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# Assortative Mixing in the Social Networks of Athenian Potters and the Search for Communities of Practice

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**Abstract** As co-directors of the Social Networks of Athenian Potters (SNAP) project from 2017–2021, we have experimented with social network analysis to map the networks of painters and potters in Archaic and Classical Athens dating between 600–400 BCE ([snap.sbs.arizona.edu](http://snap.sbs.arizona.edu)). We use sociograms to visualize connections between the artists and SNA metrics to understand individuals' roles in network terms, find clusters within the components, and then learn more about the topology and characteristics of the network as a whole. The data is derived from catalogues of vase painters who worked in the Kerameikos of ancient Athens, using techniques known as black-figure and red-figure. We have previously published the black-figure elsewhere; here we are concerned with the non-directed bimodal red-figure network composed of 13 components with 1,067 nodes and 1,583 edges. Most of the sociogram shows disassortative mixing, but we have identified one area which appears to be assortative and which we believe draws as close as possible to being representative of a social network of a community of contemporary artisans, to the extent that our data allows. This group of 70 artists with 94 ties between them is unusual in terms of its topological structure. The rest of the red-figure network appears to be disassortative, with high degree nodes in the center of a cluster and low degree affiliates. These hubs rarely link directly to other hubs in one degree. This network structure may reflect the master artist and his relationships with minor artists, though it could also simply visualize shape of vases and the many artists working on that shape; it is also possible that it merely reflects the bias of our source, i.e., Beazley's published

volumes. Limitations of applying SNA to material from 2,500 years ago emerge. Many historical SNA projects also have such problems and limitations, so here we mention the challenges involved with working with incomplete data sets and how we chose to manage them. The decisions and choices that we made are presented here knowing that others may have addressed the problems differently, and so we welcome further discussion.

## 1. Introduction to Social Network Analysis for Athenian Potters and Painters<sup>1</sup>

Community detection inside a large network has long been a basic goal and standard practice in social network analysis. It is usually accomplished through inputting the edge list or adjacency matrix, calculating each node's metrics, sorting by clusters or attributed groups, perhaps using time slices to narrow the field, visualizing the network, and then studying a sociogram to work out the topology of the network as a whole, the communities within it, and the individuals and their status and roles.

The application of SNA to identify subsets of networks (communities, clusters) is easy in modern organizations, for which a researcher can conduct interviews and gather documents for data. It is more difficult to do for ancient networks, obviously, though scholars of ancient art have been diligently working on identifying “schools” or “workshops” of ancient artists for decades.

Our data comes exclusively from the seminal scholarship of Sir John Beazley of the University of Oxford, who worked on Athenian black-figure and red-figure painters. Drawing on methods established for identifying “schools” of Renaissance painters, known as “connoisseurship studies,” Beazley created catalogues of the vases made by these Athenian potters and painters, which he published in five books, totaling over 3,000 pages.<sup>2</sup> He studied and sorted the potters and painters working in the traditional black-figure technique, publishing them in one volume (abbreviated as *ABV*), as well as those working in the red-figure technique (Figure 1), which he published in three additional volumes, and these are the sources for this study (abbreviated *ARV*; see Figures 2 and 4).

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- 1 The research for this paper has been supported by a 2020–2021 US National Endowment for Humanities Digital Humanities Advancement Grant, HAA-271803 awarded to the University of Arizona, which funded Eleni Hasaki (University of Arizona) and Diane Harris Cline (George Washington University) for their joint project entitled “Social Networks of Athenian Potters [SNAP]: Networks, Tradition and Innovation in Communities of Artists.” Hasaki received additional funding through a Faculty Research Award by the School of Anthropology, University of Arizona. Harris Cline acknowledges the generous support from George Washington University and the support of the Getty Research Institute and Villa in Los Angeles, CA. The authors are also indebted to Sandra Blakely, Eric Cline, and Alan May, who have encouraged their endeavor in meaningful ways, as well as Peter Stewart, Thomas Mannack and Gregory Parker (Classical Art Research Center and the Beazley Archive at the University of Oxford, UK), Ben Shneiderman, and Marc Smith (Smith et al. 2010). The authors warmly acknowledge Joshua Sanchez-Genao and Lauren Sides for their outstanding work on formatting the data while serving as our research assistants in 2020–2021. NodeXL software was used for this research.
  - 2 These foundational texts are Beazley 1956 (*ABV*), 1963 (*ARV*<sup>2</sup>), and 1971 (*Paralipomena*). Note that Beazley made adjustments to the entries for several artists (e.g., the Andokides Painter) between the first and second editions of *ARV*.



**Fig. 1** Athenian red-figure bell-krater depicting a scene at a potter's workshop, c. 470 BCE; attributed to the Komaris Painter. The Ashmolean Museum, University of Oxford, AN1896-1908.G.287. Reproduced with permission.

Beazley's volumes contain lists of vases for each artist, with brief commentaries relating artists to each other or to vase shapes, though no photos or diagrams were included. These stylistic ties have been foundational in understanding how the Athenian ceramic industry developed and was organized. Later monographs on specific potters, painters, and craft communities have used Beazley's lists and further studied those artists with ample visual material.



We have previously presented our methodology in recent publications on the Athenian potters' communities, which were using the black-figure technique,<sup>3</sup> but we will do so again here, briefly acknowledging again that we built our SNA edge list using data only from Beazley's volumes, for consistency. This choice to work with Beazley's dataset came with inherent challenges, which we will outline below, and includes both challenges that came from within the set as well as issues from external factors.

## 2. Methodology

Our overall research goal was to map and analyze the structure of the communities of Athenian potters and painters who worked in the Kerameikos during the period from 600 to 400 BCE. As mentioned, we hoped to discover relationships between clusters of artisans, which could be vestigial traces of the true organization of the Athenian Potters' Quarter.

Our edge list thus comes from the similarities that Beazley saw among the potters as well as the painters, based in particular on stylistic relationships that connect potters to each other through a variety of social ties: a potter can have a pupil, a follower, an imitator, or a group of companions, for example. In order to create the edge list, we went page by page through all of Beazley's volumes, searching for associations.

Our network is bipartite (or bimodal), because we can partition all nodes into two sets: artisans and pots.<sup>4</sup> We included the pot shapes in our network since these helped us to find communities even if the artists themselves did not appear to have direct ties to each other. The edges between pots and artisans may show preferential attachment to making and decorating these kinds of vase shapes.

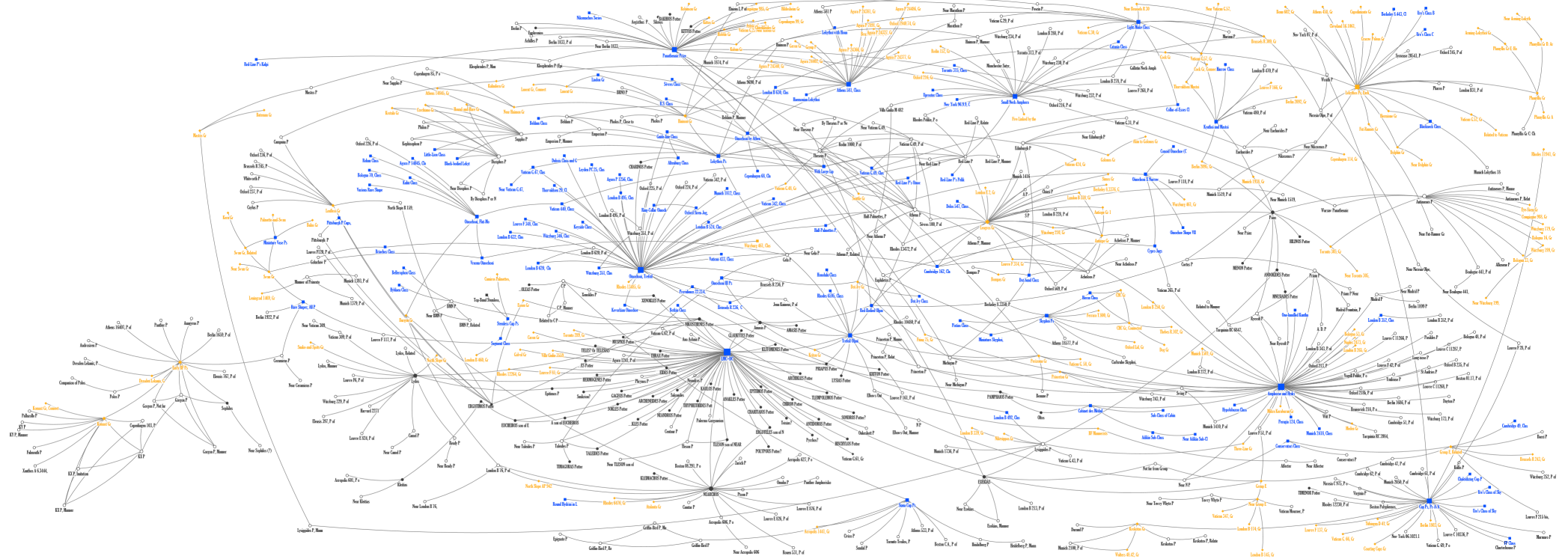
Because we believe vase shapes to be an organizational framework for linking people (artists), we made the choice not to compress or project the bipartite network into a single mode network, which would have eliminated the pots and made direct ties between the people who worked on those pots. Ordinarily, in bipartite networks it is standard practice to study them by projecting them down into one mode.<sup>5</sup> This requires us to assume the artists who work on a specific vase-shape are affiliates and belong together, or perhaps even knew each other. This is not necessarily the case, however: the various shapes continued to be produced for many generations, but the artists who made them lived and died, so we have

