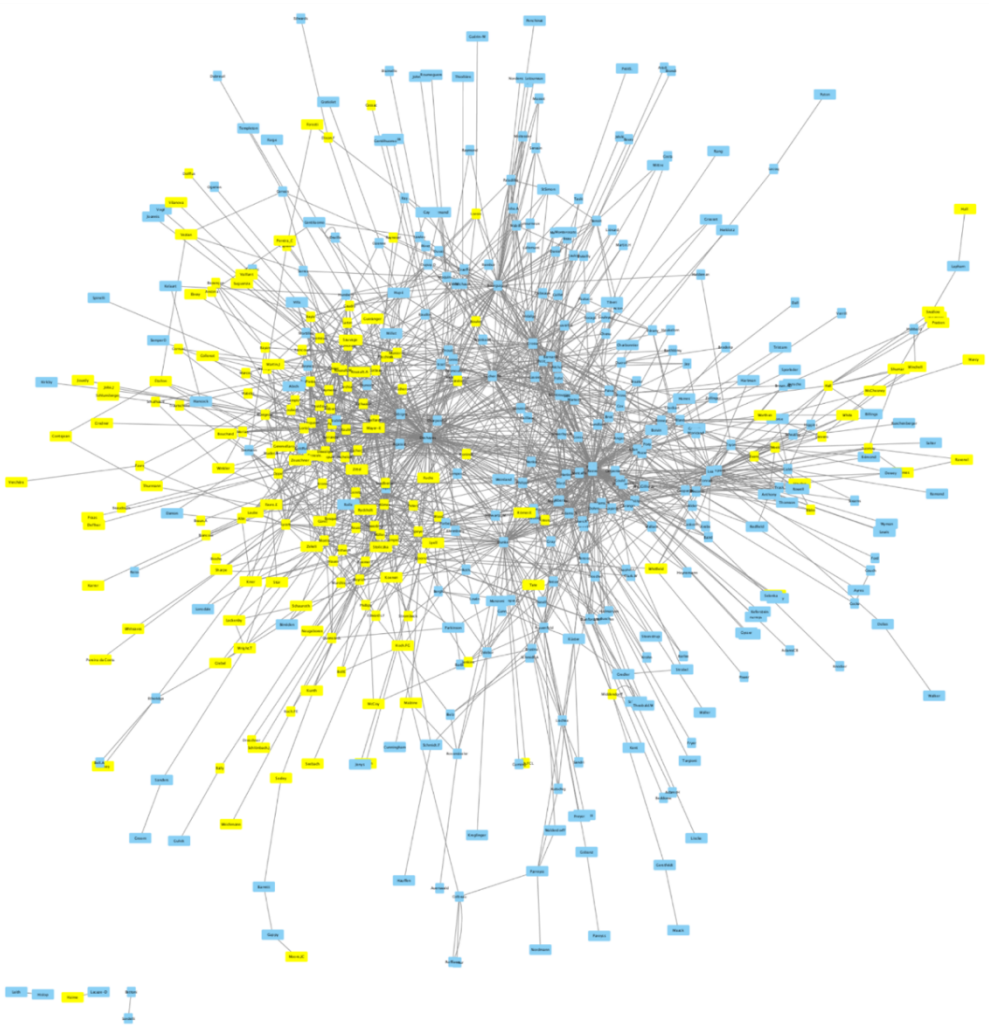

Figure 1. Overview of the total network. Blue boxes are authors who worked on extant species, yellow boxes are those who published on fossils.[30]

[29] Newman, Mark 2006. Modularity and Community Structure in Networks. *Proceedings of the National Academy of Sciences* 103: 8577-8582. doi:10.1073/pnas.0601602103.

[30] A higher resolution version of this graph is available on Figshare: doi:10.6084/m9.figshare.10807163.

Productivity

To identify the core of the malacological authors, a selection was made based on their productivity. This resulted in a subset of 113 authors (hereafter 'elite'), of which 28 (25%) were non-European; 18 were assigned as palaeontologists. Of the 85 Europe-based authors of these 'elite', 31% were from France, 24% from Germany, 23% came from the United Kingdom, and 6% from Switzerland. These authors had in total 546 relations, of which the split between national and international contacts is 43/57% (for palaeontological authors 50/50%).

Age

Because we considered only the period 1850-1870, authors were of differing age. As far as biographical data (cf. again S2) allows we have taken age into account but the ERGM analysis shows there is only a weak and negative age homophily, i.e. being of the same cohort has almost no effect in relation to eponyms.

5 Which attributes structure eponyms?

In order to consider homophily net of other network effects and, hence, test if eponyms are structured by nationality, age, productivity or research community, we utilise Exponential Random Graph Modeling (Table 2). In doing so, we first have to consider the "base probability" of having a tie in our network, which is rather unlikely in our network and can be calculated by $1 - 1/(1 + exp\ (-5.29))$ which gives us a 0.05 probability of having a tie ("edges" in Table 2). The effect corresponds to the density of the network, or in other words: the "ground-truth" of having a tie without considering anything else. Two other distinct effects are considered in order to account for the endogenous network structure: the number of degrees of each actor and the geometrically weighted edgewise shared partner. The former is counting the number of nodes with 2 and 3 degrees and adds them to the network statistic *z(x)*. The latter is taking into account that most social networks are characterised by many triangles, i.e. shared partners. The parameter gwesp does not only account for a simple triangle between A-B-C but also whether A and B share multiple partners, e.g. D, E, F, etc. Since the influence of sharing the *i*-th partner is assumed to be lower than if there are only few shared partners, a decay parameter α is added (after some exploration 0.01 provided the best fit). The

higher its value, the more do nodes with more shared partners contribute to the statistic (Snijders et al. 2006).[31]

	(1)	(2)
Edges	-5.035***	-5.259***
	(0.127)	(0.134)
Degree2	1.245***	1.129***
	(0.195)	(0.190)
Degree3	0.603**	0.522**
	(0.198)	(0.197)
gwesp (fixed)	0.958***	1.003***
	(0.072)	(0.076)
HomeCountry (nodematch)	1.368***	1.328***
	(0.065)	(0.063)
Age (nodecov)	-0.001	0.001
	(0.001)	(0.001)
Age (absdiff)	-0.009**	-0.010**
	(0.003)	(0.003)
Pubs (nodecov)	0.012***	0.011***
	(0.001)	(0.001)
Recent community (edgecov)		1.691***
		(0.123)
Akaike Inf. Crit.	7,166.108	7,009.753
Bayesian Inf. Crit.	7,235.364	7,087.665

*p<0.05; **p<0.01; ***p<0.001
Note: Standard deviation is reported in parentheses. Network endogenous effects are written in lower letters, node and edge attributes start with a capital letter. Utilized ERGM functions are reported in parentheses next to variables.

Table 2. Results of ERGM (probability of having a tie).

