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Social network analysis on the Proveana database: insights on the circulation of nazi-looted cultural goods during and after WWII

Riccardo Giovanelli¹ , Madison Leeson² , Sara Ferro¹ , Michela De Bernardin¹ and Arianna Traviglia^{1*}

*Correspondence:

Arianna Traviglia

arianna.traviglia@iit.it

¹IIT - Centre for Cultural Heritage Technology, H-Farm Campus, Via Adriano Olivetti 1, Roncade, Italy

²Turaath Tech, Praça Do Bom Sucesso, 131, 4 410, Porto, Portugal

Abstract

The Second World War (1933–1945) was the backdrop for the most prolific looting of cultural goods in recorded history, during which Nazi officers confiscated an estimated one-fifth of all art in Europe. The present study offers the first analysis of the social networks which facilitated the movement of these looted goods during and after the war based on the provenance database Proveana. Managed by the German Lost Art Foundation, Proveana holds records on individuals, events, collections, and organisations, and visualises the immediate relationship networks around each entity. This study has extracted these data, reconstructed all relationships contained in the database, and conducted social network analysis (SNA) on the resulting network. Findings from SNA indicate that the network is moderately efficient, with easy and quick interactions despite its large size. A single component comprises 94% of the entire system, with specific nodes playing crucial roles as bridges between disparate groups. Of these, the Nazi Party itself has the highest centrality according to most measures, reflecting its pivotal role in orchestrating the looting of art. This research also highlights Walter Neuling as the sole bridge linking the main network of Nazi-era looting with later government-led confiscations in the German Democratic Republic in the 1960s (codenamed 'Aktion Licht'). Other insights from this study shed light on the figures and institutions most crucial to the circulation of looted goods during and after the war and suggest new opportunities for research into previously overlooked entities to complement incomplete and unreliable postwar provenance records.

Keywords Second world war, Lost art foundation, German democratic republic, Centrality, Provenance, Walter Neuling

Introduction

In the wake of the Second World War, Allied forces determined (through the American Safehaven Program, Robert Commission, and the Office of Strategic Services' (OSS) Art Looting Unit) that the Nazi Party in Germany had confiscated an estimated one-fifth of all movable art in Europe (primarily constituting paintings, drawings, and sculpture), seizing over 5 million cultural objects from persecuted Jews and other marginalised

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groups across the continent (Bradsher 1997; Edsel and Witter 2009: xiv; Gravenstein 2022: 1; Spiegel 2001: 297–298). Of these objects, some have since been recovered, many were destroyed, and hundreds of thousands are still missing, having fallen victim to trafficking after the war's end. Allied efforts after the war sought the repatriation and restitution of looted goods back to their rightful owners or heirs in accordance with values that were later formalised as the Washington Principles on Nazi-Confiscated Art.¹ Some of these principles include:

- Art that had been confiscated by the Nazis and not subsequently restituted should be identified.
- Relevant records and archives should be open and accessible to researchers, in accordance with the guidelines of the International Council on Archives.
- Resources and personnel should be made available to facilitate the identification of all art that had been confiscated by the Nazis and not subsequently restituted.
- In establishing that a work of art had been confiscated by the Nazis and not subsequently restituted, consideration should be given to unavoidable gaps or ambiguities in the provenance in light of the passage of time and the circumstances of the Holocaust era.
- Every effort should be made to publicize art that is found to have been confiscated by the Nazis and not subsequently restituted in order to locate its pre-War owners or their heirs.
- Efforts should be made to establish a central registry of such information. (Eisenstat 1998)

In pursuit of these principles, the German Lost Art Foundation has established two databases: the Lost Art Database, which holds records of objects that were looted or confiscated during the war, and Provena, a provenance database of individuals and other entities related to the circulation of goods during and after this period. At the time of writing, the Lost Art Database holds over 184,000 object records of missing items ('search requests') and recovered items ('found-object reports'); extensive information is provided on each object, and the database records are made available for download with a CSV-export function. In addition to the object records of the Lost Art Database, Provena also holds an additional 16,000 records of individuals, literature, corporate bodies, events, provenance marks, and other entities related to the provenance of looted objects. Both databases are publicly available and free to use for academic and historical research purposes, in accordance with the Foundation's primary aim of strengthening provenance research (German Lost Art Foundation, n.d. -d).

Research on the circulation of cultural goods during and after World War II is crucially important to reconstruct the social networks that facilitated the looting of these objects (and their trafficking in the postwar period) and to recover items that are still on the market and for which provenance is unclear. Social network analysis (SNA) offers a novel approach for this research and the ultimate recovery of objects implicated in the largest mass looting event in recorded history. Leveraging valuable open resources, particularly Provena, this research can support not only the recovery of these objects, but also the identification of routes and individuals that have aided the trafficking of other items and related criminal activities.

¹ Presented 3 December 1998 by Stuart E. Eisenstat at the Washington Conference on Holocaust Era Assets.

Research aims

Despite a considerable amount of research having been published on the Proveana database,² including provenance research projects conducted by the German Lost Art Foundation itself, no social network analysis has yet been conducted on the relationship network presented in the database. This represents a significant missed opportunity for researchers of WWII-era provenance and cultural goods crime, particularly as “Proveana focuses less on the single artifacts and more on the reconstruction of collections and the circumstances of their displacement and disintegration” (Manikowska 2023: 50). The present study offers the first social network analysis of the relationship network data presented in the Proveana database, illustrating and examining the network surrounding the circulation of objects looted during WWII. It complements the mission of the German Lost Art Foundation, the tenets of the Washington Principles, and the efforts of other actors involved in provenance research and recovery of WWII-looted goods. Finally, it highlights additional opportunities for investigation into actors complicit in cultural goods trafficking during and after the war and reinforces the value of integrating traditional provenance research with new computational methods.

Beyond the relationships’ mapping, the study sees the network as a logistical supply chain: as an individual or organisation acquires goods, typically unaware of the global infrastructure behind them, looted objects are often not understood or appreciated in their full context. SNA reveals the underlying supply chain infrastructure – its efficiencies, redundancies, and bottlenecks – that made the movement of cultural goods possible during and after the Second World War. To support this assertion, we have also conducted a supply chain robustness analysis, the methodology for which is outlined in Sect. “Supply chain robustness analysis”, with the results explored in the second half of our Discussion. The analysis of the network’s fragility helps to locate the positioning of the major network players as well as identify the structural routes that would allow the system to function should key chokepoints be removed.

Methodology for data collection

Data collection for this research was conducted within the scope of RITHMS (Research, Intelligence and Technology for Heritage and Market Security) project, a European Union-funded initiative to develop a platform that leverages social network graphs to help law enforcement agencies track and thwart the trafficking of cultural goods. The initial development phase of the project involved the provisioning of data from existing repositories of stolen, missing, looted, and unprovenanced cultural goods to construct a network-focused model of the circulation of these objects, centring around actors and events. While the Proveana database holds detailed records on over 16,000 entities related to Nazi-looted objects, roughly two-thirds of the record pages also include a relationship network that illustrates that entity’s immediate network of relations. It is this element of the database that was the focus of the present study.

First, it should be noted that entities gathered from Proveana belonged to one of the following eight categories: event, person, group of persons, literature, collection, provenance mark, archival source, and corporate body. For the most part, the scope of each entity category is self-explanatory; ‘event’ refers to an activity, for instance an auction or

² See, for example, Manikowska 2023 and Heuberger 2022; also Barnstorf-Brandes et al. 2024, who report on Proveana’s records of looted objects with colonial-era provenance rather than WWII.

a government campaign; an entity of type ‘person’ represents a real human being; conversely, a ‘group of persons’ represents multiple individuals as a single unit, often referring to an entire family; ‘literature’ concerns a publication (which in most cases is an auction catalogue); a ‘collection’ is a private or public assemblage of art and/or artefacts; a ‘provenance mark’ is a symbol, label, stamp, or other element that conveys information about the object’s production or previous ownership; and ‘archival source’ is a body of archives or other primary historical materials. The only entity category that is somewhat misleading is ‘corporate body,’ which includes companies as well as political parties (e.g., the Nazi Party), government ministries (e.g., the Reich Chamber of Culture), public museums, and so on. For this reason, we have opted to refer instead to this category as ‘organisation,’ which is more in line with typical network analysis practice. This decision represents a minor deviation from the original data source but allows for a more accurate classification of entities. It has not changed the distribution of entities across types and has not impacted the network analysis. Table 1 shows the distribution of entity types in the Proveana database and in the network prepared for the current study. The discrepancies between the two distributions reflect the fact that not all entities with record pages in Proveana are part of a network, and not all entities in the relationship network have record pages.