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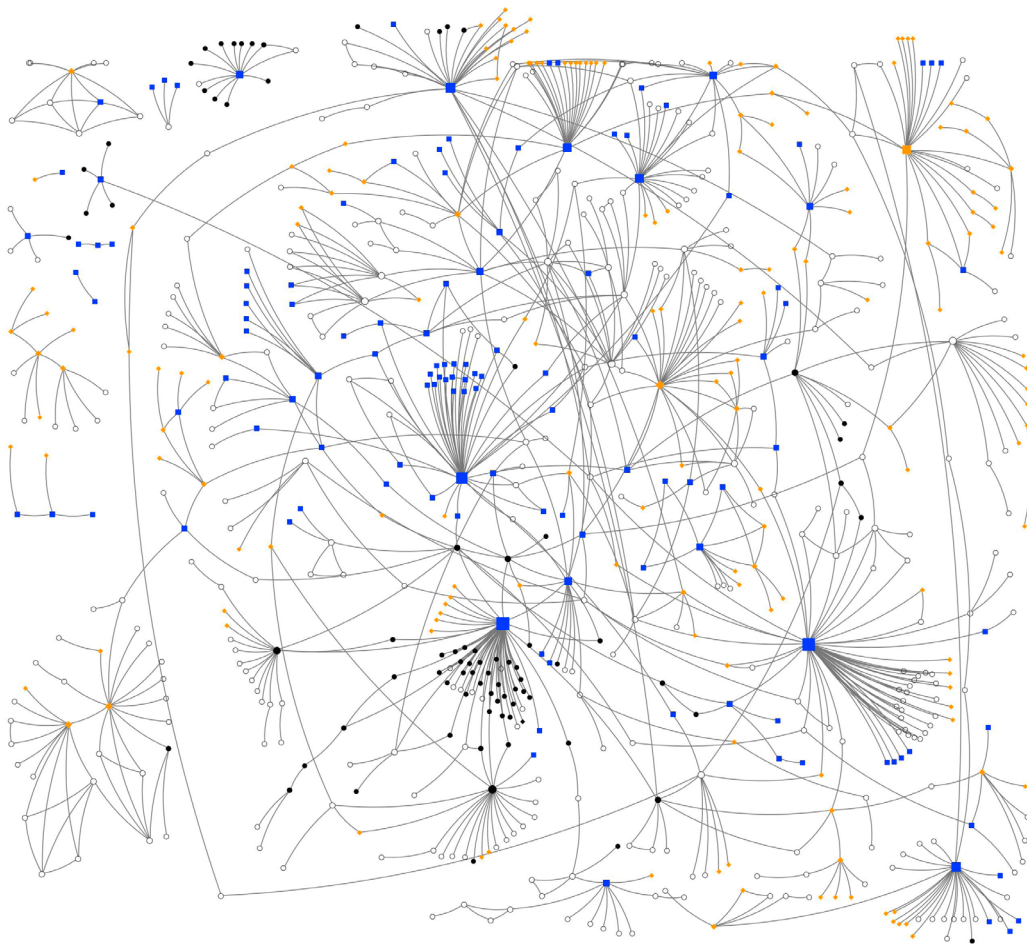
3 See Hasaki and Harris Cline 2020; Harris Cline and Hasaki 2019.

4 See Vasques Filho and O'Neale 2020. "Artisans" includes both artists with known names and artists with attributed names.

5 Vasques Filho and O'Neale 2020; Newman 2003, 24–25.



**Fig. 2** Social Network of Athenian black-figure potters and painters, as catalogued by Beazley; reproduced from Harris Cline and Hasaki 2019: Figure 5.



**Fig. 3** Social Network of Athenian black-figure potters and painters, as catalogued by Beazley, without labels. Blue squares represent vase shapes; yellow diamonds are classes of shapes; black circles are artists with known names; black disks are those with attributed names.

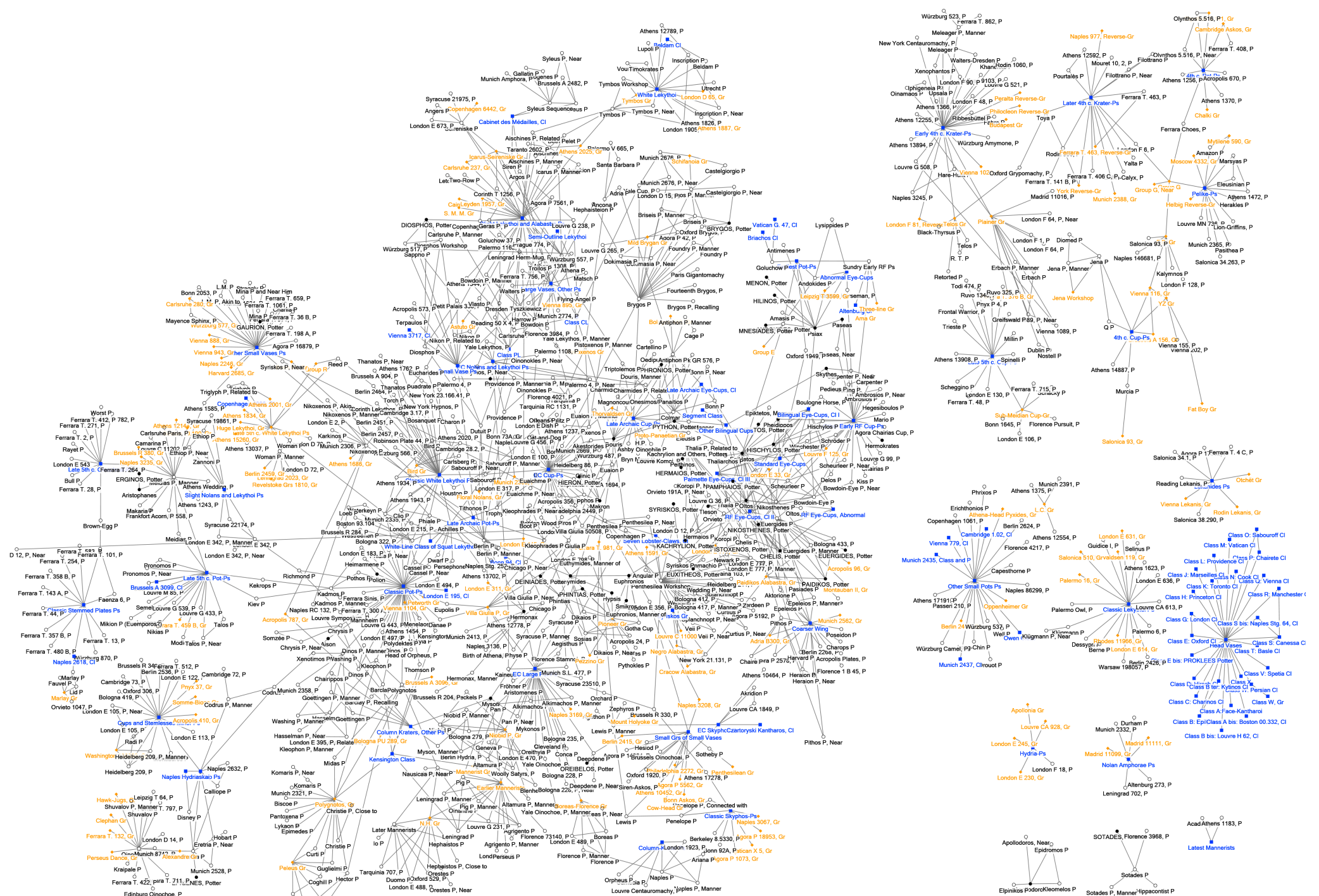


Fig. 4 Social Network of Athenian red-figure potters and painters, as catalogued by Beazley.



made the choice not to compress them, as mentioned above. It might be possible to do this inside a time slice; however, we are not confident that just because artists worked on a specific shape of pot, even at the same time, that they knew each other. On the other hand, the Athenian Potters' Quarter was not that large.

In the sociograms that we subsequently generated, we wished to see the individual potter's or painter's position within the network, as well as the topology of the whole network. For this reason we have included sociograms that are both labeled (Figures 2 and 4) and unlabeled (Figures 3 and 5), so that the network structure, components, and clusters can be more easily seen and studied. In these four sociograms, we coded the data using color and shape to distinguish the types of nodes in the network: blue represents vase shapes (e.g., cups) and yellow "classes" or sub-sets of vase shapes, while the black circles are artists with names known by their signatures (e.g., Euphronios), and black disks are artists with attributed names (e.g., the "Berlin Painter").

### 3. Context for Athenian Potters and Painters

Before proceeding further, we should provide the context for our exploration of the data. Of the various potters' quarters that no doubt existed in Athens and the Attica countryside from the 6th through the 4th centuries BCE, the most famous was probably the area in ancient Athens known as the Kerameikos, which was the main industrial hub of the city at the time. Situated NW of the ancient Agora of Athens, we think that this is where many of the artisans made their vases during this period; it is close to both the marketplace and the major urban cemetery.

Whether in smaller workshops in neighborhoods or in the Kerameikos industrial quarter with its high end products, the ceramics industry was a familiar craft, since everyone needed plates, cups, cookware, drinking ware, or containers to store liquid and dry goods. Consider, though, that all of these needs could have been satisfied with plainware, i.e., ceramics without any decoration. And yet the Athenian potters and painters developed ornate and elegant vessels, from tiny cups to enormous craters, decorated with mythical scenes, daily life, legends of heroes, and funerary tableaux.<sup>6</sup> These have provided a window into all aspects of ancient Greek life and imagination. Within the larger industry, Athenian decorated pottery from the 6th and 5th centuries BCE was the most luxurious and well made of all the ceramics from ancient Greece.

As a result, Athenian pots were a highly desirable commodity, both for local consumers and foreign markets, sold throughout the trade networks of the an-

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6 For a general overview of the rich iconography on Athenian vases, see Oakley 2013; 2020.



cient Mediterranean and Black Sea regions.<sup>7</sup> This consumer demand, both local and international, fueled competition, perhaps bringing new techniques, iconography, and refinements in shape and decoration, leading to innovation.