[31] Snijders, Tom A. B., Philippa E. Pattison, Garry L. Robins, and Mark S. Handcock. 2006. New Specifications for Exponential Random Graph Models. *Sociological Methodology* 36: 99–153. doi:10.1111/j.1467-9531.2006.00176.x.

As in almost all social networks, degree and gwesp are strong and significantly positive and improve the fit of our model considerably. Thus even scientific contacts in the 19th century indicated by eponyms follow the "social law" of transitivity and shared relationships. However, at the core of our research interest lie network exogenous effects, especially homophily. Starting with national homophily, we observe a strong tendency of eponyms to be distributed within a nation. Considering all else equal, the chance of having a tie between people with the same nationality is 1.9%, i.e. the chance of having a relationship rises almost by the factor 4 for fellow countrymen. Homophily in regard to nationality is by far the strongest effect among the node attributes. Interestingly, there is no effect of age homophily which we could detect. Other than Wang and colleagues[32] we find no age-dependent effects in terms of being in the same cohort, at least not *ceteris paribus* and net of the other exogenous and endogenous effects included in the model.

In addition to those homophily effects, we also consider if having more publications is increasing the probability of a tie within the eponyms in order to test a possible effect of productivity. And indeed, with more publications rises the probability of having a tie, though only modestly. Each publication improves the chance of being part of the eponyms network by approximately 1.2 percent of the "raw" probability indicated by edges. Thus, for instance, having 10 publications means the probability of being part of the eponyms networks rises by 12 percent, again, *ceteris paribus* and net of all other included effects.

In model 2 we introduce an edge-covariate consisting of the same network, but only considering relationships of one of the communities ("recent"). This exhibits a strong effect and implies a homophily of "sorts", so that eponyms within the same research community have a much higher likelihood than across boundaries. The importance of the effect is also underlined by the improvement in model quality as indicated by AIC and BIC.

[32] Wang *et al., Scientific collaboration patterns vary with scholars' academic ages*.

6 Discussion

Since this study is based on eponyms used by authors, it is relevant to stress that each author has a 'personal profile for eponymy', i.e. some authors give relatively more eponyms than others. Although this is a weakness, it is inevitable due to lack of (complete) correspondence being archived for all authors. Multiple eponyms per person have been taken into account, but our analysis is limited to author-author eponyms (see below for author-collector eponyms). Breure has shown that in taxonomy, eponyms may be considered as a proxy for contact.[33] Yet, the nature of this contact may vary, e.g. from gathering additional material for study to exchange of reprints. In this paper, we assume that cases of eponymy resulted in operative collaboration, which may only be tested if complete correspondence archives are preserved. These contacts may, however, also be seen as potential collaboration opportunities; contact formation logically precedes nurturing collaborative relations and are at the core of intellectual networks since ages.[34] In addition, Bozeman and Corley (2004) have formulated a theory which assumes researchers engage in collaboration to enhance their human capital. This implies viewing collaboration strategically to create new synergies in knowledge, increase visibility of publications.[35] Collaboration between scientists was in the nineteenth century far from being so omnipresent as today, and in our dataset we found only 89 pairs of authors (i.e. 0,05% of all relations in our dataset) who actually collaborated as co-authors. Yet one may presume the same social mechanisms (like mutual interest or acquired characteristics like occupation or education) stimulated contacts and eventually collaboration. This equals homophily[36], sometimes specified as specialty homophily.[37] Evans et al. also found strong support for geographical constraints, i.e. collaborations are more likely to involve scholars that are geographically co-located.[38] Already Beaver and Rosen listed spatial propinquity as one of the motives for collaboration.[39] This is also reflected in our results where several countries exhibit a relatively high percentage of national contacts. The size of a country and the less advanced means of communication

33 Breure, *Reconstructing historical egocentric social networks in malacology*.

34 Collins, *The Sociology of Philosophies*.

35 Iglič, Hajdeja, *et al*. 2017. With whom do researchers collaborate and why? *Scientometrics* 112: 153–174. doi:10.1007/s11192-017-2386-y.

36 McPherson *et al*., *Birds of a Feather*.

37 Wang, *et al*.. 2017. *Scientific collaboration patterns vary with scholars' academic ages*.

38 Evans, T.S., R. Lambiotte, and P. Panzarasa. 2011. Community structure and patterns of scientific collaboration in business and management. Scientometrics 89: 381–396. doi:10.1007/s11192-011-0439-1.

39 Beaver, Donald, and R. Rosen. 1978. Studies in scientific collaboration: Part I. The professional origins of scientific co-authorship. *Scientometrics* 1: 65–84. doi:10.1007/BF02016840.

during the study period may also be factors at play, but an in-depth analysis of these factors is beyond the scope of this paper.