Data were collected using a web scraping program written using the Python programming language and the packages BeautifulSoup, Requests, Selenium, and Pandas. As the database is frequently updated, it should be noted that the data used in the present research were collected on 4 February 2025. Efforts to reproduce this research at a later date may result in slightly different findings due to the inclusion of new records in the database and the elucidation of new links between entities.

Proveana comprises four distinct research areas: cultural goods confiscated as a result of Nazi persecution, cultural goods and collections from colonial contexts, confiscation of cultural goods in the Soviet Occupation Zone and the German Democratic Republic (GDR), and cultural goods displaced as a result of war; this work has focused primarily on the first category. This includes objects seized or confiscated by Nazi officials as well as objects sold under duress, for example to receive a visa to emigrate from Nazi-occupied territories during the war. However, data have been collected from the entire database, allowing connections to be made among entities related to the looting of cultural goods during World War II and the looting of goods in other contexts. Importantly, as

Table 1 Type and number of entities in the Proveana database and relationship network

Entity type	In Proveana	With relationship network
Person	3676	3948
Group of persons	58	33
Organisation (formerly Corporate Body)	2050	2004
Collection	471	509
Event	1009	1026
Provenance mark	261	0
Literature	8697	0
Archival source	4827	0
Physical object ^a	–	329
<i>Total</i>	28,574	7,849

^aThe category of ‘physical object’ represents artworks and artefacts with reported connections to other entities in Proveana; these objects are recorded in the Lost Art Database, which was not the focus of data collection. They were included in the network analysis because they have reported connections, but their relative centralities are low, and they do not reappear in this article

will be outlined in the Results and Discussion sections below, this methodology returned valuable insights on common actors involved in multiple contexts of state-led confiscations of cultural objects.

Data collection from the Proveana database involved two main steps. The first collected descriptive data on each entity record regardless of whether the record included a relationship network. This was achieved using the BeautifulSoup and Requests packages to iterate through each page of the database, parse the page HTML, and gather the available biographical information. The function `time.sleep()` was implemented after each record to limit the rate of requests sent to the server and not put unnecessary strain on the host. The data were then structured as a Pandas DataFrame to facilitate minimal cleaning, the removal of superfluous characters, and the translation of some data from German to English for later analysis of entity characteristics and provenance.

The second step of data collection used the Requests package to gather data on each relationship network. For this, a request was made to retrieve a structured JSON through a direct link discoverable in each page's source HTML. Each structured dataset includes the relationships of one isolated network. These data were iteratively retrieved and appended to a list, which grew with each record, then saved as a JSON file. The file was then reloaded and structured to extract the source and destination nodes from each relationship, each of which was identified by a label (the entity's name), an ID assigned to it by Proveana, and the category to which that entity belonged (person, organisation, event, etc.). This process produced a social network consisting of 7,849 nodes and 15,377 edges; each node represents a person, organisation, or other kind of actor, and each edge signifies a relationship between two nodes. The dataset was saved in JSON, CSV, and GEXF formats to facilitate analysis of the network that emerged during visualisation.

There are several essential measures of centrality that were assessed using the NetworkX library of Python; these include betweenness, closeness, degree, and eigenvector centrality. The first measure, betweenness centrality (Freeman 1977), assesses the number of 'shortest paths' through the network — in other words, how many paths pass through or rely on each node. In a similar vein, closeness centrality (Freeman 1978) judges the overall number and length of shortest paths from one node to every other, or how close each individual is to others in the network. For the purposes of the present analysis, we calculated a normalised harmonic centrality, which is a variant of closeness centrality appropriate for disconnected networks (Rochat 2009). Degree centrality describes the number of links or relationships each node has, which provides insights on the best-connected or most isolated individuals. In this context, 'degree' conveys the specific number of connections, while a normalised degree centrality score (from 0 to 1) represents the number of connections relative to the other nodes in the system. Finally, eigenvector centrality (Bonacich 1987) takes into consideration the relative influence of these nodes, giving higher scores to individuals who are linked to other influential individuals—building on the intuition of degree by weighting connections according to the prominence of the neighbouring nodes.

These metrics all analyse the position of individual nodes within the network, which allows the pinpointing of those with unusual significance; these may be entities who are inherently influential themselves or those who play important structural roles in the network such as connecting two clusters or hubs (thus serving as 'bridges' or 'cut points').

Distinct from these centrality measures, we also computed the average clustering coefficient (Watts & Strogatz 1998), a network-level property that captures the overall density of local neighbourhoods rather than the importance of individual nodes. For each node, the ego-network density is calculated as the proportion of actual ties among its neighbours relative to the maximum possible ties; the average clustering coefficient is then obtained by summing these values and dividing by the number of nodes with two or more ties. A high coefficient indicates that the neighbours of a given node tend to be connected to one another—a ‘friend of a friend is also a friend’ pattern—while a low coefficient indicates that the node bridges otherwise disconnected parts of the network. As such, the clustering coefficient captures an aspect of the network’s topography rather than node-level influence.

Finally, to characterise the network’s global macro-structure, we employed metrics such as network diameter and average path length. The diameter represents the longest of all shortest paths, indicating the network’s span, while the average path length measures the efficiency of interactions across the system. The largest connected component (LCC) refers to the maximal subgraph in which every pair of nodes is joined by at least one path; in an undirected network such as ours, its size relative to the total number of nodes indicates the extent to which the system forms a single cohesive whole rather than a collection of isolated fragments. For community detection, we utilised the Louvain method (Blondel et al. 2008). We selected Louvain over alternative algorithms (such as Girvan-Newman) for its superior efficiency in optimising modularity within large datasets, allowing us to identify tightly knit communities of nodes that interact more densely with each other than with the rest of the network.

Overall, these analyses allow us to assess the nature of the network’s communication and breadth and highlight individuals and clusters that play a particularly important role in the social structure (Hagberg et al. 2008; Freeman et al. 1991; Leeson et al., 2024).

Supply chain robustness analysis

To empirically test the network’s resilience and validate the ‘supply chain’ metaphor introduced above, we performed a targeted stress-test simulation using Python’s NetworkX library. This analysis involved the iterative removal of the network’s most connected nodes (hubs) to simulate the dismantling of the regime’s central leadership and major institutions. Specifically, we ranked all nodes by degree centrality and removed the top 100 entities sequentially. After each removal, we recalculated the size of the network’s largest connected component. This method allows us to distinguish between a fragile, centralised hierarchy (where the removal of hubs causes immediate collapse) and a robust, decentralised supply chain (where the network remains largely connected through redundant paths).

Background

One of the most influential actors in the investigation of Nazi art looting was the OSS Art Looting Investigation Unit (ALIU), an American intelligence unit that supported the so-called “Monuments Men” division in collecting evidence to support charges against Nazi art looters and recover confiscated artworks. Salter (2015) provides a critical look at the work done by the ALIU in terms of intelligence-gathering on the Nazi officers responsible for the looting of cultural goods during WWII. Although they were initially

classified and not made public for several decades after the war, the most influential reports produced by the ALIU have been relied upon as key resources in postwar restitution litigation and provenance research. The ALIU also produced a list of approximately 1,000 ‘Red Flag Names’ of individuals related to the looting of cultural assets (Central Registry 2025); of these 1,000, however, just 3–5% have records in Proveana,³ which represents an opportunity for future integration of these two large datasets. Further, while Salter recognises the ALIU’s many accomplishments, he argues that international criminal law is fragile and occasionally misses the mark when faced with a range of geopolitical priorities. He stresses that the postwar Nuremberg prosecutions were extremely selective and saw pre-trial diplomatic negotiations, plea bargaining, political interventions, and unofficial immunity deals occur outside the official court proceedings. Another of the ALIU’s oversights was their failure to prepare a detailed intelligence report on the prolific art dealer Hildebrand Gurlitt, among other notable figures, which allowed Gurlitt to escape criminal proceedings for his involvement in forced confiscations during the war. A further weakness was the unit’s inability to overcome the apathetic and unhelpful stances of Italian, French, and Swiss authorities in prosecuting art dealers in their countries, likely due to national embarrassment of claims of collusion with occupational forces.