The black-figure technique (first developed in Corinth and then adopted by other Greek cities by ca. 630 BCE) owes its name to the post-firing black/dark brown color that the decoration received after firing.<sup>8</sup> The figures were drawn in silhouette with incised details against a red background, which is the natural color of the clay, in Athens. The red-figure technique (invented by the Athenians around 525 BCE) reversed the color scheme; it is called red-figure because the figures appear red, as they are created using the reserved, unslipped area of the reddish clay (see Figure 1). To liven up this uncovered area, painters used an intricate system of relief lines and dilute slip for details. The background was covered in slip that becomes black after firing. The new technique largely replaced the old technique and continued to be used for several centuries.<sup>9</sup>

In studying ancient Greek potters and painters, the identification of communities, namely the workshops, has been a desideratum, but unfortunately the Kerameikos has been built over for centuries and archaeological evidence comes primarily from rescue excavations, which makes it difficult to locate and reconstruct the physical evidence for their workshops. So far, excavations have not succeeded in uncovering a single, kiln-anchored workshop of a “named” ancient Athenian potter or painter whose signature survives (e.g., Exekias, Amasis, or Euphronios).<sup>10</sup> Nor do we have the archaeological foundations for the workshops of collaborating artisans, such as those who produced cups and signed them together (e.g., Hischylos “made this” and Pheidippos “painted this”).<sup>11</sup>

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- 7 For discussions of the trading networks of Athenian producers, Etruscan consumers, and the major role of middlemen, see Bundrick 2019, Johnston 2006.
  - 8 For a detailed description of the black- and red-figure techniques with informative visuals, see Bentz, Geominy, and Müller 2010.
  - 9 The bibliography for Athenian vase-painting is immense. Overviews can be found in, e.g., Rotroff 2021; Boardman 2001. See also Schreiber 1999 for a technical study on the shapes of Athenian vases.
  - 10 For signatures on Athenian pottery, see Bolmarcich and Muskett 2017; Hurwit 2015.
  - 11 These names appear together on a red-figure kylix, British Museum inv. no. 1846,0512.2. The collaboration also appears in the assortative cluster discussed in sections 6–7 below. In Athens, a few pits may relate to ceramic workshops. For example, in one pit archaeologists found debris which included deformed red-figure pelikai and bell craters attributed to the Amazon Painter (Eschbach 2014), which had been discarded. A second pit contained works by the Brygos Painter (Baziotopoulou-Valavani 1994; mostly unpublished) and the Briseis and Triptolemos Painter. Both pits are known mostly from preliminary reports. More workshop examples of “attributed” artists come to us from South Italian red-figure vase-painting, where the study of the Metaponto Kerameikos has demonstrated that the Dolon Painter and Creusa Painter worked together (D’Andria 1980).

Furthermore, unlike studying a modern social network, scholars attempting to study the ancient ceramic industry face severe challenges because of the lack of contemporary written information of how a pot was made or how a workshop operated, in addition to the question of where the workshop was located. However, there is a relative abundance of actual pot sherds and vases, some of which show potters at work (Figure 1), along with kilns and excavated ceramic workshops.<sup>12</sup> Apprenticeship was the primary way a young artist joined the community, suggesting the likelihood that there was, in fact, life-long social connectivity. Surely people working in the Kerameikos had social networks. Discovering these based on our incomplete data and lack of written records was one of the challenges that we faced.

Traditional scholarship on the study of artist workshops in ancient Athens has emphasized the role of specific painters or potters and their circles. As such, scholarly publications have tended to focus on the attributed works of single artists and their worlds, but without actually mapping those worlds.<sup>13</sup> The imbalance of sources steers many scholars of vase painting towards research questions concerned with identifying “who made this,” thereby focusing on individual painters or potters by themselves, and where they fit into the matrix.

In reaction to what we (and others) see as an overemphasis in earlier scholarship on such attributions – that is, putting the most scholarly effort into the question of attribution so as to put the extant ancient pots in the hands of specific potters and painters – we join a small but growing set of researchers interested in relational questions concerning the organization of the workshops which produced the pottery, in order to situate them within the social and economic contexts of the periods in question. We are thus more interested in finding out how individual artisans formed workgroups, collaborated, learned from, or copied each other, and innovated in their techniques and iconography inside communities of practice.

Despite all of the inherent problems involved, we were interested in seeing if we could use social network analysis to visualize the diffusion of technical innovations and understand the structure and pathways inside these communities of artisans. While we were able to make headway with community detection, tracing paths for the diffusion of innovation proved more difficult in this data set, especially since all members of the network had already adopted the red-figure technique of vase painting. In the sections below, we present our methodology as well as further exploring some of the challenges that come from using data based

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12 For an updated discussion on ceramic technology in ancient Greece, see Hasaki 2021.

13 E.g., Padgett 2017 for the Berlin Painter (but see Williams’ essay on workshops in the same volume, 144–87); von Bothmer 1987 for the Amasis Painter.

primarily on scholarly handbooks which catalogue and categorize the relevant Greek pottery, before then presenting some of our results.

#### 4. Challenges

In working through the data, we realized that there were a number of challenges to be faced and, hopefully, overcome. Among these we would mention the following in particular:

(1) Beazley relied on (mostly European) museum collections for his study of Athenian decorated pottery, primarily Athenian pottery exported to Etruria and recovered from looted tombs. As a result, these pots, coming mostly from burial contexts, tended to be larger, thereby both satisfying the desires of museum curators to acquire impressive pieces and enabling Beazley to study a painter's style on a larger surface.<sup>14</sup> Therefore his lists favor larger vessels, such as amphoras, kraters, and hydrias. Moreover, since the museums mostly acquired them from places to which they were exported, rather than being found in Athens where they were manufactured, our dataset highlights producers who were active in the export ceramics trade.<sup>15</sup>

(2) There are two types of stylistic personalities in Beazley's dataset: "attributed" artists and "signed" artists. In mapping the network, we opted to use black circles for artists with known names and black disks for those with attributed names (as noted in the captions for some of the figures). Using these symbols allows our viewers to understand just how few named artists we actually have.

(3) In the past half century, since the time of Beazley, the scholarship on vase painting has intensified, with numerous monographs and articles written about specific artists or workshops. However, we have chosen to leave these later studies out of our dataset because including or inserting studies on single painters would skew the metrics (since artists who do not yet have such monographs or studies would by default be left with lower scores). Thus, with some reluctance, we settled on only using Beazley's data when creating our edge list, even though this put constraints on our ability to trace pathways directly between artists.

(4) Moreover, scholarly consensus has shifted over the years on whether a set of pots belongs to one artist with a lengthy career, whose style and technique evolves over time, or if the set should be split into two or more different hands. For ex-

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14 For general descriptions of the method of connoisseurship, see Hasaki and Harris Cline 2020; Harris Cline and Hasaki 2019; Arrington 2017; Neer 2005; Whitley 1997; Opperman 1990; von Bothmer 1987; Kurtz et al. (eds.) 1985; Kurtz 1983, 1985; Robertson 1982.

15 Bundrick 2019; Johnston 2006.

ample, the current thinking is that two named potters (the Bonn Painter and the Colmar Painter) should be combined into one (the “Bonn-Colmar Painter”), with early and later works.<sup>16</sup> This would be represented by two nodes in this sociogram, to keep it consistent with Beazley’s data, but understood to be perhaps earlier and later work of the same artist or shop. In recent decades, specialists on Athenian vase-painting have added more complexity to the collaborations among painters, especially when studying a specific artist, such as the workshop of the potter Nikosthenes,<sup>17</sup> but we are considering here only those which were catalogued by Beazley. Modern scholarly consensus would generally agree that the number of painters has changed since Beazley’s day.

(5) In our study we generated sociograms of the whole network, including those who were distant from each other in time. Beazley assigned dates of activity for each artist using decades and/or quarter centuries, as the paucity of data made it almost impossible for him to assign absolute dates (e.g., 408 BCE). Our edge list, which is based entirely on Beazley’s work, therefore includes artists working in the red-figure technique who lived, in some instances, nearly a hundred years apart. In these all-inclusive sociograms, the earliest clusters are in the upper right of the main component and flow over time to the far left; the disconnected component on the right consists of clusters without obvious ties to any node in the main component (Figures 4, 5). Thus, in order to understand our artists’ contemporary communities, we chose to divide the edge list into time slices of quarter centuries (like Beazley) in order to investigate more closely the artists that we believe were in fact contemporaries. However, since Beazley sometimes gave an artist a thirty- or forty-year period of productivity, we had to decide to which time slice that artist belonged. Since we decided to work with quarter-century slices to agree with the dataset from the Beazley Archive, and in order to accommodate the dates traditionally assigned to the majority of our artists, and since our data set is incomplete to begin with, we must acknowledge that our time slices would benefit from further refinement. We do, however, have confidence in the contemporaneity of artists presented in Figures 7, 9, and 10.

(6) There is a lack of written sources from Greek and Latin literature which discuss the ceramic industry and individual artists. Therefore our knowledge, and our edge lists, comes exclusively from archaeological excavations and art historical studies. We don’t have known associations between these ceramic artists from written sources, apart from the inscriptions on the vases themselves.<sup>18</sup> Therefore, in cases where we had artists for whom there is nothing known about their

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16 For the Colmar Painter, see *ARV*<sup>2</sup>: 352–357.

17 Tosto 1999.

18 For another craft sector, the marble sculptors of the Hellenistic period, Larson (2013) studied the inscriptions on statues to highlight father-son relationships and used the find spots of the sculptures or their bases to reconstruct networks of mobility.

social ties, which is the vast majority, but could nonetheless see that they work on the same vase shapes or share stylistic commonalities, we decided that we had to make a link between them on the assumption that they either collaborated or were located physically close to each other; at the very least, they must have seen each others' work. We took this step with some trepidation, but had we not done so, we would have had hundreds of disconnected solo potters and painters, leaving us unable to see any kind of social networks or patterns. Since we think it highly unlikely that there were no connections at all, given their proximity in the Kerameikos, we made the decision to include the shapes of the vases in the edge list to tie artists together, thereby creating a bipartite network, and without compressing the pots and people.

(7) Finally, we are certain that we have included all of the artists studied by Beazley in our large sociograms, but recognize that we have therefore included artists who couldn't possibly have known each other. For these reasons, we have limited our observations and conclusions presented below to explore only assortative clusters inside the larger connected component.