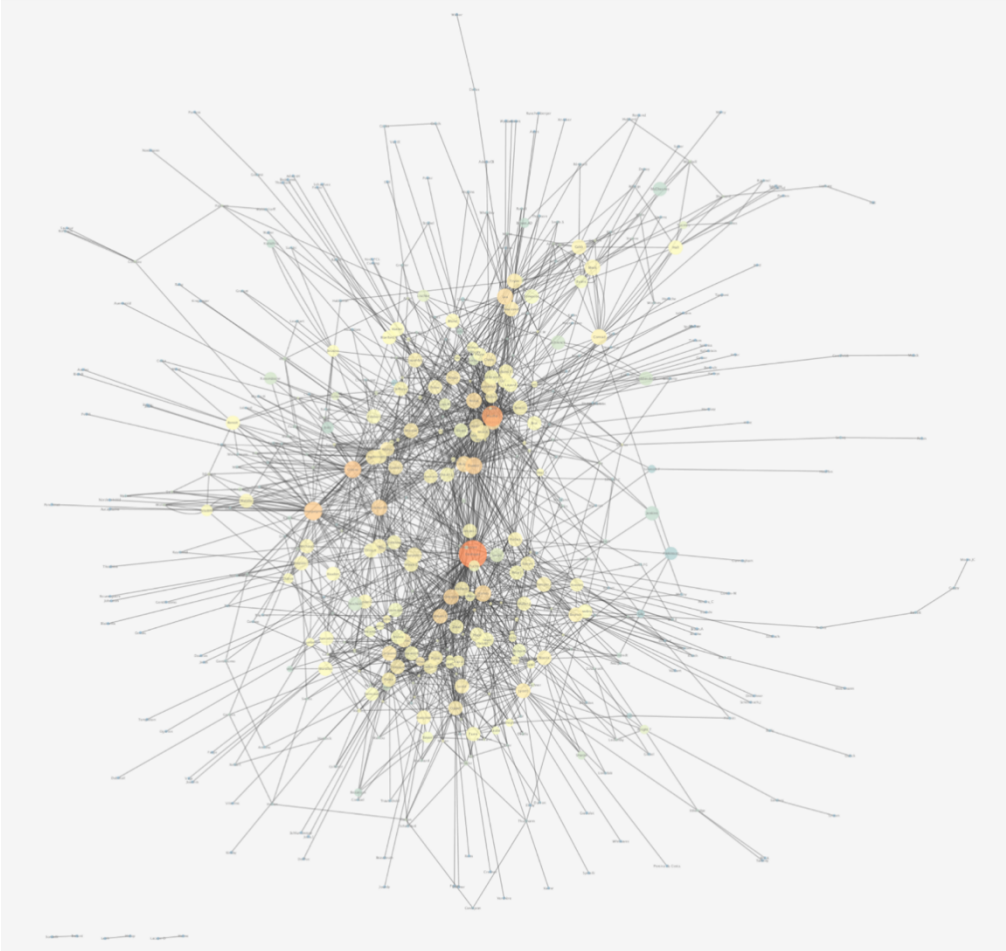

Figure 2. Elite malacologists, 1850-1870. Network showing the most influential authors based on Betweenness Centrality (darker colour is greater BC) and Edge Count (larger circle is higher EC).[40]

[40] A higher resolution version of this graph is available on Figshare: doi:10.6084/m9.figshare.10807160.

When society is viewed "as a market in which people exchange all variety of goods and ideas in pursuit of their interests"[41], gifts of eponyms may be considered as an immaterial good that initiate or reinforce the 'trust-building loop'[42] necessary for maintaining contact or collaboration. As these authors showed, building trust is a cyclical process which builds on itself incrementally. Multiple eponyms, especially if they were given or exchanged over time, may thus reflect this process. But this process can be equally reinforced by sending reprints or material, both actions which are not easily visibly unless there are archival sources to provide evidence.

Our results may also be viewed as analogous to Madaan and Jolad, who studied scientific collaboration and observed that "collaboration between scientists is increasing with time and few numbers of scholars publish a large number of papers while most of the authors publish a small number of papers, which is consistent with Lotka's law on frequency of publications".[43] The findings presented in the previous section on the 'elite' group fits with this statement.

To explore this group of elite authors further, we provide an overview of the most central authors in Figure 2 and Table 3. The "betweenness" of an author is thereby an indicator of influence and who controls the flow of information between most others. The 20 most influential authors show an interesting mix of scholars in different stages of their career, with a number of young 'rising stars' and relatively few 'old stars'. According to Iglič et al.[44] "the longer researchers engage in research, the more knowledge and skills they accumulate. Furthermore, the larger the number of potential collaborators, since engaging in past collaborations, the greater the access to social capital". But according to van Rijnsoever et al.[45], after approximately 20 years of an active research career, collaborative activity starts decreasing and results in an inverted U-shaped relationship between experience and collaboration. These findings are based on current-day situations and cannot be compared directly with the historical situation in our study. Collaboration in a nineteenth century setting has to be

41 Burt, Ronald S. 2001. The network structure of social capital. Research in Organizational Bahaviour 22: 345–423.

42 Vangen, Siv, and Chris Huxham. 2003. Nurturing collaborative relations: Building trust in interorganizational collaboration. *Journal of Applied Behavorial Science* 39: 5–31. doi:10.1177/0021886303253179.

43 Madaan, Gaurav, and Shivakumar Jolad. 2014. Evolution of scientific collaboration networks. *IEEE International Conference on Big Data*. doi:10.1109/BigData.2014.7004346.

44 Iglič et al., *With whom do researchers collaborate and why?*

45 Rijnoever, Frank J. van, Laurens K. Kessels, and Rens L.J. Vandenberg, 2008. A resource-based view on the interactions of university researchers. *Research Policy* 37: 1255-1266. doi:10.1016/j.respol.2008.04.020.

Author	B	Nationality	N	Age
Deshayes	0.15639624	FR	37	54
Pfeiffer	0.07707799	DE	206	46
Bourguignat	0.0510438	FR	42	21
Crosse	0.03512731	FR	124	24
Dunker	0.03495205	DE	29	41
Hörnes	0.02944485	AT	6	35
Lea	0.02626771	US	113	58
Fischer.PH	0.02436345	FR	115	15
Philippi	0.0242428	CL	33	42
Meek	0.02300076	US	34	33
Conrad	0.02253792	US	82	47
Reeve	0.02134736	UK	21	36
Carpenter.P	0.01859395	UK	35	31
d'Orbigny	0.01778389	FR	9	48
Adams.A	0.01580836	UK	125	30
Charpentier	0.01536733	CH	1	64
Tryon	0.01425264	US	52	12
Morelet	0.01237858	FR	41	41
Lycett	0.01218458	UK	15	46
Semper.J	0.01144716	DE	3	?

Table 3. Overview of elite authors.

interpreted with contextual information. In addition, the relatively strong homophily in the Recent / Palaeo communities was an unexpected result in our study. We have found no mentioning of this phenomenon in literature on nineteenth century scholarly activities.

7 Conclusion

In the mid-nineteenth century the field of malacologists was relatively limited with 476 authors who published one or more publications during the period 1850-1870. The world of malacology at that time was mainly a 'Europe-centred' world. The main countries with active authors were France (135), Germany (72), and the United Kingdom (68). Viewing eponyms as social contacts, we investigated several typical properties of social networks. Homophily is known to be one of the prevailing forces to structure social relationships. Given the limited data resources, it is less explored in historic periods and has not been considered at all in the context of taxonomic (zoological) systematics.

Utilising ERGMs revealed that the social exchange underlying eponyms follows similar rules as other social relationships like friendships [46] or collaborations.[47] Especially those two sorts of social contacts are well-explored and mainly characterised by network endogenous structures and homophily.[48] Interestingly, the productivity of authors seems to be well recognised among contemporary researchers and increases the probability of a tie within the network significantly. At the same time, we can observe a differentiation between relationships of Recent and fossil shells, indicating a epistemological divide in the research community. Thus already in the 19th century and at a time when science was just emerging as a differentiated social system [49] epistemological distinctions seem to be a defining concept for scientific contacts.

---

46 Heidler, Richard, Markus Gamper, Andreas Herz and Florian Eßer. 2014. Relationship patterns in the 19th century: The friendship network in a German boys' school class from 1880 to 1881 revisited. *Social Networks*, 37: 1-13. doi:10.1016/j.socnet.2013.11.001; Wimmer, Andreas and Kevin Lewis. 2010. Beyond and below racial homophily, ERG models of friendship networks documented on Facebook. *American Journal of Sociology* 116, 583–642. doi:10.1086/653658.

47 Zhang, Chenwei, Yi Bu, and Ying Ding. 2018. Understanding scientific collaboration from the perspective of collaborators and their network structures. *Journal of the Association for Information Science and Technology* 69, 72–86. doi:10.9776/16470.

48 McPherson *et al.*, *Birds of a Feather*.

49 Allen, David Elliston. 1994. *The naturalist in Britain: a social history*. Princeton, NJ: Princeton Univ. Press, p.292.