During the war, four art dealers in particular took on the tasks of purchasing and selling works for the enrichment of the German national collection or the raising of funds to support the war effort. These dealers were Hildebrand Gurlitt, Karl Buchholz, Ferdinand Moeller, and Bernhard Boehmer. Of these, perhaps the most active was Gurlitt, who was also found by the present research to be one of the most central, well-connected, and influential nodes in the network of Nazi looting. Hoffman (2017) details how Gurlitt’s early professional life as an art dealer led to long-term relationships with expressionist artists, the working class, and the avant-garde, which he would leverage throughout his later career. Quarter Jewish, Gurlitt was required to transfer ownership of his gallery to his wife following the enactment of the Nuremberg Race Laws, which limited the economic, social, and political rights of non-Aryan Germans. Despite this, he successfully petitioned the Nazi government for the right to sell confiscated artworks following their removal from German museums. He later joined the other three Nazi art dealers in increasingly acquiring works for German museums (on behalf of the Linz Commission) and was closely involved in cultural propaganda campaigns in France. At the end of the war, Gurlitt avoided punishment by leveraging the fact that he was also considered a persecuted person (due to his Jewish heritage) and was able to retain his own personal collection, which consisted largely of confiscated works.

One of the principal looted collections during the war was that of so-called ‘degenerate art’ (*Entartete Kunst*), which either promoted values that were believed to undermine Nazi ideology or were produced by artists belonging to a persecuted ethnic or religious group. Gravenstein (2022: 12) emphasises how the Nazi looting campaign and accompanying rhetoric “comforted the people, hiding the atrocities of Hitler’s war under a veil of beauty and high culture”. She notes that resistance to Nazi looting further put works of

³It is difficult to determine the exact number of Red Flag Names included in Proveana due to differences in how names are recorded in the two datasets (e.g., the order of first and last names, insertion of middle names or initials, and whether an individual is reported by themselves or as part of a larger group or organisation). According to Zuckerman (2021: 2), only 18 Red Flag Names were included in Proveana as of 20 November 2021; as of our last estimation on 22 April 2024, this number had risen to 34.

art in danger of destruction during the war, resulting in what German art conservationist Hermann Bunjes called “conservation by acquisition” (Edsel and Witter 2009: 335, cited in Gravenstein 2022: 13). This logic endured following the end of the war, in which thousands of ownerless works were officially accessioned by museums across Europe, ostensibly for safekeeping.

A literature review of scholarship that engages with the Proveana database determined that no social network analysis has yet been conducted on the relationship networks presented in the repository. This represents an opportunity for cultural historians, cultural heritage crime researchers, and network analysts to leverage extensive open data resources and the opportunities of novel technologies to address a pressing sociocultural issue. Zuckerman (2021) has visualised the networks around Nazi art looting but using the native graph functions in Wikidata, performing gap analysis using Sparql queries to assess the comprehensiveness of the knowledge graph. She notes that no solution has yet been found for accurately representing multiple versions of provenance texts or coding the data as semantic triples (e.g., Actor, IsRelatedTo, Actor), and she recommends a property such as “retracted” or “proven false” to be added to provenance texts to facilitate more accurate research.

Provenance research is crucial for legitimating claims for restitution or repatriation of looted objects. It is also important to determine the specific individuals from whom objects were seized rather than solely their countries-of-origin. This addresses an ongoing challenge in the restitution of wartime looted goods, which is often state-centric, focusing more on the *repatriation* of looted goods (to their country-of-origin) than their *restitution* (to the rightful owner or heir) (German Lost Art Foundation, n.d. -b; Gravenstein 2022; Köhler 2019; Manikowska 2023). To a certain degree, this results from a lack of information about the original owners and surviving heirs – a challenge that can be mitigated by more extensive and interdisciplinary research on the social circles on which the confiscation and subsequent circulation of cultural goods relied. This represents one opportunity for novel insights which was pursued by the present study.

Another challenge is the fact that *provenance* in museum documentation during WWII and the postwar period “was very often neglected, intentionally generalised, and even forged” (Manikowska 2023: 47). At the Central Collecting Point in Munich, for example, where Allied forces consolidated looted goods for restitution, archival index cards pertaining to works that went through Gurlitt are often incomplete, failing to mention the dealers from whom Gurlitt sourced his pieces. As a result, researchers must rely partly on alternate data sources, such as social networks, to track the likely movement of artworks both during and after the war.

Results

The present study’s reconstruction, visualisation, and analysis of the Proveana network offers insights on where further investigations might be needed and highlights actors who played a larger role than previously thought. Further, these social networks can provide insights on the route taken by looted objects, helpful in the absence of comprehensive provenance. This dataset was modelled in Graphistry to illustrate the network’s structure, which is quite clustered, as shown in Fig. 1. The lack of directedness and weight on the edges indicates a focus on the mere existence of relationships rather than their nature or strength. The overall structure is non-bipartite, with a clear division

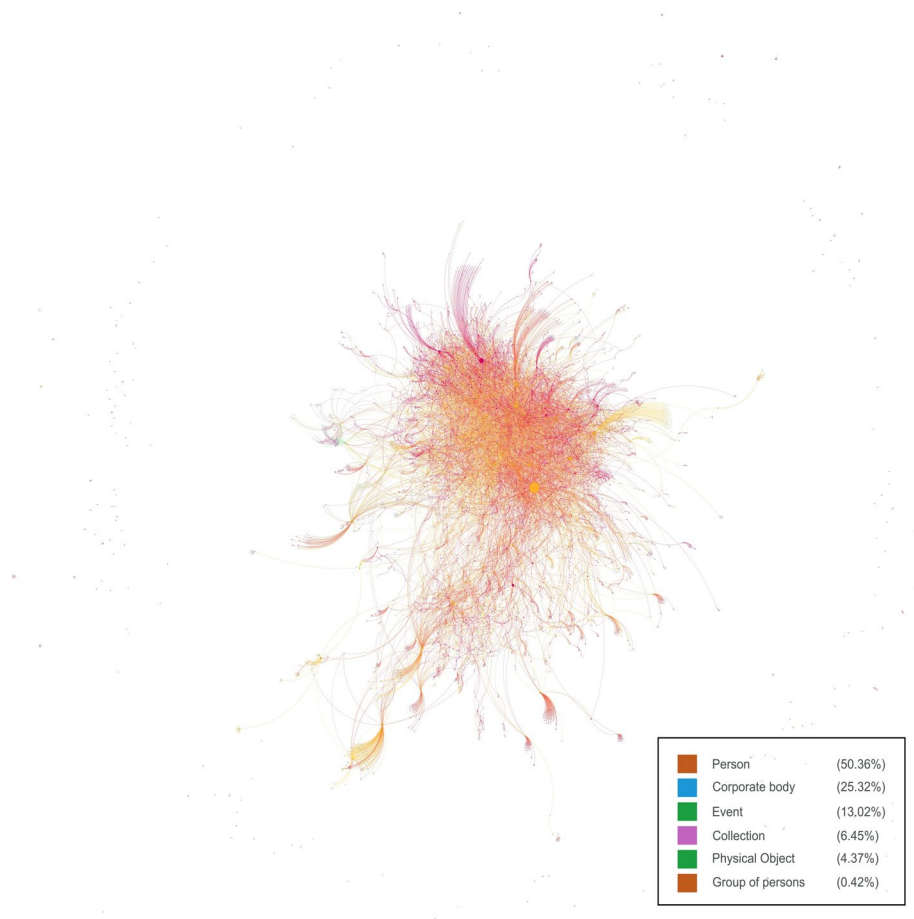


Fig. 1 Network of entities collected from the Proveana database

into a single distinct group representing the largest connected component: 94% of the network.