## 5. Results: Topological Analysis of the Red-Figure Network of Artists and Vase Shapes

Overall, we discovered 1,067 unique nodes with 1,583 edges in the network. In the red-figure network, the sociogram has 13 components (Figures 4 and 5). The smaller components shown on the right are groups which Beazley separated from the core because of their unusual shapes or late 4th century date, although we believe that the makers of these pots were part of the artist community. Without them, we have one large core component with 821 nodes and 1,312 edges. However, these numbers should not be mistaken for the precise number of people who worked in the Potters' Quarter of Athens.<sup>19</sup> Because of the numerous components, the geodesic distance and average path lengths are unusually large: the diameter is 23 and the average geodesic distance is 7.787. These are disappointing metrics for identifying a social network of artists, even a bipartite one that includes their vases. In Figure 5, the small components may be more easily seen on the right side.

The large diameter and average geodesic distance may also be explained by our choice to map all the artists in Beazley's ARV in one sociogram, even though the length of this time period, from c. 525–400 BCE, means that not all artists in the network were contemporaries. We note that not all nodes represent individual artists, because some of our nodes are actually vase shapes, while others

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19 For different estimates of the potters' population in Archaic and Classical Athens, see Sapirstein 2013, 2020; Stissi 2020.



are groups of artists, within which Beazley did not tease out the individuals. We know the picture is very incomplete; the Potters' Quarter had these artists, the painters and potters, but this was a multiplex community of artisans with apprentices, merchants, suppliers, kiln-workers, and errand boys, all working as a complex system, in coordination but without formal supervisory leadership. Some were citizens, some slaves, some foreigners living in Athens, and all were of a variety of ages, from young apprentices to very aged community members.<sup>20</sup>

In both the black-figure and red-figure, the shapes of the vases often serve as the hub for clusters inside the network as a whole. Because we have more than one type of node (artisans and vases), the vase shapes can be interpreted as affiliation-networks, as artists tend to specialize in shapes, and those actors who were contemporaries perhaps knew of each other and trained together. Artists specialized in larger or smaller vessels, which required learning specific drawing skills, because each vase shape had different curvatures, but they became comfortable painting on lower or higher curved surfaces as they gained expertise.

This is our current explanation for why the shapes often have the highest degree in a cluster. All this shape-specific technical knowledge was transmitted from generation to generation in the potters' quarters, where potters and painters learned how to adhere to a strong tradition in shape specialization, while making room for innovation and experimentation.<sup>21</sup> Through our social network analysis, the impact of shapes on the organization of the Athenian Potters' Quarter becomes very clear.<sup>22</sup>

When we studied the black-figure vase painting network in 2018–19, we found that the structure was relatively uniform, with clusters very lightly connected to each other, centered around the shapes (Figures 2 and 3). One or two artists might be tied directly with each other, such as a potter and a painter who signed their work, but generally the connections between these hubs were the result of an artist who worked on two shapes, tying the two clusters together very lightly.<sup>23</sup> Few of the high degree actors in the center of the cluster have first order ties to the others with high scores, because they are vases. The distribution is disassortative (see, e.g., Figure 6), where assortativity is defined as “a network-level measure which quantifies the tendency of nodes to mix with similar nodes in a network.”<sup>24</sup> This may also be identified as a preferential-attachment pattern, which makes

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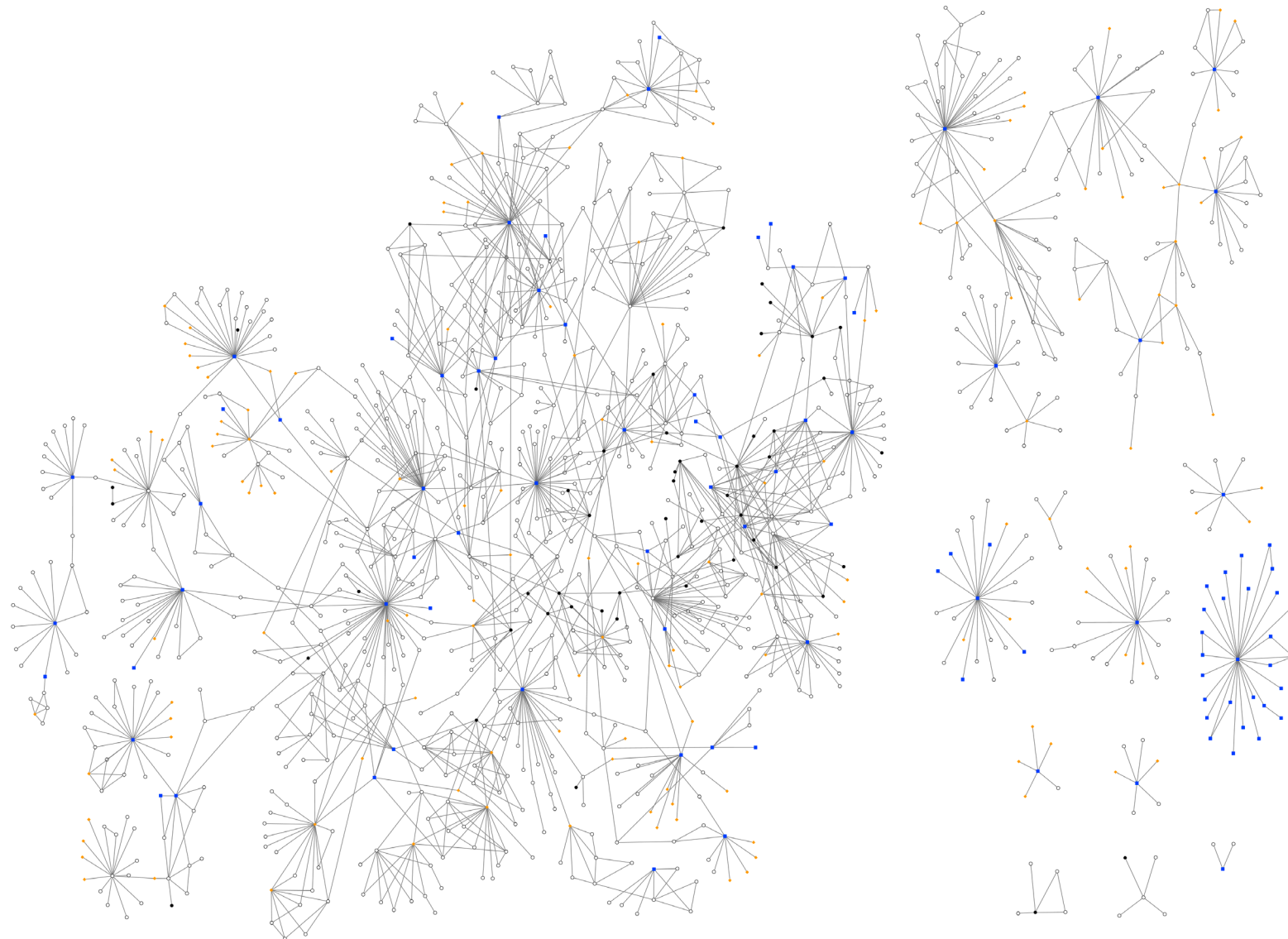
20 Rotroff 2021, 276–77; Stissi 2002; Keuls 1989, 153.

21 On craft networks and communities of practice, see Gandon et al. 2020; Kadrow and Müller 2019; Harris Cline 2018; Fejfer 2015; Williams 2017; Crown 2014; Arnold 2012; Hasaki 2012; Knappett 2011; Singh 2005.

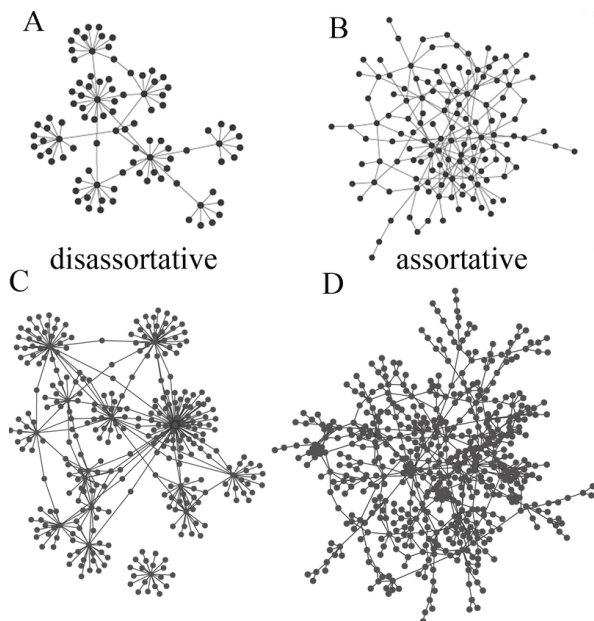
22 Harris Cline and Hasaki 2019.

23 Hasaki and Harris Cline 2020; Harris Cline and Hasaki 2019.

24 Piraveenan et al. 2018, 329.



**Fig. 5** Social Network of Athenian red-figure potters and painters, as catalogued by Beazley, shown without labels.



**Fig. 6** Schematic illustration of disassortative and assortative mixing in social networks. Created by Hao and Li (2011); available from Creative Commons (<https://creativecommons.org/licenses/by/4.0/>)

sense in a knowledge-based community, as low degree centrality members try to join the community by attaching themselves to influencers or hubs (Figures 4 and 5).<sup>25</sup> Nevertheless, Jiang et al. found that true human social networks tend to have assortative mixing.<sup>26</sup>

It seems that our red-figure network is mainly disassortative, with the vase shapes in the center of each cluster. The shapes tend to have a lot of ties, while the individual artists or groups have just one or two. This is measured using simple Degree Centrality, wherein the top vase shapes are those that are less specialized, which would have had far more samples and more artists. Thus, in descending order, the top ten are as follows: the Classic Pot-Painters (44), Early Classical Cup-Painters (35), Slight Lekythoi and Alabastra Painters (32), Early Fourth-Century Krater-Painters (30), Classic White Lekythoi Painters (29), Early Classical Large Pot-Painters (28), Other Early Red-Figure Cup-Painters (28), the Penthesi-lea Workshop (28), Head Vases (26), and Other Small Vase Painters (24).