Taken together, the structure and effects of the network strongly confirm that eponyms can be interpreted as social contacts as suggested by Breure.[50]

Several alternative avenues are possible for further research, both in-depth or extending the scope. For instance, some of the authors in our dataset clearly had a link to (or at least a preference for) a certain journal, and there may be also links to learned societies. This was beyond the scope of our current study, but may reveal interesting networks once examined. Also the exploration of citation networks may shed light on the geographies of reception of scientific papers and books. While in current-day practice of bibliometrics this is facilitated by digital sources and explicit reference lists, the lack of these in nineteenth century literature makes this a more challenging task. In addition, a counter-test with a dataset on the same community would underline the validity of our results.

Furthermore, Beaver and Rosen found a link of collaboration with professionalisation, and according to their data[51] co-authoring was nearly non-existent before 1800 in the field of natural history. During Napoleonic times French scientists institutionalised themselves on a grand scale, soon followed by scientists in Germany and England. The development of malacology during the nineteenth century deserves further study in the light of collaboration and professionalisation.[52] When describing species, authors often mentioned the name of the collector. According to Secord this served to enhance the reliability of the information and to deflect any challenge over the accuracy of information away from the author to the source of information.[53] Such field collectors often had connections to more than one scientist (often in their home country), but studies of such multi-level networks of authors c.q. cabinet collectors with field collectors could shed more light on development of these 'webs of transfer'.

Closely linked to this topic is the shift between amateurs and professionals in time. According to Shapin the boundaries between the professional scientific community and mere amateurs had been fairly well defined in most areas of sciences by the late nineteenth and early twentieth century.[54] There are several

---

50 Breure, *Reconstructing historical egocentric social networks in malacology*.

51 Beaver, Donald, and R. Rosen. 1979. Studies in scientific collaboration Part III. Professionalization and the natural history of modern scientific Co-Authorship. *Scientrometrics* 1: 231–245.

52 See also the work of Kretschmer and Kretschmer (2013) and Kretschmer et al. (2015) on collaboration and graphical representation.

53 Secord, Anne. 1994. Corresponding interests: artisans and gentlemen in nineteenth-century natural history. *The British Journal for the History of Science* 27: 383–408. doi:10.1017/S0007087400032416.

54 Shapin, Steven. 1982. History of science and its sociological reconstructions. *History of Science*: 157–211, p.273.

other studies about professionalisation in certain disciplines.[55] Breure has shown a malacological example in the late 19th / early 20th century, but a wider perspective for malacologists is needed and a study extending backwards could fill a gap.[56] Beaver and Rosen have shown that in the 19th century, specialisation gradually increased, but 'conceptual revolutions' (like Darwin's publication in 1859 on evolution) accelerated the professionalisation (in this case for biology) and "such revolutions were factors in eliminating amateurs from scientific research".[57] Taxonomy, however, was during those years predominantly a science which demanded no or relatively few instruments nor laboratory equipment. Our hypothesis is therefore that the percentage of amateurs in relation to professionals which had a paid position at a museum or institution remained relatively high at the end of the nineteenth century.

This brings us to longitudinal extension of the current study (e.g., 1800-1820, 1900-1920). To what extent will our current outcomes result in a changed perspective when we take a longer time frame into account? For instance, Elias noted a change in occupation and demography between the 1750s and the end of the 19th century when he studied the data of coleopterists.[58] If a similar dataset for malacologists would be available it may reveal further insights of the early days of scientific research.

55 Porter, Roy. 1978. Gentlemen and Geology: the Emergence of a Scientific Career, 1660–1920*. *The Historical Journal* 21: 809. doi:10.1017/S0018246X78000024; Shortt, S E D. 1983. Physicians, science, and status: issues in the professionalization of Anglo-American medicine in the nineteenth century. *Medical History* 27: 51–68. doi:10.1017/S0025727300042265.

56 Breure, A.S.H. 2016. Philippe Dautzenberg (1849-1935) and his time, towards the reconstruction of an ancient science network. *Basteria*: 47–58.

57 Beaver and Rosen, *Studies in scientific collaboration: Part II*.

58 Elias, Scott A. A brief history of the changing occupations and demographies of coleaopterists from the 18th through the 20th century. Journal of the History of Biology 47: 213–242. doi:10.1007/s10739-013-9365-9

8 References

Allen, David Elliston. 1994. *The naturalist in Britain: a social history*. Princeton, NJ: Princeton Univ. Press.

Bakker, Hans. 2017. Scientific Networks and Invisible Colleges. *The Blackwell Encyclopedia of Sociology*. London: Blackwell. doi:10.1002/9781405165518.wbeoss051.pub2

Beaver, Donald, and R. Rosen. 1979. Studies in scientific collaboration: Part II. Scientific co-authorship, research productivity and visibility in the French scientific elite, 1799–1830. *Scientometrics* 1: 133–149. doi:10.1007/BF02016966.

Beaver, Donald, and R. Rosen. 1978. Studies in scientific collaboration: Part I. The professional origins of scientific co-authorship. *Scientometrics* 1: 65–84. doi:10.1007/BF02016840.

Beaver, Donald, and R. Rosen. 1979. Studies in scientific collaboration Part III. Professionalization and the natural history of modern scientific Co-Authorship. *Scientrometrics* 1: 231–245.

Beaver, Donald. 2001. Reflections on scientific collaboration (and its study): past, present, and future*. *Scientrometrics* 52: 365–377.

Bijl, Bram van der, Robert Moolenbeek, and Goud Jeroen. 2010. *Matheus Marinus Schepman (1847-1919) and his contributions to malacology*. Leiden: Netherlands Malacological Society

Bozeman, Barry, and Elizabeth Corley. 2004. Scientists' collaborating strategies: implications for scientific and technical human capital. Research Policy 33: 599–616. doi:10.1016/j.respol.2004.01.008.

Breure, Abraham S.H., and Wim Backhuys. 2017. Sauveur Abel Aubert Petit de la Saussaye (1792–1870), his malacological work and taxa, with notes on his correspondence. *Archiv für Molluskenkunde International Journal of Malacology* 146: 71–96. doi:10.1127/arch.moll/146/071-096.

Breure, Abraham S.H. 2015. The malacological handwritings in the autograph collection of the Ph. Dautzenberg archives, Brussels. *Folia conchyliologica*: 1–111.

Breure, Abraham S.H. 2017. Reconstructing historical egocentric social networks in malacology: is there a link between eponyms and contacts of an author? *Folia conchyliologica*: 3–12.

Breure, Abraham S.H., and Cédric Audibert. 2017a. 'Mon cher Directeur': an inventory of the correspondence addressed to Hippolyte Crosse during his years as director of the 'Journal de conchyliologie.' *Folia conchyliologica*: 3–108.