In this network, each node represents an entity included in the Proveana relationship network for which there is, in most cases, a designated record page with additional information. Each edge linking two nodes represents a relationship or interaction reported in the relationship network and on that entity's record page. The relationships in this network are undirected, which means they illustrate mutual relations. In other words, the visualisation and subsequent analysis of this dataset simply illustrate the existence of interactions between entities rather than the precise nature of these relationships. However, entities in the network are of different types, and the types of entities can shed light on the nature of otherwise uncontextualised relationships; for instance, a connection between an event and a publication could suggest that the publication was produced as a result of the event (e.g., the relationship between an auction and auction catalogue). It is important to note, particularly in the context of organisations, that we intentionally chose a one-mode network representation because our primary focus is on interactions rather than affiliations. This means that an edge linking an individual with the Nazi Party does not necessarily mean that that person had membership in or was affiliated with the Nazi Party, but only that they interacted in some capacity. This is important for appreciating that organisations themselves are greater than the set of individuals comprising them and are capable of exerting influence themselves. In other words, organisations are

not treated as proxies for their leadership just because individual-level data may have been unavailable in certain cases.

Some initial remarks can be made on the social network that are not particularly surprising to scholars familiar with Nazi-looted art and the confiscation of cultural goods during WWII. The central cluster, for example, is concentrated around the Nazi party itself, which was the overarching entity behind most seizures. Many of these confiscations were carried out by various departments of the German government and by individual actors who are well-known in the historical record, including the Linz Special Commission, Nazi leader Hermann Goering, and art dealer Hildebrand Gurlitt. Important museums relied upon for the storage and exhibition of works include the Nationalgalerie Berlin and the Landesmuseum für Kunst und Kulturgeschichte Oldenburg, which remain culturally and politically significant today.

The network analysis presented in this section focused on four measures of centrality: betweenness, closeness, degree, and eigenvector. While each measure offers different advantages for the analysis of the network, there are significant and valuable overlaps in the list of entities regarded as the most central according to each. For the most part, the NSDAP (Nationalsozialistische Deutsche Arbeiterpartei, the Nationalist Socialist German Workers' Party, or Nazi Party) is the most central node by all measures. Other influential nodes include Hildebrand Gurlitt, who acquired thousands of cultural goods during the war, particularly those intended to fill the proposed 'Führer-Museum' in Linz, Austria, and those designated as 'Degenerate Art' (due to his predilection for modern art). Other influential nodes include the Linz Collection itself, the Nationalgalerie Berlin, the State Museum for Art and Cultural History in Oldenburg, and the C. G. Boerner auction house in Leipzig, which specialised in the so-called 'Jewish auctions' and developed the auction regulations of the German Reich.

There is a high number of connected components in the network, referring to distinct and separate groups of connected nodes. There are also many Louvain communities, which refer to tightly knit groups of interconnected nodes (Blondel et al. 2008). Together, these metrics allow for an extended analysis of the connected components' sizes. This analysis revealed that the network's largest connected component comprises 7,376 nodes, which is 94% of the full system. Conversely, the second largest component has just 10 nodes. The giant component, as the most connected part of the network, includes the bulk of the nodes and edges, embodying the primary interaction space in the database (Fig. 2). The metrics indicated in Table 2 provide an overview of this giant component. Overall, a diameter of 19 suggests elongated paths within the network with a high number of nodes. Nonetheless, the average path length of 5.534 indicates relatively short paths between nodes, suggesting easy and quick interactions across the network, fully aligned with the six degrees of separation paradigm – the notion that all people are six or fewer social connections apart. This high efficiency suggests a robust supply chain where goods could be moved, laundered, or hidden quickly through very few intermediaries, making the looting machine resilient to local disruptions.

The connectivity of the network, indicated by a radius of 10, provides a new focal point for analysis. The connectivity of the giant component suggests that it includes major entities and common relationships within provenance research, while smaller components represent isolated and specific cases. The similar average length of the giant component emphasises its centrality to the network's structure, while the high radius of 10

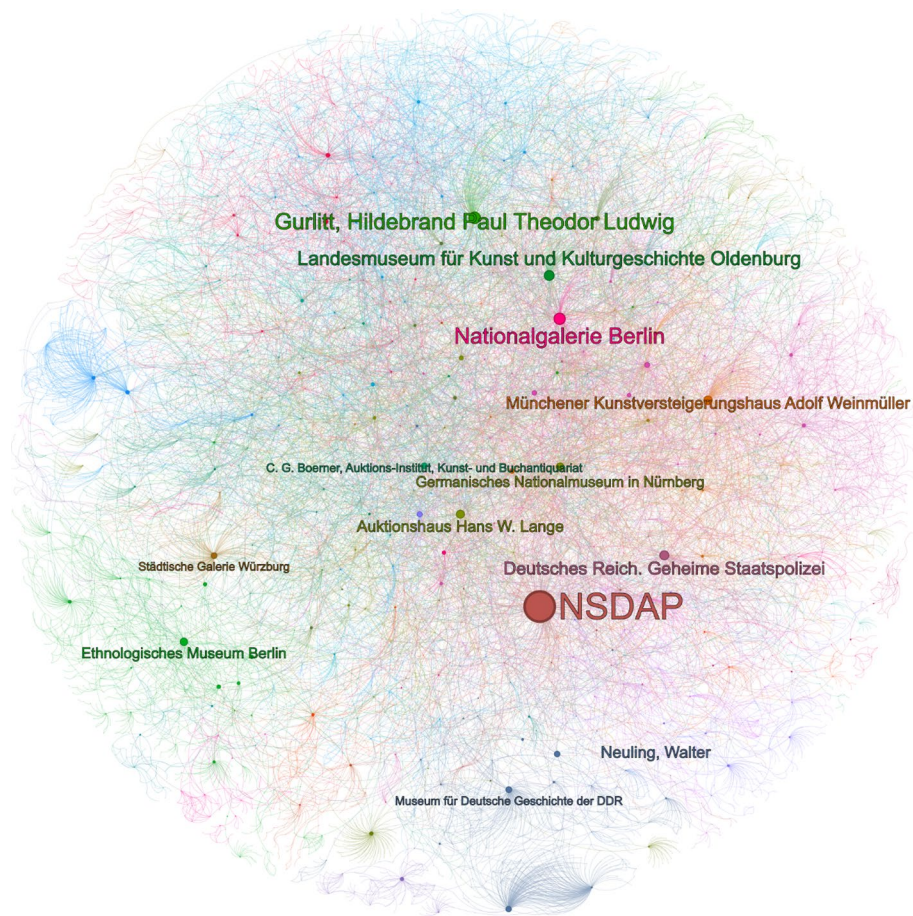


Fig. 2 Giant component, with colour determined by the Louvain Community index of each node

Table 2 Relevant network measures of the entire network and its giant component

Measure	Entire network	Giant component
Nodes	7849	7376
Edges	15,377	15,042
Diameter	–	19
Radius	–	10
Is bipartite	False	False
Is connected	False	True
Connected components	178	1
Louvain communities	220	44
Is directed	False	False
Is weighted	False	False
Average path length	–	5.534
Mean degree	3.918	4.079
Mean betweenness centrality	0.001	0.001
Mean closeness centrality	0.570	0.184
Mean eigenvector centrality	0.004	0.005

highlights the presence of a few nodes far from the central node, indicating outliers or special cases within the giant component, worth specific analysis.

Centrality measures provide a profound understanding of the influence and connectivity of nodes within a network. For the Proveana network’s giant component, these

metrics reveal how entities play different roles based on their structural positions. Betweenness centrality measures the extent to which a node acts as a bridge on the shortest path between other nodes, representing entities that often control the flow of information within the network and act as vital conduits between different clusters. In the giant component of the Proveana network, the mean normalised betweenness centrality is 0.0008, marginally higher than the overall network's 0.0006 (both rounded to three decimal points in Table 2). This suggests that specific nodes within this component play crucial roles in connecting disparate groups or entities.

Among these nodes, the National Socialist German Workers' Party (NSDAP) has the highest betweenness centrality of 0.175, reflecting its significant role during World War II in orchestrating the looting of art (Table 3). The NSDAP's position in the network connects a vast array of transactions, confiscations, and redistributions of art and cultural assets, underscoring its critical role in the network related to Nazi-looted art. Similarly, Hildebrand Paul Theodor Ludwig Gurlitt, with a centrality score of 0.066, is another prominent node, with a betweenness centrality that highlights his central role in art transactions. His involvement bridged various groups, individuals, and institutions, playing a pivotal role in the art transactions and the historical narrative surrounding Nazi-looted art. His direct connections to various individuals and events suggest his active role in organising, curating, or otherwise facilitating influential art auctions (Hoffmann 2017).