We found that, just as for the black-figure networks, the high scoring nodes for most of the red-figure networks are not usually in a first order direct relationship with each other. When we looked purely at Degree Centrality, 31 of the top 50 were vase shapes. Of the 29 that were artists, 7 were really workshops or groups.

25 Kadushin 2012, 117: “In the preferential-attachment model, high degree nodes are linked to others with low degree.”

26 Jiang et al. 2016.

Our dependence on Beazley's chapters, where he used vase shapes to bring the artists together for his descriptions, could easily explain this pattern, for our sociograms may be visualizations of Beazley's books, rather than a representation of the communities themselves. In other words, in the majority of our black- and red-figure networks, we might not have true social networks and must consider the possibility that we have mapped the books rather than the communities, except for one zone, as we will see below.

But even given the predominantly disassortative network, there are important areas for specialists in vase painting to study further. In both the black- and red-figure techniques, the shapes of the vases are often the hub for clusters inside the network as a whole, as discussed above. One cluster in particular shows well the interrelationships between artists and the vase shapes, and also gives strong evidence of the social networks between the artists, despite the bimodality of the study. Here we find a small subset of red-figure potters and painters, first identified by John Oakley, who were working in a variety of shapes (Figure 7).<sup>27</sup> These are not the only artists to work on these shapes, but were selected for their interlocking positions within the network. Four artists stand out in this cluster: the Achilles Painter, Berlin Painter, Phiale Painter, and Persephone Painter.

The sociogram allows us to see the shared vase shapes but also the shared techniques, since the White Ground Lekythos (Figure 7, lower right), for example, is a vase shape used in funerals for offering perfume. It was usually decorated using a specialty technique, requiring vase painters to be trained and share traditional knowledge on how to apply the white ground and decorate using a wider range of colors than in traditional black- or red-figure. Apparently, artists and pots shown together in bipartite networks can sometimes facilitate new observations in ways that a written description cannot.

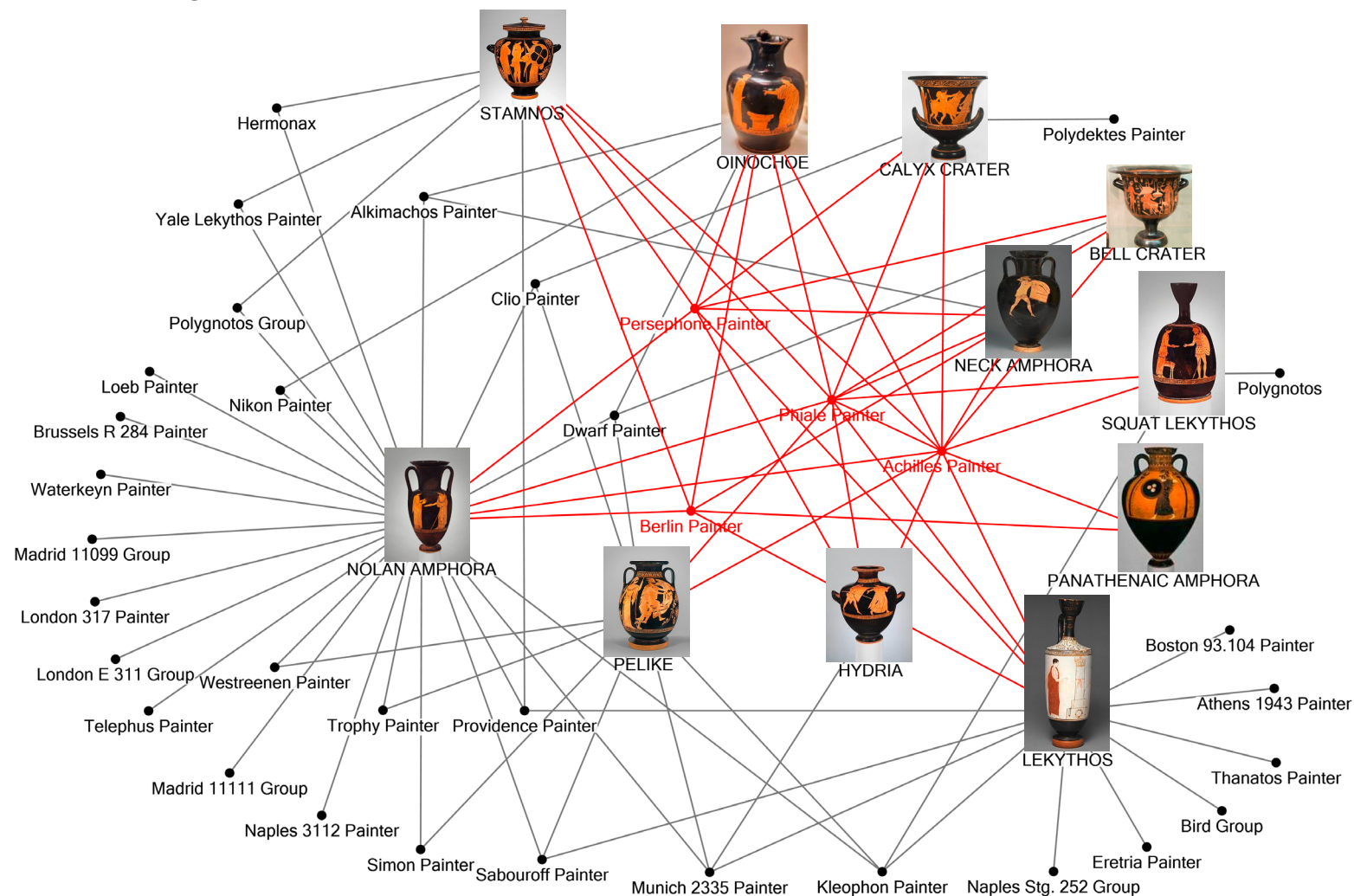
## 6. The Zone with Assortative Mixing

Let us now take a deeper look at one particular zone, where we discovered assortative mixing and where we believe there is a chance of recovering a real social network of artists (Figures 8, 9, 10). This group of interlocked artists, who worked in the late sixth and early fifth centuries BCE (ca. 520–490 BCE), appear to have been part of a contemporaneous artistic community. Indeed, they have been previously identified, independently from our study, as the "Pioneer Group," whose preserved signatures included the names Epiktetos, Euphronios, Euthymides, Oltos, Phintias, Andokides, Nikosthenes, and Psiax, among others.<sup>28</sup>

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27 Data set adapted from Oakley 1997, 93–94.

28 See, e.g., Neer 2002, 27–86; Robertson 1992, 20–42; Boardman 1975, 29–54.



**Fig. 7** The vase shapes which the Achilles Painter, Berlin Painter, Persephone Painter, and Phiale Painter have in common.

This assortative cluster also contains the highest percentage of signed artists in the entire red-figure dataset: 17 potters and 12 painters who signed their vases, and 41 attributed artists (i.e., whose work is identifiable stylistically even though we don't have their signatures). This set of artists worked on at least ten vase shapes. Based on network positions and connoisseurship scholarship, these artists are among the well-connected painters who propelled the acceptance of the red-figure technique. One could potentially label these artists as influencers, for they chose to collaborate with multiple potters.<sup>29</sup> The cluster includes collaborations attested through the signatures of a potter and a painter on the same vessel, such as the painter Epiktetos with the potters Andokides, Hischylos, Nikosthenes, Pamphaios, and Pistoxenos, as well as style-based collaborations such as Epiktetos and the Euergides Painter. The ties are among contemporary artists, either of comparable age, or across two generations, as Psiax is believed to have been a pupil of the Amasis Painter.<sup>30</sup>

Their direct ties with each other are notable. In fact, we know that many of them collaborated with each other as potters and painters. In context, we can situate this tightknit group within the broader network, for we also have chains of potters and painters who worked with each other. In Figure 8, therefore, we can see numerous potters and painters who signed their work, tied directly to each other. The vase shapes appear as nodes so that we can see which potters created which kinds of shapes, and the painters that were affiliated with them. Subsequently, in Figure 9, we can see the potters and painters with the vase shapes they worked on, and in Figure 10, without them, we can see this area of the network as a social network with individuals or groups of artists only.

This zone is also unusual in terms of its topological structure (Figure 8). The rest of the red-figure network appears to be disassortative, as mentioned, with high degree nodes in the center of a cluster with low degree affiliates, which look like daisy petals. These hubs rarely link directly to other hubs in one degree. This structure may reflect the master artist and his relationships with minor artists, or with the shapes of vases and the many artists working on that shape. However, the assortative area is different. Here we see assortative mixing, the bias in favor of connections between network nodes with similar characteristics, or like tending to connect with like.<sup>31</sup> This means that while we are looking at a generally