Breure, Abraham S.H., and Wim Backhuys. 2017. Science networks in action: the collaboration between J.G. Hidalgo and H. Crosse, and the creation of 'Moluscos del Viaje al Pacifico, Univalvos terrestres.' *Iberus* 35: 11–30.

Breure, A.S.H. 2016. Philippe Dautzenberg (1849-1935) and his time, towards the reconstruction of an ancient science network. *Basteria*: 47–58.

Breure, Abraham S.H., Cédric Audibert, and Jonathan D. Ablett. 2018. *Pierre Marie Arthur Morelet (1809-1892) and his contributions to malacology*. Nederlandse Malacologische Vereniging.

Burt, Ronald S. 2001. The network structure of social capital. Research in Organizational Bahaviour 22: 345–423.

Carpenter, Russell Lant. 1880. *Memoirs of the life and work of Philip Pearsall Carpenter, chiefly derived from his letters*. London,: [s.n.]. doi:10.5962/bhl.title.87586.

Coan, Eugene V., and Alan R. Kabat. 2018. *2,400 years of malacology*. American Malacological Society.

Collins, Randall. 2002. *The Sociology of Philosophies: A Global Theory of Intellectual Change*. Cambridge, Mass.: Belknap Press of Harvard University Press.

Elias, Scott A. A brief history of the changing occupations and demographies of coleaopterists from the 18th through the 20th century. Journal of the History of Biology 47: 213–242. doi:10.1007/s10739-013-9365-9.

Evans, T.S., R. Lambiotte, and P. Panzarasa.2011. Community structure and patterns of scientific collaboration in business and management. Scientometrics 89: 381–396. doi:10.1007/s11192-011-0439-1.

Genuth, Joel, Ivan Chompalov, and Wesley Shrum. 2000. How Experiments Begin: The Formation of Scientific Collaborations. *Minerva* 38: 311–348.

Harris, Jenine. 2014. *An Introduction to Exponential Random Graph Modeling*. 2455 Teller Road, Thousand Oaks California 91320 United States: SAGE Publications, Inc. doi:10.4135/9781452270135.

Heidler, Richard, Markus Gamper, Andreas Herz and Florian Eßer. 2014. Relationship patterns in the 19th century: The friendship network in a German boys' school class from 1880 to 1881 revisited. *Social Networks*, 37: 1-13. doi:10.1016/j.socnet.2013.11.001

Iglič, Hajdeja, *et al*. 2017. With whom do researchers collaborate and why? *Scientometrics* 112: 153–174. doi:10.1007/s11192-017-2386-y.

Knorr Cetina, Karin. 2009. *Epistemic Cultures: How the Science make Knowledge*. Harvard University Press.

Kretschmer, Hildrun, Donald Beaver, Bulent Ozel, and Theo Kretschmer. 2015. Who is collaborating with whom? Part I. Mathematical model and methods for empirical testing. *Journal of Informetrics* 9: 359–372. doi:10.1016/j.joi.2015.01.004.

Kretschmer, Hildrun, and Theo Kretschmer. 2013. Who Is Collaborating with Whom in Science? Explanation of a Fundamental Principle. *Social Networking* 02: 99–137. doi:10.4236/sn.2013.23011.

Madaan, Gaurav, and Shivakumar Jolad. 2014. Evolution of scientific collaboration networks. *IEEE International Conference on Big Data*. doi:10.1109/BigData.2014.7004346

Marples, A., and V. R. M. Pickering. 2016. Patron's review: Exploring cultures of collecting in the early modern world. *Archives of Natural History* 43: 1–20. doi:10.3366/anh.2016.0342.

McPherson, Miller, Lynn Smith-Lovin, and James M Cook. 2001. Birds of a Feather: Homophily in Social Networks. *Annual Review of Sociology* 27: 415–444. doi:10.1146/annurev.soc.27.1.415.

Merton, Robert K. 1973. *The Sociology of Science*. Chicago: The University of Chicago Press.

Mierzwa-Szymkowiak, D., and Abraham S. H. Breure. 2017. Inside and outside the Neotropics: three Polish naturalists during the late nineteenth and early twentieth centuries. *Archives of Natural History* 44: 151–158. doi:10.3366/anh.2017.0423.

Newman, Mark. 2004. Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences* 101: 5200–5205. doi:10.1073/pnas.0307545100.

Newman, Mark. 2006. Modularity and Community Structure in Networks. *Proceedings of the National Academy of Sciences* 103: 8577-8582. doi:10.1073/pnas.0601602103.

Ponds, Roderik, Frank van Oort, and Koen Frenken. 2007. The geographical and institutional proximity of research collaboration. *Papers in Regional Science* 86: 423–443. doi:10.1111/j.1435-5957.2007.00126.x.

Porter, Roy. 1978. Gentlemen and Geology: the Emergence of a Scientific Career, 1660–1920*. *The Historical Journal* 21: 809. doi:10.1017/S0018246X78000024.

Rijnoever, Frank J. van, Laurens K. Kessels, and Rens L.J. Vandenberg, 2008. A resource-based view on the interactions of university researchers. *Research Policy* 37: 1255-1266. doi:10.1016/j.respol.2008.04.020

Robins, Garry, Pip Pattison, Yuval Kalish, and Dean Lusher. 2007. An introduction to exponential random graph (p*) models for social networks. *Social Networks* 29: 173–191. doi:10.1016/j.socnet.2006.08.002.

RStudio Team (2018). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA. http://www.rstudio.com/.

Ruhoff, F.A. 1980. Index to the species of Mollusca introduced from 1850 to 1870. *Smithsonian Contributions to Zoology*: 1–640.

Secord, Anne. 1994. Corresponding interests: artisans and gentlemen in nineteenth-century natural history. *The British Journal for the History of Science* 27: 383–408. doi:10.1017/S0007087400032416.

Shannon, P., A. Markiel, O. Ozier, N.S. Baliga, J.T. Wang, D. Ramage, N. Amin, B. Schwikowski, and T. Ideker. 2003. Cytoscape: A Software Environment for Integrated Models of Biomolecular Interaction Networks. *Genome Research* 13: 2498–2504. doi:10.1101/gr.1239303.

Shapin, Steven. 1982. History of science and its sociological reconstructions. *History of Science*: 157–211.

Shortt, S E D. 1983. Physicians, science, and status: issues in the professionalization of Anglo-American medicine in the nineteenth century. *Medical History* 27: 51–68. doi:10.1017/S0025727300042265.

Snijders, Tom A. B., Philippa E. Pattison, Garry L. Robins, and Mark S. Handcock. 2006. New Specifications for Exponential Random Graph Models. *Sociological Methodology* 36: 99–153. doi:10.1111/j.1467-9531.2006.00176.x.

Stokols, Daniel, Kara L. Hall, Brandie K. Taylor, and Richard P. Moser. 2008. The Science of Team Science. *American Journal of Preventive Medicine* 35: S77–S89. doi:10.1016/j.amepre.2008.05.002.