The Nationalgalerie Berlin, with a betweenness centrality of 0.065, stands out as one of the leading art museums in Germany. Its position in the network emphasises its significant role in the art scene during the period under study, connecting different epochs, artists, and styles within the broader art historical narrative. The Landesmuseum für Kunst und Kulturgeschichte Oldenburg (State Museum for Art and Cultural History in Oldenburg), with a betweenness centrality of 0.057, also holds a significant place in German history and art trade, reflected in its important connective role within the network. The next most influential node according to betweenness centrality is the 'Geheime Staatspolizei' – the Secret State Police, also known as the Gestapo. The Gestapo's role in art looting was closely tied to its broader function as an instrument of state terror and expropriation (McLaughlin 2022). They were responsible for identifying and seizing artworks from persecuted individuals, particularly Jewish collectors and dealers, often in coordinating with agencies like the Einsatzstab Reichsleiter Rosenberg (ERR, under ideologue Alfred Rosenberg) (Lugoboni 2019). The Gestapo's involvement ensured that confiscated artworks were funnelled into Nazi-controlled markets, sent to institutions favoured by the regime, or hoarded by high-ranking individuals, including Goering as well as Adolf Hitler himself (Lugoboni 2019; Petropoulos 2004). Their prominence in the present network analysis reinforces how state security agencies were not just participants in repressive activities but also logistical hubs in the systematic plunder of cultural goods.

The mean closeness centrality in the giant component is 0.184, which is significantly lower than the overall network's 0.570. This indicates that nodes are, on average, less centrally positioned in terms of distance to all other nodes within the giant component. This pattern suggests a more distributed structure where influential nodes might not be centrally located but still hold significance due to their specific roles or historical links. Nodes with high closeness centrality can spread information efficiently through direct or

Table 3 Top 10 most central nodes in the network according to betweenness centrality

Entity name (English translation)	Entity type	Betweenness centrality
NSDAP	Organisation	0.175
Hildebrand Paul Theodor Ludwig Gurlitt	Person	0.066
Nationalgalerie Berlin (National Gallery, Berlin)	Organisation	0.065
Landesmuseum für Kunst und Kulturgeschichte Oldenburg (State Museum for Art and Cultural History, Oldenburg)	Organisation	0.057
Deutsches Reich. Geheime Staatspolizei (German Empire. Secret State Police)	Organisation	0.052
Münchener Kunstversteigerungshaus Adolf Weinmüller (Adolf Weinmüller Art Auction House, Munich)	Organisation	0.048
Auktionshaus Hans W. Lange, Berlin (Hans W. Lange Auction House, Berlin)	Organisation	0.045
Ethnologisches Museum Berlin (Berlin Ethnological Museum)	Organisation	0.043
Germanisches Nationalmuseum in Nürnberg (Germanic National Museum in Nuremberg)	Organisation	0.040
Museum für Deutsche Geschichte der DDR (Museum of German History of the GDR)	Organisation	0.035

indirect interactions with most other nodes. Unsurprisingly the NSDAP is also the most central node according to this metric (Table 4).

Tied with the second highest score (0.272) are the Landesmuseum in Oldenburg and Hildebrand Gurlitt. This indicates both entities' efficient connectivity within the network and underscore the ability of both to access and influence various network nodes quickly, reinforcing their significant positions in the cultural history and art collection network within Germany. Further, this score suggests that both the museum and Gurlitt not only bridge various groups and entities but also communicate and influence efficiently across the network. The efficiency in connectivity complements their roles as central figures in the system.

The third most influential node in terms of closeness centrality is C. G. Boerner, Auktionen-Institut, Kunst-und Buchantiquariat (C.G. Boerner Auction Institute, Art and Book Antiquarian) (0.270), a famous auction house and antiquarian bookshop which appears to have had efficient access to a network of buyers, sellers, and artworks. Its closeness centrality underscores its influence and operational efficiency in the circulation of artworks and books. It is joined in this list by other auction houses, including the Hans W. Lange Auction House and the Adolf Weinmüller Art Auction House, both in Berlin. Overall, it is logical that they (as well as museums) feature significant closeness centrality scores, considering their businesses rely on the institutions' influential connections and networking potential.

Also appearing in this list (in the eighth position) is Sonderauftrag Linz (the Linz Special Order, or Linz Commission) (0.268) an initiative to establish a renowned national museum in Hitler's hometown of Linz, Austria – a project which demanded extensive looting of Europe's greatest treasures. Its high closeness centrality reflects the central role of the project in the Nazi looting apparatus. Its centrality score is tied with Hans Posse, listed immediately above it; he was appointed as the director of the project and played a critical role in acquiring art for Hitler's planned (but ultimately unrealised) museum. This score underlines the efficient operational capabilities in accessing a wide range of artworks and entities across Europe, essential for the execution of the vast art looting campaign.

Degree centrality refers to the number of direct connections a node has with other nodes and is fundamental for identifying the most connected entities, which often serve as major hubs within the network due to their numerous interactions. The NSDAP not only features the highest centrality scores across every measure discussed so far but also the greatest degree in the network, with 213 immediate connections (Table 5). This emphasises the party's pivotal role as a central orchestrator of art looting during World War II, interacting extensively across the network with various entities involved in transactions of art and cultural assets. In theory, while this suggests that the Nazi campaign of art looting should feature a high degree of centralisation and, perhaps, efficiency, the confiscation of art across Europe was, in practice, characterised by bureaucratic redundancy and polycratic overlap, with a range of actors (including the Linz Special Commission, Goering, Gurlitt, and ERR, among other individuals and sub-agencies and task forces) all tasked with initiating seizures across Nazi-controlled territories (Petropoulos 2004). Despite systematic efforts at inventorying confiscated works (evidenced by no fewer than nine separate numbering systems used during and after the war), such a project took place in a climate of upheaval and uncertainty which led to the designation

Table 4 Top 10 most central nodes in the network according to closeness centrality

Entity name (English translation)	Entity type	Closeness centrality
NSDAP	Organisation	0.285
Landesmuseum für Kunst und Kulturgeschichte Oldenburg (State Museum for Art and Cultural History, Oldenburg)	Organisation	0.272
Hildebrand Paul Theodor Ludwig Gurliitt	Person	0.272
C. G. Boerner, Auktions-Institut, Kunst- und Buchantiquariat (C. G. Boerner Auction Institute, Art and Book Antiquarian)	Organisation	0.270
Auktionshaus Hans W. Lange, Berlin (Hans W. Lange Auction House, Berlin)	Organisation	0.269
Galerie Dr. W. A. Luz	Organisation	0.269
Hans Posse	Person	0.268
Sonderauftrag Linz (Linz Special Order)	Organisation	0.268
Nationalgalerie Berlin (National Gallery, Berlin)	Organisation	0.267
Münchener Kunstversteigerungshaus Adolf Weinmüller (Adolf Weinmüller Art Auction House, Munich)	Organisation	0.266

Table 5 Top 10 most central nodes in the network according to degree

Entity name (English translation)	Entity type	Degree
NSDAP	Organisation	213
Hildebrand Paul Theodor Ludwig Gurlitt	Person	150
Nationalgalerie Berlin (National Gallery, Berlin)	Organisation	137
Münchener Kunstversteigerungshaus Adolf Weinmüller (Adolf Weinmüller Art Auction House, Munich)	Organisation	136
Städtische Galerie Würzburg (Würzburg Municipal Gallery)	Organisation	127
Aktion Licht (Action Light)	Event	119
Deutschland (DDR). Ministerium für Staatssicherheit (Germany (GDR) Ministry of State Security)	Organisation	118
Auktionshaus Hans W. Lange, Berlin: Verschiedener deutscher Kunstbesitz: Gemälde alter und neuerer Meister (zum größten Teil aus Sammlung Budge, Hamburg) (Hans W. Lange Auction House, Berlin: Various German art collections: Paintings by old and new masters (mostly from the Budge Collection, Hamburg))	Event	114
Landesmuseum für Kunst und Kulturgeschichte Oldenburg (State Museum for Art and Cultural History, Oldenburg)	Organisation	109
Museum für Deutsche Geschichte der DDR (Museum of German History of the GDR)	Organisation	102

of over 1,000 repositories for the storage of looted goods just in southern Germany (Gravenstein 2022: 14). It should be noted that this is another factor that greatly hindered postwar efforts to recover and restitute looted artworks, and it continues to complicate provenance research today.