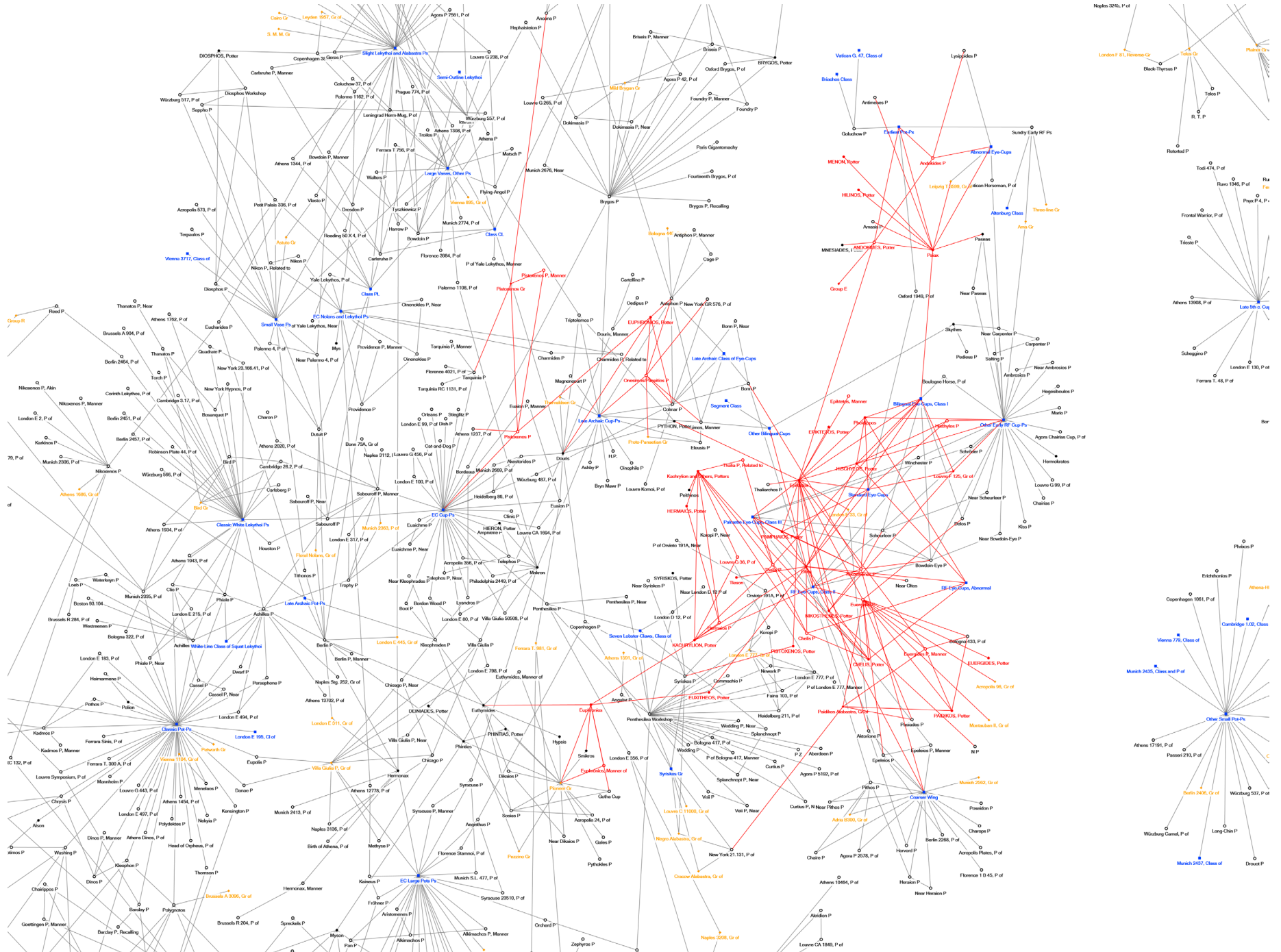
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29 For the influence of community leaders in social networks and social contagion, see Centola 2018; Hodder and Mol 2016; Christakis and Fowler 2013; Kadushin 2012, 209–210; Iyengar et al. 2011.

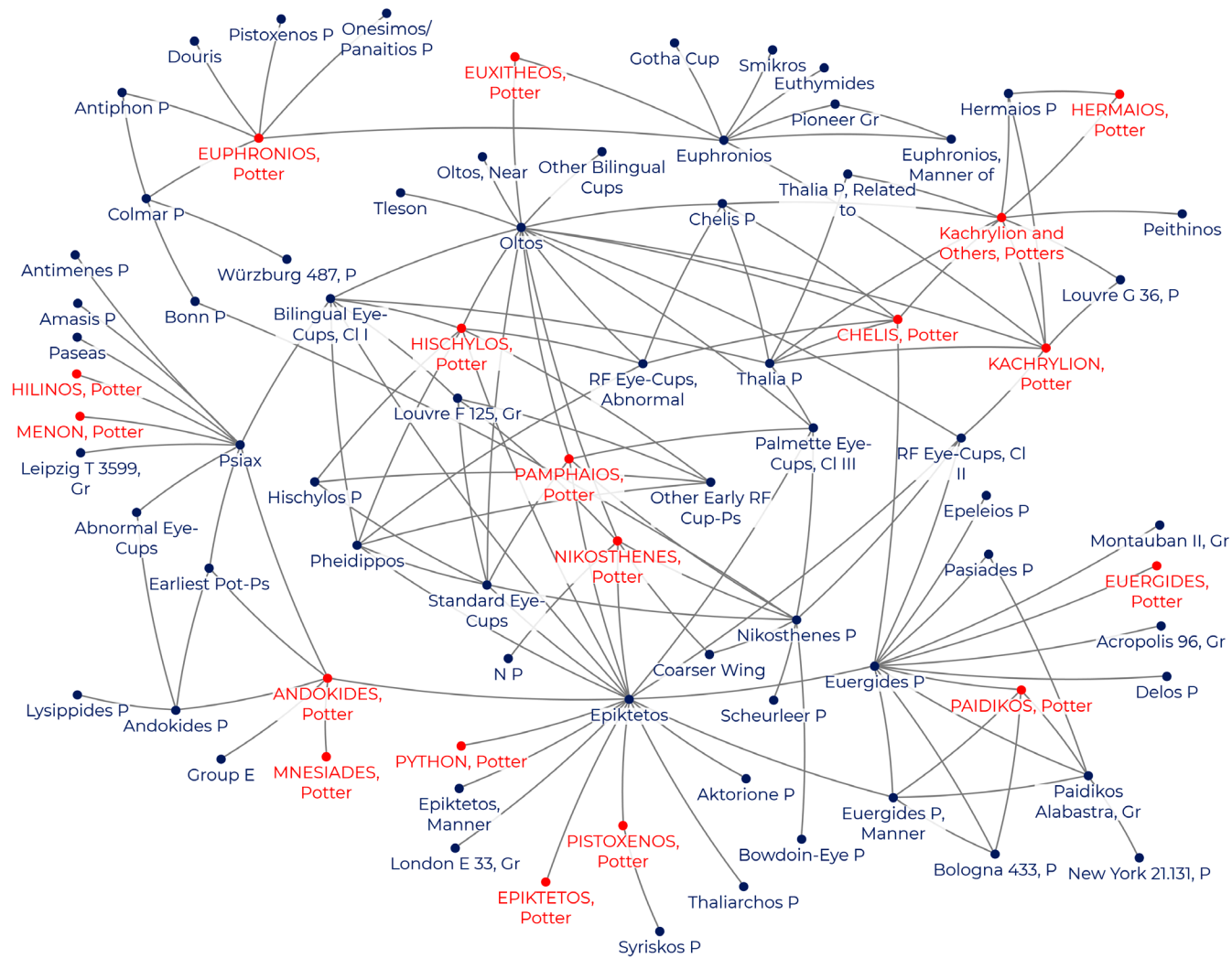
30 ARV<sup>2</sup>: 6. See, e.g., Hasaki and Harris Cline 2020, Figure 2b; Harris Cline and Hasaki 2019, Figures 2 and 3.

31 On assortative and disassortative mixing, see Vasquez Filho and O'Neal 2020; Peel et al. 2018; Piraveenan et al. 2018; Arcagni et al. 2017; Jiang et al. 2016; Newman 2003, 191–93; Goh et al. 2003.





**Fig. 8** The zone with assortative mixing inside the red-figure network.



**Fig. 9** The red-figure potters (in red) and painters (in blue), along with the shapes and the vases, within the assortative zone.

disassortative network for red-figure, within it there is also one high density assortative area.

We first identified this anomalous area purely by sight: the density (a large number of connections between the members of social networks) appeared higher (Figure 8).<sup>32</sup> Here, within this observable assortative high density area, potters and painters are directly tied, and there are few low degree members in the cluster. There appears to be something special going on with them. On closer inspection, many named red-figure potters and painters are in first order zone direct relationship, which is unusual for our networks (Figure 9). The signatures in this cluster alone – 29 named artists (17 potters and 12 painters) – account for approximately half of all 51 signed artists in the entire sociogram, so here we come closer to a true social network with named artists.

## 7. Centrality Measures

Whereas the network as a whole includes artists who worked a century or more apart, this assortative mixing zone only consists of artistic contemporaries. The difference between the whole network and this assortative zone in their average geodesic distance and density metrics is quite remarkable, signifying much more connectivity and the possibility of a healthy flow of information; it also bears more similarity to human social networks. If this were a modern social group, we would interpret the density as an indicator that this part of the network enables members to find social support and facilitates the transmission of ideas.

Overall, in assortative, non-directed scale free social networks, we should find many links within the community, but fewer ties to other clusters. Inside such community structures, one expects to find high node embeddedness, and high link density. In contrast, disassortative mixing describes networks which exhibit hub dominance and high compactness with short path lengths between members of the community.<sup>33</sup>

In terms of Degree Centrality, the painters Epiktetos and Oltos stand out, having 18 and 15 ties, respectively. They also have three nodes in common, all potters: Hischylos, Pamphaios, and Nikosthenes. Additionally, Epiktetos and Oltos, as vase painters, both painted the same shapes of vases, mainly cups, requiring the same technical expertise and traditional knowledge. The specific shapes of vases which they both decorated include Standard Eye-Cups, Bilingual Eye-Cups Class I, Palmette Eye-Cups Class III, and Red-Figure Eye Cups Class II. Cups are