Vangen, Siv, and Chris Huxham. 2003. Nurturing collaborative relations: Building trust in interorganizational collaboration. *Journal of Applied Behavorial Science* 39: 5–31. doi:10.1177/0021886303253179.

Villanueva-Felez, Africa, Jordi Molas-Gallart, and Alejandro Escribá-Esteve. 2013. Measuring Personal Networks and Their Relationship with Scientific Production. *Minerva* 51: 465–483. doi:10.1007/s11024-013-9239-5.

Wang, Wei, Shuo Yu, Teshome Megersa Bekele, Xiangjie Kong, and Feng Xia. 2017. Scientific collaboration patterns vary with scholars' academic ages. *Scientometrics* 112: 329–343. doi:10.1007/s11192-017-2388-9.

Wimmer, Andreas and Kevin Lewis. 2010. Beyond and below racial homophily, ERG models of friendship networks documented on Facebook. *American Journal of Sociology* 116, 583–642. doi:10.1086/653658

Zhang, Chenwei, Yi Bu, and Ying Ding. 2018. Understanding scientific collaboration from the perspective of collaborators and their network structures. *Journal of the Association for Information Science and Technology* 69, 72–86. doi:10.9776/16470.

9 Supplementary files

The following files are available in Figshare repositories:

Details of authors used in the analysis: BreureHeiberger_Appendix_1: doi:10.6084/m9.figshare.10322114

Overview of relations of source nodes at national scale and international: Table S2: doi:10.6084/m9.figshare.10322114

Transdisciplinarity in interrelations between communities of Recent and palaeontological authors: Table S3: doi:10.6084/m9.figshare.10322114

Figure 1 (Network1-600dpi): doi:10.6084/m9.figshare.10807163

Figure 2 (Network2-600dpi): doi:10.6084/m9.figshare.10807160.

RAAB, JÖRG

Eine relationale Perspektive auf den Umsturzversuch gegen Hitler vom 20. Juli 1944.

Rezension zu Linda von Keyserlingk-Rehbein: Nur eine »ganz kleine Clique«? Die NS-Ermittlungen über das Netzwerk vom 20. Juli 1944. Lukas Verlag 2018

Journal of Historical Network Research 3 (2019) 118-122.

Keywords

Review, Covert Networks, Second World War, Assassination Attempt

Linda von Keyserlingk-Rehbein, Nur eine »ganz kleine Clique«? Die NS-Ermittlungen über das Netzwerk vom 20. Juli 1944. Lukas Verlag 2018.

Auch 75 Jahre nach dem Attentat auf Hitler am 20. Juli 1944 tobt der Streit unter Historikern und Feuilletonisten über die historischen Fakten und die Interpretation der Motive und Ereignisse, die mit diesem Tag verbunden sind. Stellvertretend dafür können die kürzlich erschienen Publikationen von Thomas Karlauf über Claus Schenk von Stauffenberg (2019), die Replik durch die Enkelin Stauffenbergs (2019), Sophie von Bechtolsheim (2019), und ein Artikel von Matthew Olex-Szczytowski (2019) dienen. Alle drei nehmen sehr unterschiedliche Perspektiven ein und kommen zu radikal anderen Einschätzungen und Interpretation zu den Motiven, Handlungen und Verantwortlichkeit von Stauffenberg und anderen Mitverschwörern und der damit verbundenen Verantwortung. Während Karlauf Stauffenberg's Rolle als Attentäter zentral stellt, der Hitler nicht aus moralischen sondern primär aus militärischen Gründen beseitigen wollte, um das Deutsche Reich zu retten, betont von Bechtholsheim aus einer familiären Perspektive die tiefe moralische Verwurzelung Stauffenbergs, die weit vor 1944 zurückreiche. Anderseits probiert Olex-Szczytowski wiederum nachzuweisen, dass Stauffenberg ebenso wie andere zentrale militärische Verschwörer wie Henning von Tresckow und Fritz Dietlof Graf von Schulenburg an Kriegsverbrechen und Verbrechen gegen die Menschlichkeit beteiligt waren, wie diese nach 1945 im internationalen Recht definiert wurden, eine Ansicht, die auch bereits u.a. von Christian Gerlach (1995) vertreten wurde. Passend ist daher ganz sicher der Satz des Soziologen Ekkehard Klausa „Wer sich auf den deutschen Widerstand gegen den Nationalsozialismus ehrlich einlässt, darf sich vor kognitiven Dissonanzen nicht fürchten" (zitiert in Christian Staas: Umkämpfte Helden, Die Zeit, 18.7.2019, 36). Was den meisten historischen Arbeiten zum 20. Juli jedoch gemeinsam ist, ist eine starke Fokussierung auf einzelne Akteure und deren Motive oder auf Gruppen oder Kohorten von Akteuren. Dabei bleibt häufig außer Betracht, dass Akteure in Beziehungen eingebettet sind, die ihre Wahrnehmung beeinflussen und Handlungen je nach Beziehung und der weiteren Struktur erst ermöglichen bzw. erschweren. Aus der Perspektive des amerikanischen Soziologen Mark Granovetter (1985) ist daher eine ausschliessliche Fokussierung auf Akteure oder Akteursgruppen eine „undersocialized Perspective" auf die soziale Realität und er plädiert dafür, dass Analysen zu sozialen Akteuren die spezifischen Strukturen, in denen Akteure eingebettet sind, mitberücksichtigen müssen. Neben der Fokussierung auf einzelne Personen richtet sich vor allem das öffentliche Interesse am 20. Juli sehr stark auf das Attentat selbst sowie den militärischen Teil des Umsturzversuchs. Ausgeblendet bleiben dabei zum Großteil die Beteiligung ziviler Akteure aus Verwaltung, Kirche, Politik und Gewerkschaften sowie das komplexe Netzwerk hinter dem Attentat, das sich zudem über die Zeit veränderte. Hier setzt die Arbeit von Linda von Keyserlingk-Rehbein an, die minutiös die beteiligten Akteure, ihre Beziehungen