Art dealer Hildebrand Gurlitt displays the next highest degree score, of 150, complementing his significant closeness centrality as well and confirming his central role in art transactions during the Nazi era. This extensive connectivity underscores his ability to bridge various groups and entities efficiently, enhancing his influence across the network. Similarly, the Nationalgalerie Berlin confirms its substantial closeness centrality with a degree of 137, which further solidifies its status as a key institution in the art world. Likewise, the Münchener Kunstversteigerungshaus Adolf Weinmüller has 136 immediate connections, indicating its crucial role in the circulation of cultural goods as a major node for the sale and distribution of a vast number of artworks.

A somewhat surprising node that emerged during analysis of degree scores was Aktion 'Licht', or secret operation 'Light'. This initiative started on January 3, 1962, well after the end of the Nazi period, and was orchestrated by the Ministry for State Security (also known as the Stasi – East German secret police) in East Germany (officially the German Democratic Republic). It involved the extensive and secretive search of over 3,000 buildings across all districts and counties of East Germany, highlighting its significant operational scale and the need for extensive personnel and secrecy (Kersten 2023). The primary goal was to investigate financial institutions and other locations suspected of hiding valuable assets. A degree score of 119 indicates a substantial number of direct connections within Provenance's relationship network, suggesting significant interactions and influence across various nodes related to financial and historical artefact management, also reflecting its extensive involvement in operations that had widespread implications for cultural assets. Its relatively high degree indicates it played a significant role within the network, although its profile in terms of the other centrality measures (discussed below) differs from that of the most influential Nazi-era hubs.

Eigenvector centrality measures the influence of a node within a network, assigning relative scores based on the principle that connections to high-scoring nodes contribute more to the score of the node in question. In this sense it refines the intuition offered by degree: rather than counting connections, it weights them according to the prominence of the neighbouring nodes, highlighting entities that are not only well-connected but also associated with other well-connected nodes. The mean eigenvector centrality in the giant component shows a slight increase (0.005) compared to the overall network (0.004). This suggests that within this component, certain nodes are both well-connected and linked to other influential nodes, fortifying their roles as central figures in the network. The central role of the NSDAP in orchestrating extensive art looting is reinforced by the highest eigenvector centrality, with a score of 0.308 (Table 6): this score underpins its position as a highly influential entity, connected to other significant nodes involved in these operations. In fact, we see many of the same entities in this list as in the previous ones: art dealer Hildebrand Gurlitt, the Linz Commission, Adolf Weinmüller Art Auction House, the State Museum in Oldenburg, National Gallery in Berlin, Hans Posse, and others. This reflects the fact that these individuals and organisations were deeply embedded in both the bureaucratic and logistical machinery of expropriation and circulation during the war, coordinating between agencies, facilitating transactions, and legitimising

Table 6 Top 10 most central nodes in the network according to eigenvector centrality

Entity name (English translation)	Entity type	Eigenvector centrality
NSDAP	Organisation	0.308
Hildebrand Paul Theodor Ludwig Gurliitt	Person	0.234
Sonderauftrag Linz (Linz Special Order)	Organisation	0.186
Münchener Kunstversteigerungshaus AdolfWeinmüller (Adolf Weinmüller Art Auction House, Munich)	Organisation	0.171
Landesmuseum für Kunst und Kulturgeschichte Oldenburg (State Museum for Art and Cultural History, Oldenburg)	Organisation	0.168
Nationalgalerie Berlin (National Gallery, Berlin)	Organisation	0.147
Hans Posse	Person	0.129
Stuttgarter Kunstkabinett (Stuttgart Culture Room)	Organisation	0.129
C. G. Boerner, Auktions-Institut, Kunst- und Buchantiquariat (C. G. Boerner Auction Institute, Art and Book Antiquarian)	Organisation	0.118
Auktionshaus Hans W. Lange, Berlin (Hans W. Lange Auction House, Berlin)	Organisation	0.115

or laundering stolen works within high-profile markets and institutions. The repeated presence of these entities across all four centrality measures indicates that they are not only well-connected but also crucial for the flow of information, resources, and control.

The eigenvector centrality of Aktion Licht, though relatively low (0.006), coupled with its closeness centrality (0.174), positions it as a node that, while not centrally influential like major museums or political entities such as the NSDAP, still played a crucial operational role in the network. Its activities primarily revolved around the physical search and recovery of assets, which, while essential, placed it differently in the network's hierarchy of influence compared to nodes involved in policymaking, direct art transactions, and active looting during the Nazi period. The betweenness centrality of 0.009, albeit not as central as more influential nodes, indicates that this entity acted as an intermediary in some paths within the network: occasionally it bridged communication and operational pathways between different nodes, facilitating specific transactions or information flow that related to the locations and assets it was tasked to investigate. This is crucial for shedding light on the networks which facilitated the circulation of looted goods well after the war and after the initial restitution efforts of the immediate postwar period.

Combining Aktion Licht's centrality measures highlights its unique function within the network. While it has a considerable number of direct interactions (degree) due to its widespread operational mandate across East Germany, its role as a conduit (betweenness) is more focused, indicating its involvement in specific operational channels rather than across the entire network. Its relatively low eigenvector centrality confirms that while it is connected to many nodes, those connections are not necessarily with the most influential nodes within the network. This demonstrates that Aktion Licht typifies a node with a specialised yet crucial function within the Proveana network, characterised by its significant number of interactions, targeted intermediary role, and limited but focused influence on the broader network dynamics. This multifaceted role highlights the complex nature of operations and interactions that define the flow of cultural assets and the enforcement of state policies in postwar contexts.

By examining degree and eigenvector centrality in conjunction with closeness and betweenness, a clear pattern of influence and connectivity emerges that defines these nodes' roles within the Proveana network. Nodes like the NSDAP and Hildebrand Gurlitt emerge as central figures not only because of their many connections but also due to their strategic positions within the network, which allowed them to significantly control and influence the flow of information and assets.

To analyse the effective interrelations between the actors described so far, a subgraph was generated by identifying the shortest paths between each of the nodes described above (see Fig. 3). Within this subgraph, the shortest paths among nodes indicate the most direct and influential relationships. An extended analysis also includes nodes directly connected to the endpoints of each identified path but not listed among the predefined set. This method allowed for the exploration of the influence and connectivity of core nodes while capturing their immediate network context, to understand the interrelations between them and the nearest nodes of the full network.

In the refined subgraph analysis, the NSDAP emerges naturally as the dominant force with unparalleled influence, evidenced by its eigenvector centrality and normalised betweenness centrality, indicating its central role in controlling information and resource flows within the network. Close behind, Hildebrand Gurlitt holds substantial

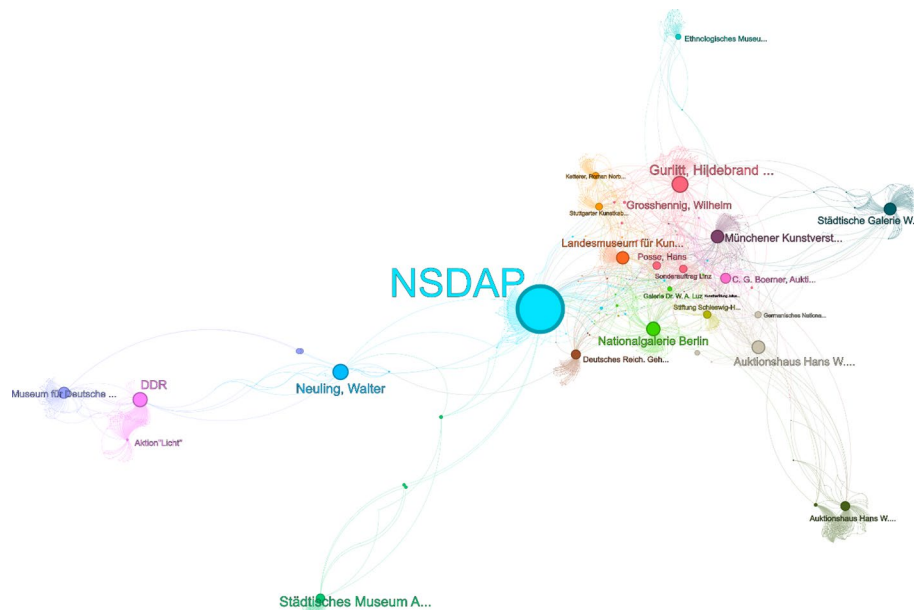


Fig. 3 Subgraph of the most central nodes

sway with significant betweenness and closeness centrality values, pinpointing his crucial intermediary role in art transactions during the Nazi era, his connections ensuring swift communications across the network. The Nationalgalerie Berlin, another node of considerable importance, facilitates connections across various epochs and artistic movements, its strategic position underpinned by a notable betweenness centrality. Similarly, the Münchener Kunstversteigerungshaus Adolf Weinmüller stands out not only for its role in the art market but also for its high betweenness and closeness centrality, suggesting its efficiency in connecting buyers and sellers. The Landesmuseum für Kunst und Kulturgeschichte Oldenburg, with the highest closeness centrality in this analysis, acts as an effective conduit for cultural transmission, echoing its principal role in the network.