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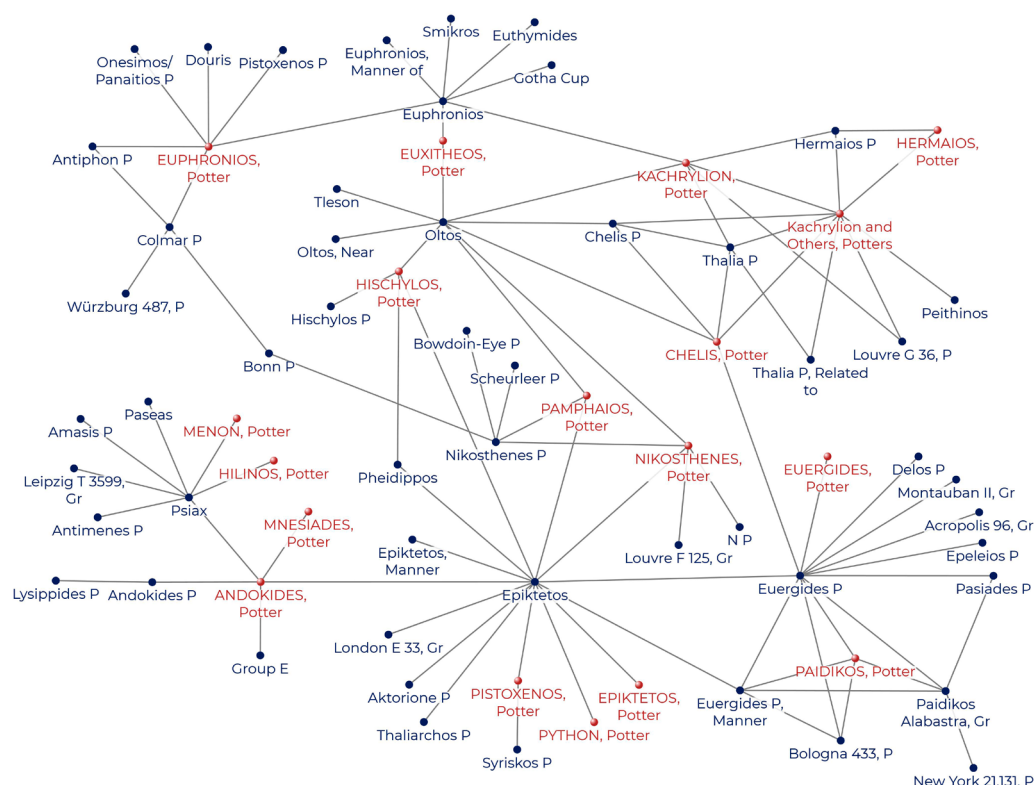
32 “Density is defined as the number of direct actual connections divided by the number of possible direct connections in a network” (Kadushin 2012, 29).

33 See Jiang et al. 2016, 1, 9–14 for fuller definitions of these terms.

among the most ornately decorated shapes, as both their exterior sides and their interior central circular space (tondo) were painted with scenes. Floral ornaments filled even the areas under the handles. This intense painting activity fostered collaboration as the sharp curvature of the exterior sides required different painting techniques than the flat interior tondo. With both artists working in such a variety of specific cup shapes as their contemporaries, we must assume that they knew each other, or were at least familiar with each other's work. These common ties indicate a close relationship through style, form, and technical expertise.

In a sociogram where we omit the vase shapes (thus compressing the bipartite network), the relationships between potters (red) and painters (blue) becomes even more evident (Figure 10). As noted, in this one cluster without the vase shapes there are 70 nodes with 94 edges. Some of these nodes are attributed groups of painters, so the number of artists should actually be higher than 70.

Furthermore, for this group in the assortative zone, there are multiple connections between the top five artists in Betweenness Centrality. For instance, Epiktetos (#1) and the Euergides Painter (#2) have a direct tie. Euphronios (#4) has



**Fig. 10** The red-figure potters (in red) and painters (in blue), projected down into one-mode to exclude vase shapes.

direct ties to both Oltos (#5) and the potter Kachrylion (#3), while Oltos and Kachrylion also have a direct tie to each other, thereby creating a triangle between the three nodes/artists. In no other part of the larger network have we found peer-to-peer interaction at this scale. Newman explains that the highest-scoring nodes in Betweenness Centrality “may have considerable influence within a network by virtue of their control over information passing between others.”<sup>34</sup> Individuals in these key positions can serve as gatekeepers or bridges. These nodes can have low degree scores (that is, they are tied to relatively few other nodes) and still have high Betweenness Centrality scores, because they can lie on a path between two nodes with high degree, but are the only (or primary) way for all of their associates to get information across the network from both sides.<sup>35</sup>

Epiktetos and the Euergides Painter also rank #1 and #2 in Degree, with 14 and 12 ties, respectively. Although we find no direct ties, three potters link Epiktetos and Oltos, and one potter connects Oltos to the Euergides Painter (Figure 10). By using the same potters, we learn they were contemporaries who worked on the same shapes, and most likely knew each other personally.

In this subset of the red-figure sociogram we believe that we may have come closer to capturing a real situation on the ground of interactions among craft-people working in the Potters’ Quarter of Athens. In the assortative zone (Figures 8, 9, and 10), we hypothesize that potters who collaborated with painters may have been bridges or brokers, who possibly introduced painters and other potters to each other, perhaps even sharing collaborators, although we have no evidence for them playing these roles besides their network positions. The potters who are connected to the top five Betweenness Centrality painters include Chelis, Hischylos, Kachrylion, Nikosthenes, and Pamphaios. We met three of these above through their collaborations with Epiktetos and Oltos. We see a higher concentration of potters in this zone than anywhere else in the network, and they signed their works and collaborated with multiple painters. In describing assortative network distribution, Kadushin explained that we can observe “connections in a small world made through elites that have many links to one another.”<sup>36</sup> Although we cannot claim that the Athenian red-figure network is a “small world,” we do believe that something special is happening in the assortative zone.<sup>37</sup> As a result of our social network analysis, we believe that here we may have located and identified an actual community of artists who worked in the Potters’ Quarter in Athens.

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34 Newman 2010, 186.

35 Newman 2010, 188 Figure 7.2.

36 Kadushin 2012, 209–210.

37 Harris Cline 2020.

## 8. The Mirage of the Achilles Painter

There is a cautionary tale involved in our analysis of the large component as a whole, however. Overall, the top ten individual artists with high Betweenness Centrality scores in the entire network are a surprising mix of obscure and famous painters. For instance, the Achilles Painter, the Phiale Painter, the painter whom Beazley thought worked in the “Manner of the Achilles Painter”, the Painter of Munich 2335, and the painter Beazley called “Near the Phiale Painter” rank as the top five artists in Betweenness Centrality.

About half of these top ten artists are also those usually identified by specialists as the innovators of Athenian vase painting, including the Achilles Painter, Berlin Painter, Sabouroff Painter, Douris, and Epiktetos. Others are more obscure and drew our attention because of their high scores. Within the disassortative zones, however, unfortunately the artists with high scores are those with first-degree ties to two main vase shapes, inflating their Betweenness and Eigenvector Centrality metrics. Perhaps the statistics are not so valid or useful in this historical social network as a whole. Nevertheless, there are a few stand out artists, despite the limitations of dealing with the bipartite problem of vase shapes in the mix.

Using social network analysis brought these artists to our attention, as it probably would never have occurred to us using conventional methodologies, which is one of the major advantages of creating a panoramic view of the whole community of artists. Of them all, the Achilles Painter turns out to be the highest scoring individual artist in both Betweenness and Eigenvector Centrality scores. The central role of the Achilles Painter has been highlighted by John Oakley, in his monograph on this artist, who suggests that this painter channeled his energies and his “innovative spirit” not only into the dominant red-figure technique but also into a second minor technique, the white ground one.<sup>38</sup>

In all, the Achilles Painter has 14 first-degree ties, which included 11 artists and 3 vase shapes. In his second order ties, we find all the Classic White Lekythos Painters and the so-called Classic Pot-Painters as groups with which he is affiliated, plus well-connected and influential (stylistically, at any rate) painters such as the Phiale Painter and Berlin Painter. By the time we light up the third order ties of the Achilles Painter, we find his ego-network occupies substantial space in the center of this much larger red-figure network (Figure 11).

A problem becomes evident, though, and doubts arise. If a vase shape has many ties and acts as a hub (high Degree), then anyone who bridges two or more

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38 See Oakley 1997, 68; Beazley 1963, 986–1013.