untereinander sowie deren Rollen beschreibt und analysiert. Auf Basis der zugänglichen NS-Quellen konstruiert die Autorin dann das Netzwerk des 20. Juli mit insgesamt 132 Akteuren, die den Umsturz bewusst unterstützten, und analysiert dieses mit netzwerkanalytischen Methoden. Dabei gebraucht und kombiniert sie geschickt sowohl die hermeneutischen Methoden der Geschichtswissenschaften als auch die quantitative Netzwerkanalyse aus der Soziologie, was zu sehr interessanten und aufschlussreichen Einsichten führt. So zeigt sie beispielsweise systematisch die wichtige Rolle und strukturelle Position der Reserveoffiziere als Vermittler zwischen den gegensätzlichen Interessen, Weltbildern und Charakteren des Clusters der militärischen und des Clusters der zivilen Akteure. Zudem wird durch ihre Analyse deutlich, dass neben Stauffenberg auch noch Friedrich Olbricht sowie Fritz-Dietlof von der Schulenburg und Carl Goerdeler wichtige strukturelle Positionen innerhalb des Netzwerks einnahmen. Daher kann man mitnichten von einer „kleinen Clique" sprechen und es wird deutlich, dass die Fixierung auf Stauffenberg als Hauptakteur des Umsturzversuchs nicht der historischen Realität gerecht wird. Keyserlingk-Rehbein demonstriert in ihrer Analyse, dass der Kern des Netzwerks aus 19 Personen bestand, neben den vier oben genannten, waren das u.a. der hochrangige Reservegeneral Ludwig Beck, Helmuth Moltke vom Kreisauer Kreis sowie der Gewerkschafter Wilhelm Leuschner und der Sozialdemokrat Julius Leber (S. 492). Wie kann diese Zusammensetzung und Beziehungsstruktur gedeutet werden? Anders als von Christian Staas geäußert, sieht die Autorin diese nicht als Zeichen einer demokratisch-pluralistischen Orientierung (Umkämpfte Helden, Die Zeit, 18.7.2019, 36). Was die Akteure verband, war das Bestreben, die katastrophale Niederlage, auf die das Deutsche Reich zusteuerte, abzuwenden, den Krieg zu beenden, das faschistische Regime zu beseitigen und Deutschland wieder in einen Rechtsstaat zu verwandeln. Das Netzwerk des 20. Juli stellte das letzte und einzige Aufgebot dar, dies zu bewerkstelligen. In gewisser Weise war eine Struktur entstanden, die 1933 nicht existierte, um der NS-Machtergreifung etwas entgegensetzen zu können: die Zusammenarbeit von konservativen bürgerlichen und adligen Kreisen mit Vertretern der Kirchen, Gewerkschaftern und Sozialdemokraten, von zivilen und militärischen Kreisen, um ein faschistisches Regime zu stürzen bzw. dessen Machtergreifung zu verhindern.

Um dies 1944 mit zumindest ein wenig Aussicht auf Erfolg bewerkstelligen zu können, war man auf zahlreiche Personen in vor allem auch militärischen Schlüsselpositionen angewiesen. Wer zu diesem Zeitpunkt im NS-Staat noch solche Schlüsselpositionen bekleidet, hatte sich jedoch mit großer Wahrscheinlichkeit mitschuldig gemacht (S. 474). Die Autorin unterstreicht damit mit ihrer Arbeit die Ambivalenz des Netzwerks und eines größeren Teils der handelnden Akteure.

Die Analyse basiert (notgedrungen) überwiegend auf Quellen des NS-Verfolgungsapparats. Obwohl die Autorin erfolgreich versucht, die

Informationen mit anderen (nicht NS) Quellen abzugleichen, bleiben mutmaßlich Verzerrungen bestehen, da Beziehungen übersehen oder bewusst nicht dokumentiert wurden (S. 504). Obwohl die Autorin daher einerseits manche Ergebnisse und Einschätzungen relativieren muss, eröffnet sich anderseits jedoch ein zweiter starker Erzählstrang innerhalb der Studie, nämlich, wie der NS-Verfolgungsapparat mit dem Umsturzversuch umging, die Ermittlungen gesteuert wurden und welche Umstände und Beziehungen der Akteure im Netzwerk dem Reichssicherheitshauptamt verborgen blieben.

Aus organisationssoziologischer Sicht enthält die Studie einen Schatz an Empirie zu sogenannten verborgenen (‚covert' oder ‚dark') Netzwerken. So ist das Vielfach beschriebene Dilemma zwischen Sicherheit und Effizienz bzw. Effektivität solcher Netzwerke (Morselli, Giguère und Petit [2007] sprechen vom security-efficiency-trade off) auch im Fall des Netzwerks des 20. Juli gut sichtbar. Welche Beziehungen müssen aktiviert werden, welche Kontaktaufnamen sind absolut notwendig, um die gemeinsamen Ziele zu erreichen und die Aktionen zu koordinieren, wobei jede Kontaktaufnahme und jedes Treffen mit dem Risiko, entdeckt zu werden, verbunden sind? Die Akteure innerhalb des Netzwerks des 20. Juli sahen sich ebenfalls mit diesem Dilemma konfrontiert, es gelang ihnen jedoch trotz starker Überwachung einzelner Personen durch die Gestapo, den NS-Sicherheitsapparat mit dem Attentat völlig zu überraschen. Dies gelang beispielsweise durch die Nutzung ‚legitimierter' beruflicher Kontakte als Deckmantel für Umsturzaktivitäten sowie die Geheimhaltung von Mitverschwörern und Kontakten, die über das absolut notwendige Wissen hinausgingen. Leider geht die Autorin nicht weiter auf die Konsequenzen dieser Strategie ein, obwohl sie im Eingang kurz die Literatur zu verdeckten Netzwerken streift. So bleibt die Frage hier noch unbeantwortet, wie trag- und organisationsfähig das Netzwerk eigentlich war, um den Umsturz zu bewerkstelligen und Deutschland neu aufzubauen, falls das Attentat auf Hitler gelungen wäre. Obwohl diese Frage eine einzelne historische Untersuchung übersteigen mag, ist sie nichtsdestotrotz interessant und aus theoretischer Sicht relevant. Obgleich die Autorin die Fixierung auf das Attentat kritisiert, bleibt sie daher letztlich in ihrer Diskussion auch relativ dicht bei der militärischen und organisatorischen Dimension des Attentats selbst.

Das Netzwerk des 20. Juli bietet darüber hinaus einen sehr interessanten Sonderfall für die Forschung zu verdeckten Netzwerken. Die meisten Studien auf diesem Gebiet handeln von kriminellen oder terroristischen Netzwerken, es gibt jedoch meines Wissens noch keine Netzwerkstudie zur Organisation eines politischen Umsturzes unter den Bedingungen eines totalitären Überwachungsstaats, bei dem höchste Kreise aus Militär, Politik und Verwaltung involviert sind.

Trotz dieser offenen Fragen handelt es sich bei der Studie um eine beispielhafte Arbeit für eine historische Netzwerkanalyse. Man kann sich selbst

fragen, warum es 75 Jahre gedauert hat, bis solch eine Studie vorgelegt wurde. Obwohl die Autorin sich im Buch selbst aus den eingangs geschilderten Kontroversen weitestgehend heraushält, enthält die Studie so viel detailliertes empirisches Material und Einsichten, dass sie sehr dazu angetan ist, die Diskussion zur historischen und politischen Bedeutung des 20. Juli aus einer relationalen Perspektive und auf breiter empirischer Basis voranzubringen.