Further, the Sonderauftrag Linz and Hans Posse feature substantial centrality metrics, reflecting their operational efficiencies and central positions in the Nazi art looting campaign. In contrast, C. G. Boerner appears as a critical hub for the circulation and auctioning of artworks in general (not necessarily looted), with its centrality scores highlighting its role in the broader network of art and cultural history. Aktion Licht appears as a peripheral node, with minimal centrality values that reflect its specialised and limited role within the network. Its strategic implications are profound, however, hinting at the operation's involvement in a second round of state-driven confiscations and appropriation of cultural assets.

In this framework, among the most interesting nodes appears Walter Neuling; his position within the network, marked by lower but still relatively significant centrality measures (Table 7), reveals an intriguing aspect of his involvement in the state-led confiscation of cultural goods. Despite being a lesser-known figure, his unique role in the network is critical, especially in how he modulates connections with peripheral but strategically important nodes like Aktion Licht. This node, acting as a cut vertex, serves as a critical bridge connecting Aktion Licht with the rest of the network: this disconnection capability suggests that Neuling acts as a gatekeeper for specific operational or historical

Table 7 Centrality scores of Neuling compared with the mean scores of the network’s giant component

Measure	Walter Neuling	Giant component
Betweenness centrality	0.032	0.001
Closeness centrality	0.253	0.184
Eigenvector centrality	0.002	0.005
Degree	24	4.079
Clustering coefficient	0.068	0.382

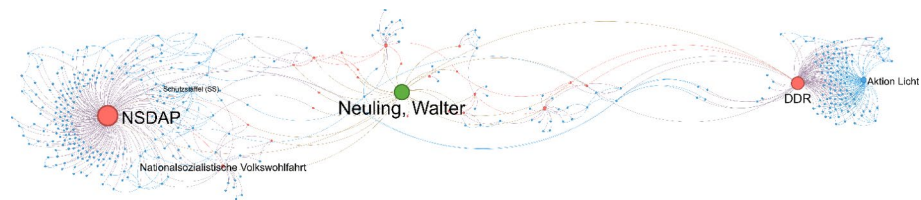


Fig. 4 Neuling’s ego-network with two hops

paths within the network, controlling access to information or resources crucial for understanding the broader dynamics of cultural asset management and state-driven operations (see Fig. 4). In network analysis parlance, this gatekeeping role indicates that Neuling’s connections, while fewer, are highly strategic, serving as critical junctions or choke points in the network. It is important to clarify, however, that this does not suggest that Neuling in reality played an active role in either network, but only that he interacted with both spheres; the precise nature of these interactions is expanded on in the Discussion below.

Neuling’s clustering coefficient (0.068) is markedly lower than the mean value of the giant component (0.382), a finding consistent with his structural role as a bridge between otherwise disconnected regions of the network. Because his neighbours belong to distinct spheres of activity—the NSDAP-centred WWII looting network on one side, and the GDR-era Aktion Licht network on the other—they are, by definition, sparsely interconnected. A low clustering coefficient in conjunction with his position as a cut vertex reinforces the interpretation of Neuling as a rare structural connector whose removal would fragment the historical continuity between the two confiscation periods.

From a network analysis point-of-view, cut-point positions such as Neuling’s can often go unnoticed in traditional centrality analyses but become apparent when examining the flow of interactions and the structural vulnerabilities of the network. In this context, the presence of a single bridging node emphasises the secrecy and obscurity of state-led campaigns for the confiscation of cultural goods, which was paralleled in both circumstances (WWII and Aktion Licht) by the concealment of historical narratives.

Discussion

Neuling, born in Salzwedel, Germany in 1894, led a complex life that brought him in contact with exceptionally influential individuals and organisations. Initially involved in university administration in Berlin, his career took a significant turn when he was sent to Prague during World War II as part of the Friedrich-Wilhelms-Universität Berlin delegation (German Lost Art Foundation, n.d. -c). In Prague, he held administrative roles at the German Institute for Foreign Studies (*Deutsches Auslandswissenschaftliches Institut*), which connected him with influential figures such as Hildebrand Gurlitt, known

for his involvement in art transactions during the Nazi era. Neuling's membership in the NSDAP and various other Nazi-affiliated organisations signify his ties to the political landscape of the time. His administrative experience, appreciation for art, and relationships within the NSDAP later facilitated his involvement in activities related to the Nazi regime's art looting operations, intersecting with entities like the Linz Commission and the Adolf Weinmüller auction house in Munich. During the war, Neuling built a considerable private collection of art, artefacts, books, and other cultural goods that had been looted from both the USSR and Jewish collections in central Europe (German Lost Art Foundation, n.d. -c, -e). Following the war, Neuling's career shifted to museum management, notably as the first director of the Danneil-Museum in Salzwedel, just east of the Berlin Wall separating so-called 'East' and 'West' Germany. His subsequent involvement in smuggling cultural artefacts from East Germany to West Berlin led to his arrest by the Stasi in 1960 and a criminal trial in 1961, which found evidence of his possessing WWII-era looted goods (German Lost Art Foundation, n.d. -c, -e).

While Neuling's biography in Proveana details his involvement with various institutions and organisations, such as the NSDAP and the Danneil-Museum, there is no explicit mention of Aktion Licht – the broader context of state-led confiscations within which his illicitly-acquired collection was itself appropriated (German Lost Art Foundation, n.d. -c). It is worth noting that the operation involved extensive searches across the entire territory of East Germany, including banks, storage depots, and other locations where valuables might be hidden (Kersten 2023).

Throughout his life, Neuling's centrality within the network is reflected in his connections to key nodes such as the NSDAP, Gurlitt, and institutions like the Nationalgalerie Berlin and Landesmuseum für Kunst und Kulturgeschichte Oldenburg. His diverse roles in university administration, museum management, and involvement in political organisations position him as a central figure within the network, influencing the flow of information and assets across various domains within it. His presence as the bridge linking Aktion Licht (with which he also shares the same Louvain community) with the other central nodes in the subgraph indicates that he is an intermediary among different spheres of activity (see Fig. 5). Despite this, his role in the broader context of Nazi art looting was more that of a beneficiary rather than active plunderer, considering that he benefitted from the state confiscation of Jewish- and Soviet-owned cultural goods without participating in the seizure of these items himself. Indeed, he is notably missing from the ALIU's 'Red Flag Names' list of individuals linked to the spoliation of cultural property during the war (Central Registry 2025).