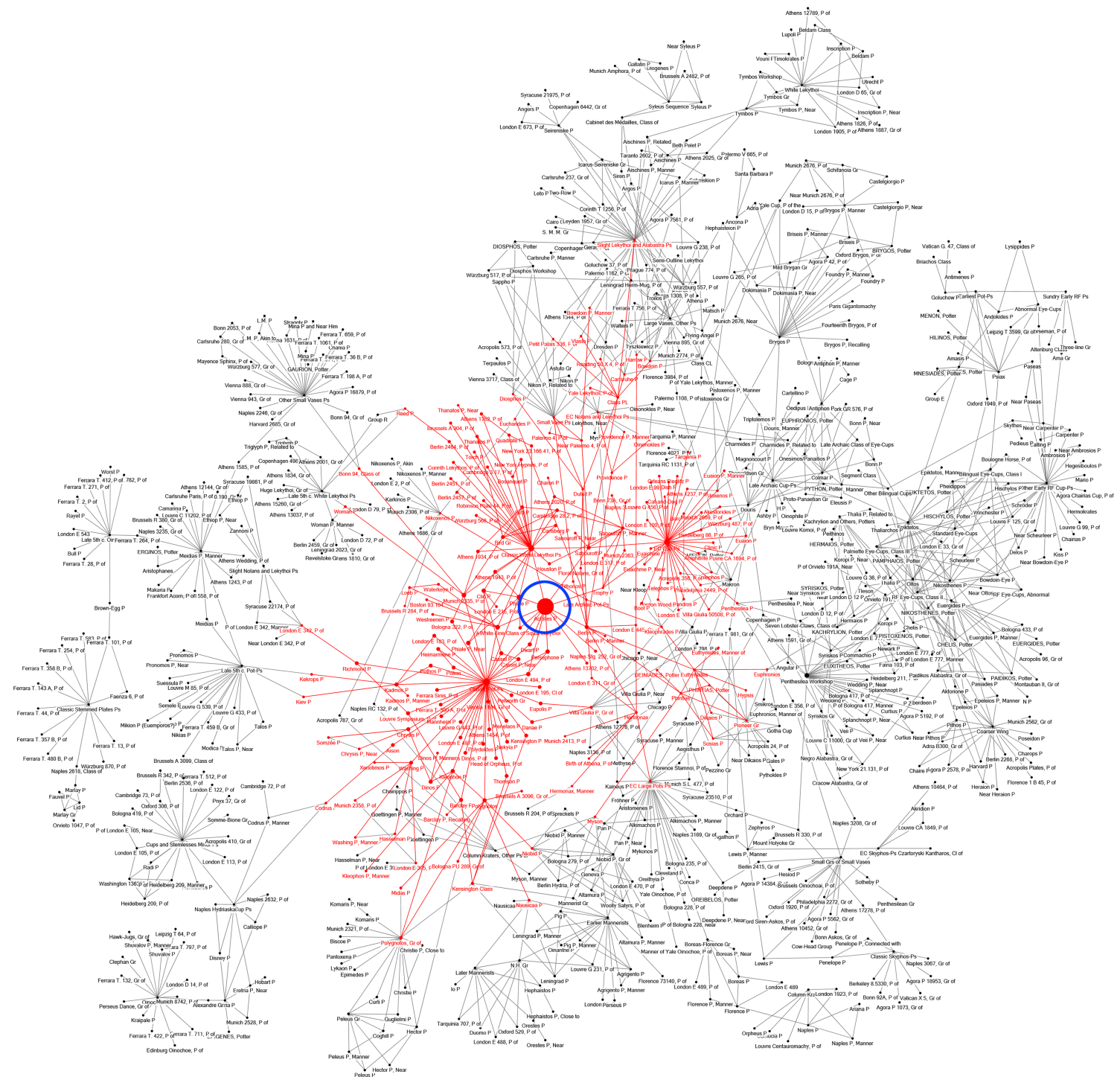


Fig. II Third order ties of the Achilles Painter.

such shapes earns extremely high scores both in Eigenvector and Betweenness. Centrality scores in a bipartite disassortative network make statistical analyses unconvincing. The Achilles Painter may have been stylistically influential, but his high scores cannot be used as evidence of this. His ties to three vase shapes mean that every artist affiliated with those shapes is, at maximum, second degree in his ego-network; however, it is unlikely they were all influenced directly by the Achilles Painter (Figure 11). Situated inside a disassortative zone, we must conclude that his high scores are a mirage. Betweenness Centrality may have seemed like a useful vector to trace the transmission of technology and style diffusion, but what does an Eigenvector Centrality score mean in reality, if vase shapes hold so much “power,” or skew the statistics by giving “power” to individuals just because there are a lot of painters who work on that shape? Having realized this, we stopped using this metric early on in our study, and remain sceptical about the use of any other SNA metrics in this project.

## 9. Summary

During the course of mapping the networks of artists working in red-figure in Athens from 600–400 BCE, we successfully uncovered evidence for one assortative zone with a community of 70 interlocked Athenian artists or workshops. We also grappled with the methodological challenges of having to rely on Beazley’s connoisseurship studies for our data, and how his reliance on shapes obstructed our ability to find other human social networks. One subset featuring the Achilles Painter, Phiale Painter, and Berlin Painter showed that shapes have an important role in linking actors to the network, and created communities around making and decorating the specific vase shapes. Such work connected artisans through sharing technical and embodied knowledge, which helped communities of practice grow over time.

Through social network analysis, we investigated the connectedness of these potters’ networks, searching for communities of practice. Social networks can be used to evaluate and fill in the gaps for the methodological problems linked to the nature of the sparse archaeological and literary evidence for craft communities of pottery workers. The SNA provided comprehensive visualizations which will encourage scholars to see the entire *Kerameikos*. On the other hand, the predominantly disassortive structure of the resulting sociograms and the associated metrics are problematic, as our networks are bipartite with shapes and artists. Straightforward answers on how craft and business partnerships informed their technical and artistic decisions to either maintain traditional methods or embrace innovation in red-figure pottery are unlikely to be provided solely by using social network analysis, but the sociograms that are generated may be useful for viewing old problems in new ways. One thing that is quite clear is that the disassortative structure of the sociograms built solely on Beazley’s original publications reflects the formalist organizational character of connoisseurship

studies.<sup>39</sup> In this respect, sociograms based on connoisseurship present their own challenges compared to social networks derived from historical texts.<sup>40</sup>

It is conceivable that with more integrated approaches from the Beazley Archive Pottery Database in terms of shape specialization, additional decorative techniques used (such as coral red or white ground), imagery choice, and targeted markets in export trade, scholars of Athenian pottery production could perhaps explore further questions about the connected communities of practice based on their own expertise. Themes for continued research in the study of the social networks of Athenian potters might include searching for evidence for the diffusion of innovation, apprenticeship, knowledge transfer, mobility, comparative studies, and more detailed studies of shorter chronological spans (Figure 12).

The use of SNA and sociograms have several affordances: they are useful for helping researchers evaluate their own datasets; they point to individuals, groups, clusters, and zones which may be worth investigating; and they have illustrative value. For historical network researchers, after gathering and organizing the data, one must consider how incomplete the set is, and what skews or biases are inherent. Some research topics do not lend themselves to applying SNA, but experimentation can still be helpful in understanding the characteristics and limits of the data set. During the research phase, sociograms may be used to identify anomalous or interesting areas or individuals in the network which one might not have thought to investigate without them. Metrics of centrality also point to nodes or clusters worth investigating. They are also illustrative of one's findings, with the power to convincingly present results to others.

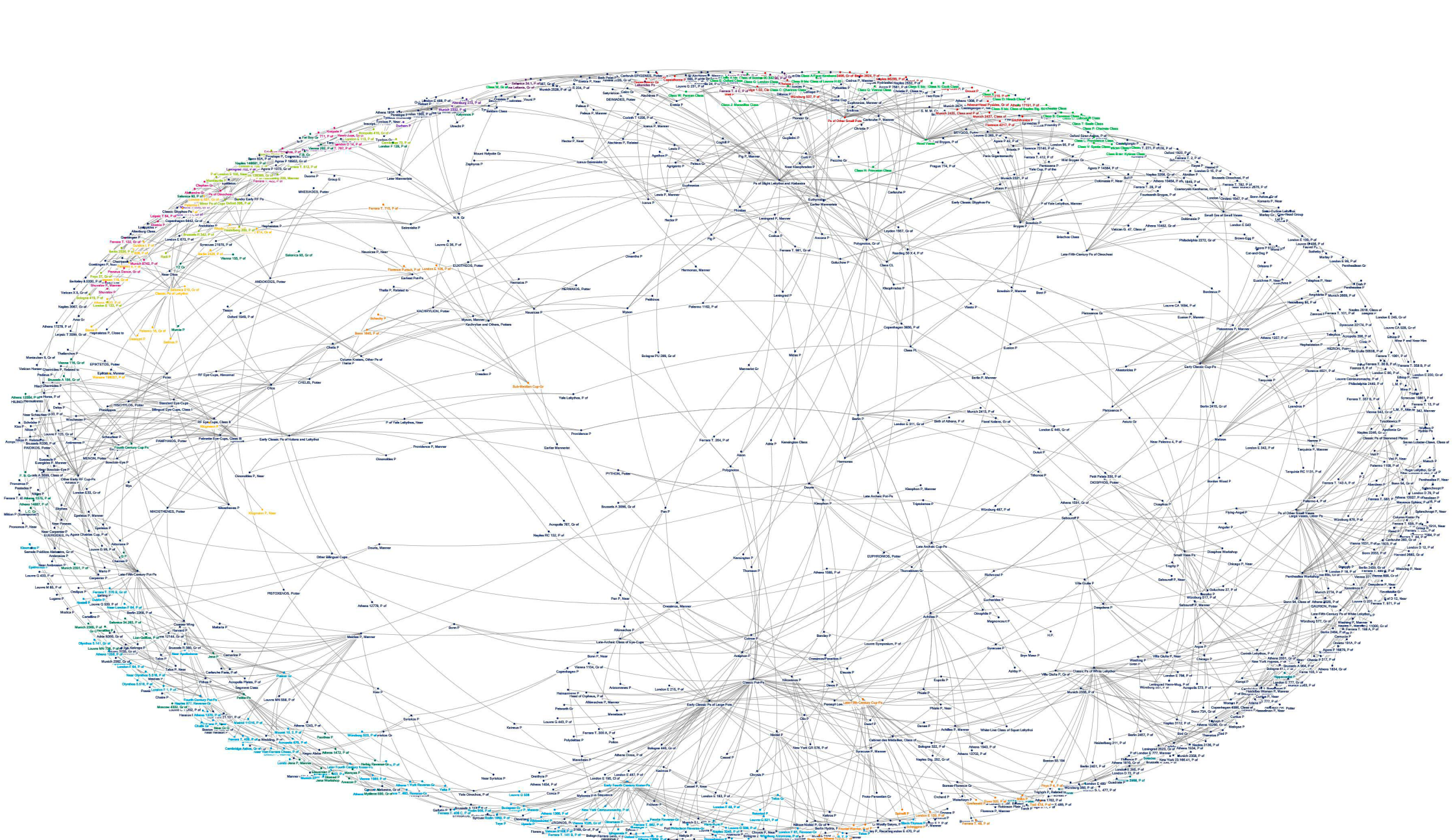
For the field of classical archaeology overall, and for ancient Athenian vase painting in particular, the application of a social network analysis approach is experimental, allowing us to probe central questions from a different angle. All else aside, it clearly has the potential to move us from an understanding of artist communities traditionally focused on single actors towards a more relational perspective, which involves seeing how things and people are entangled and become greater than the sum of their parts.

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39 For formalist and relationalist theory in Network Analysis, see Erikson 2013; for formalism in Art History and Connoisseurship see, for example, Neer 2005 and Opperman 1990.

40 For Cicero's correspondence, see Alexander and Danowski 1990; for historical figures in Classical Athens, see Harris Cline 2019, 2020. A useful survey of challenges in networks with material culture can be found in Collar 2020.





**Fig. 12** Social Network of Athenian red-figure potters and painters, as catalogued by Beazley; colors are clusters of contemporary artists in 25 year segments. Dates provided by Gregory Parker from the Beazley Archive Pottery Database.

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