Bibliographie

Bechtolsheim, Sophie von. *Stauffenberg. Mein Großvater war kein Attentäter*. Freiburg: Herder Verlag, 2019.

Gerlach, Christian. "Männer des 20. Juli und der Krieg gegen die Sowjetunion." In *Vernichtungskrieg. Verbrechen der Wehrmacht 1941-1944*, edited by Hannes Heer Hannes and Klaus Naumann, 427-446. Hamburg: Institut für Sozialforschung, 1995.

Granovetter, Marc. "Economic Action and Social Structure: The Problem of Embeddedness," *American Journal of Sociology*, 91, no. 3 (November 1985): 481-510.

Karlauf, Thomas. *Stauffenberg: Porträt eines Attentäters*. München: Verlag Blessing, 2019.

Morselli, Carlo, Giguère, Cynthia, Petit, Katia. "The efficiency/security trade-off in criminal networks." *Social Networks 29*, (2007): 143 – 153.

Olex-Szczytowski, Matthew. "The German Military Opposition and National Socialist Crimes, 1939 – 1944: The Cases of Stauffenberg, Tresckow, and Schulenburg," *War in History*: 1-25, doi: 10.1177/0968344519840054.

BIXLER, MATTHIAS

Lemercier, Claire and Claire Zalc. Quantitative Methods in the Humanities. An Introduction

Journal of Historical Network Research 3 (2019) 123-126.

Lemercier, Claire and Claire Zalc. 2019. Quantitative Methods in the Humanities. An Introduction. Translated by Arthur Goldhammer. Charlottesville and London: University of Virginia Press. (vii + 177 pages, PBK 27,50€/19,50$, ISBN 978-0813942698).

1 Introduction

There is a shortage of text books on quantitative methods that are accessible to historians with little or no training in statistics. With their recent book Lemercier and Zalc try to bridge that gap by providing a non-mathematical overview of quantitative methods that have been successfully applied in historical research. Although its title suggests a broader approach (the humanities), for the most part the text clearly addresses historians and draws on examples from historical research. What follows is a general review of the book with a focus on the parts concerning Historical Network Research.

2 A very short summary

The book is as much an introduction to quantitative methods for historical research as it is a historical account of quantification in the field of history. Chapter 1 tells the story of the rise and fall of quantitative research among historians and the controversy over its use and misuse that started in the early 20th century and goes on to the present day. In subsequent chapters the particular methods are discussed against this background by pointing out their respective origins and showing where and how they were applied in historical research so far. The authors make an effort to reconcile quantitative historians and their critics by emphasizing throughout the book that quantitative methods are supposed to complement traditional hermeneutics instead of replacing them and by arguing against the naïve use of numbers.

The chapters on quantitative methods start with the premise that any source can be quantified regardless of its type or degree of standardization. Given that measurement, if adequately performed, transforms certain features of a source from its original to a numerical representation, I totally agree with that. Whether a quantitative approach is useful to answer a meaningful research question then depends solely on how these features are selected and what rules are applied to quantify them. The authors then elaborate on comparison and combination of data from different sources, sampling techniques and sample sizes that are both manageable and yield meaningful results. Those general remarks as well as the chapter on data collection come in handy for any historian in the process of developing a quantitative research project. Contingency tables and the chi-squared test serve as an example to explain the reasoning behind correlations and hypothesis testing in statistics. Subsequent chapters cover a wide array of more advanced techniques, i.e. regression, factor analysis, social network analysis, sequence analysis, visualizations, maps, and text analysis.

There is also a companion blog to the book.[1] By November 2019 it consists of 20 entries not all of which provide further insights into the topics discussed in the text. In the future it is supposed to be expanded with tutorials and recommendations for further reading.

[1] https://quanthum.hypotheses.org.

3 What's in it for historical network researchers?

The coverage of social network analysis, however short (13 pages on SNA and 8 pages on techniques for visualizing network data), is certainly one of the strongest parts of the book. The authors point out the differences between relational data and variables for standard procedures including a separate section on data collection, before going into detail about the possibilities and restrictions of social network analysis in historical research. These sections are loaded with excellent practical advice that may save a beginner in HNR from wasting much time and energy in repeated trial and error. It is also rare to see a text book pointing out so clearly when a network approach is not appropriate. For example, referring to a type of research question that is regularly brought forward by beginners, they state:

> Network analysis is not intended to find out whether or not an individual "is in the network" (p. 104).

As can be expected from an introduction, researchers who already made their first steps into HNR will presumably find little information that is completely new to them. The section on social network graphs provides a vivid example of how successive modifications on the same network graph can provide additional insights.

4 Critique

There are some points worthy of criticism. Historians who expect a hands-on introduction that actually teaches them how to gather data and to conduct quantitative analyses will be disappointed. The authors claim to follow a practical approach. However, they also make it explicit that the book is not intended to be a tutorial on any of the methods described (p. 3-4). The latter, however, written from the point of view of a historian and with an introduction to accessible software, would be necessary to reach the author's aim to really enable their readers to understand and criticize published analyzes (cf. p. 77f.).

For the amount of material covered in this book, it is incredibly short. Statistical models are presented at a very high level in order to be able to rely solely on verbal explanations and skip their mathematical foundations. To be as accessible as possible while providing a broad overview is a noble goal for an introductory text. But in this case it seems that the authors did too much of a good thing. In particular, they left out the very fundamentals of data analysis and statistics that are absolutely crucial to understand more sophisticated models, e.g. levels of measurement, how to construct hypotheses that can be tested, choosing among the most common descriptive statistics and how to interpret them, etc. In their discussion of visualizations, again, they skip most of

the basic plots than can yield so much insight to focus mainly on social network graphs and maps which only a small proportion of quantitative historians will ever use.

Therefore, a reader with no prior experience in quantitative research will have to read the book at least twice to be able to to understand many of the best practice examples and suggestions on how to avoid pitfalls. Once before and once after he/she turned to other resources to learn about the fundamentals of quantitative methods and how to apply them in a practical manner. Those who are trained in quantitative methods, on the other hand, might be puzzled by sections, where the authors decided to leave out crucial information so they didn't have to introduce more formal language.

Finally, the book contains a multitude of useful suggestions that can help avoid requirement violations, overinterpretation of results, or time consuming reexamination of the sources. Some of them are clearly summarized in lists of best practice guidelines. However, many of them - and among them some of the most useful - are embedded somewhere in the text. It up to the readers to identify them in the first place and then find them again, when they need them.

5 Conclusion

That said, I think the book is useful as a primer, especially for traditionally trained historians who want to get an overview over quantitative methods in historical research and for quantitatively trained researchers who collaborate with historians and want to get a feeling for the peculiarities and potential pitfalls of working with historical sources. Historians who are intrigued by the possibilities of social network analysis for their own research will find a short overview that supports them in deciding whether a network approach is applicable to their sources and appropriate to answer their research questions or not.