His role within the network makes it all the more interesting that he has emerged as the only bridge between the two periods of confiscations, Nazi-led and GDR-orchestrated. That is to say, it is notable that none of his peers and counterparts who similarly built collections of looted goods during the war are recorded in Proveana as having been targeted by the GDR confiscations or indeed involved in any capacity in Aktion Licht. We see in Neuling a figure with above average centrality metrics and yet someone who operated in relative obscurity, unknown enough to not be mentioned in the ALIU's wide-reaching Red Flag Names List, which included a whopping one thousand individuals directly and indirectly linked to looting activities. It is this unique and remarkable combination of traits (centrality and obscurity) that likely enabled Neuling to retain his

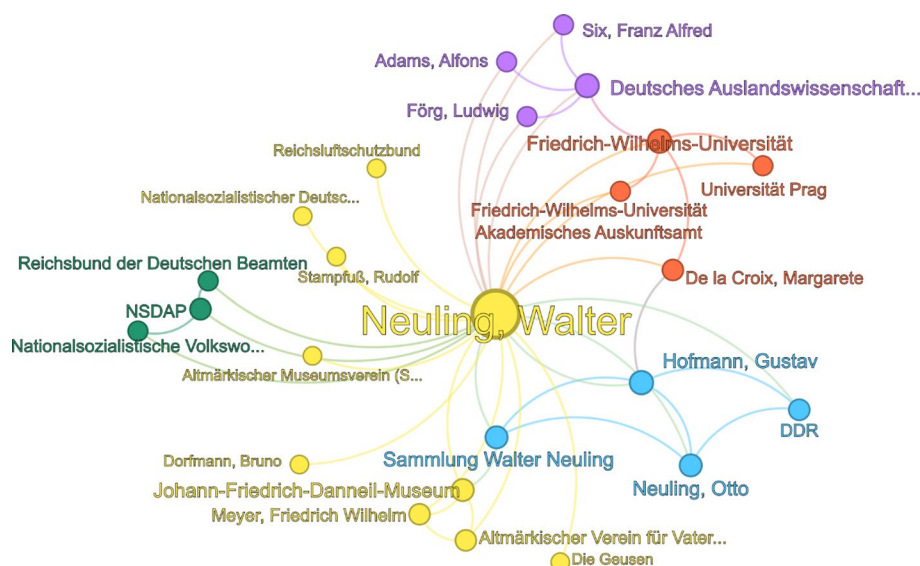


Fig. 5 Neuling's ego-network

collection in the wake of the international campaign to recover and restitute stolen art in the years after the war.

Supporting this theory is a provenance research project conducted by Proveana in collaboration with the Potsdam Museum, where most of his collection is currently held (German Lost Art Foundation, n.d. -a). This project found that, of the thousands of books and artworks with wartime-era or postwar Neuling provenance, almost none were labelled as such. Beginning in 1961, the confiscated collection was distributed across multiple museums and archives, representing a national appropriation of the objects in the absence of information on their original owners. Further, items were later sold or donated to raise funds for the GDR, and undesirable objects (including books and archives) were destroyed. Neuling's coin collection, meanwhile, disappeared; and, to further complicate the mishandling of the items, provenance records from the period feature extensive erasures of details of previous ownership, missing pages, and the removal of entire sections of otherwise intact record books. Thus, Neuling's already obscure role was obscured further, in many cases removing all traces of his involvement in the confiscation or circulation of these items.

The robustness analysis revealed a remarkable structural resilience within the Proveana network. As illustrated in Fig. 6, the network does not suffer a catastrophic collapse even when its primary hubs are targeted.

Even after the removal of the 100 most connected entities – effectively stripping the network of the NSDAP, Hildebrand Gurlitt, major state museums, and key auction houses – the largest connected component of the full network retained 72.5% of its original nodes (dropping from 94.0 to 68.2% of the total graph size). When applying the same stress test to the strictly social graph (filtering for Persons and Organisations only), the network still maintained a connectivity of 65% relative to its initial state.

The gentle slope of the decay curve indicates that the ecosystem was a diffuse, decentralised supply chain rather than a top-down hierarchy hinged on a few leaders. The high interconnectivity among mid-level dealers and opportunistic actors created a redundant infrastructure capable of sustaining the flow of goods even without the

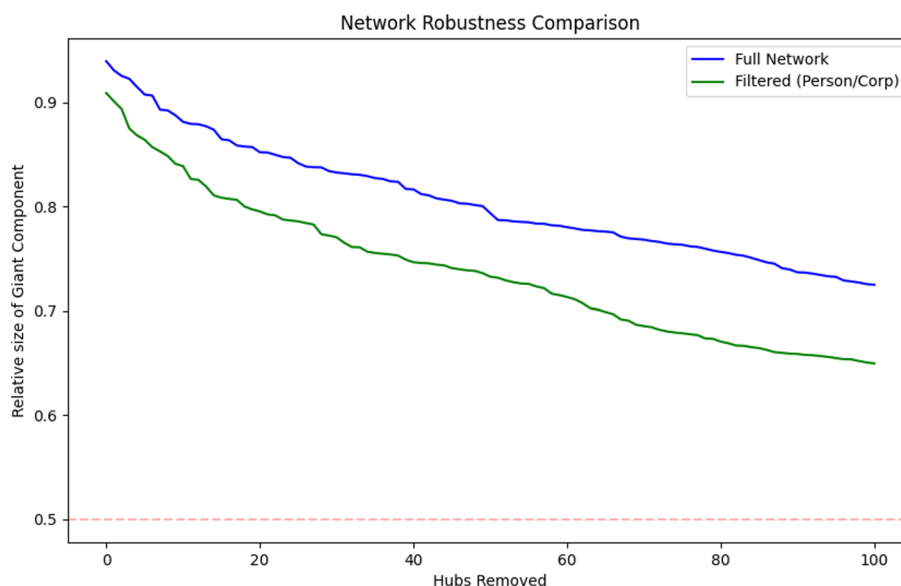


Fig. 6 Network robustness analysis showing the decay of the giant connected component as the top 100 nodes by degree are removed. The blue line represents the full network, while the green line represents the social network (Persons and Organisations only)

primary architects. Notably, Walter Neuling remained connected to the giant component throughout the simulation, empirically validating his role as a resilient structural bridge rather than a dependent satellite.

While the central hubs of the Nazi looting machine were dismantled or identified due to their high visibility, Neuling's position allowed the supply chain to effectively re-route. His relative obscurity protected the flow of assets between two distinct political regimes, demonstrating how portions of the network adapt to post-war disruptions through less visible intermediaries. In such a climate, provenance research that leverages a combination of diverse sources is required to reconstruct the networks which contributed to the original acquisition of Neuling's collection, to identify and compensate the rightful heirs of the confiscated goods while also acquiring a more accurate picture of Neuling's role in both the 1940s and the 1960s.

Limitations

Several caveats should be noted. First, the Proveana database is itself a curated and incomplete resource: the network analysed here reflects the relationships that the German Lost Art Foundation has been able to document, and gaps or asymmetries in record coverage translate into structural features of the graph. Second, edges in Proveana are unweighted and undirected, meaning our analysis captures only the existence of interactions rather than their frequency, duration, or directionality; a dealer who mediated a single transaction is represented identically to one involved in dozens. Third, the one-mode representation of organisations aggregates institutional activity into a single node, which simplifies but also flattens internal hierarchies. Finally, robustness claims rest on the assumption that degree is a reasonable proxy for 'hub-ness'; alternative targeting strategies (e.g., by betweenness) may produce different decay curves. Our findings should therefore be read as a structural reading of an evolving and partial dataset, to be integrated with—not substituted for—traditional provenance research.

Conclusion

This research has offered an unprecedented visualisation and analysis of the social network derived from the Proveana database. The network is dominated by a single cluster, in which a short average path length suggests efficient interactions in line with the six degrees of separation paradigm. Analysis has highlighted the critical place of Walter Neuling, who is relatively unknown to scholarship but plays an important and unique role in the bridging of the WWII network with the separate network of cultural goods confiscation that occurred in later decades. Further, several measures of centrality reinforce the influential roles of known individuals and institutions, specifically Hildebrand Gurlitt, the Nationalgalerie Berlin, and the State Museum for Art and Cultural History in Oldenburg in the confiscation, storage, and circulation of cultural goods. Unsurprisingly, the Nazi Party itself emerges as the most central and influential node by most measures. The present network analysis also highlights powerful nodes in close proximity to the NSDAP, including the auction houses C.G. Boerner and Adolf Weinmüller, which acted as prominent intermediaries in the reselling of confiscated works. In the absence of universally reliable provenance documentation, this network dataset and analysis can fill gaps on the routes through which looted objects travelled, complementing investigations and demonstrating the value of integrating traditional provenance research with novel technologies.

Future research in this domain should focus on the consolidation of other open resources, such as the ALIU's 1,000 Red Flag Names, Wikidata, the resources of the German Digital Library, and other databases of looted goods and wartime provenance. It could also look at the intersections of the Nazi-looting network with the other periods of confiscation addressed by Proveana, particularly during Germany's imperial period and in its colonial territories. This would serve to highlight additional continuities with a broader geographic and temporal scope, potentially identifying other individuals, organisations, and themes that feature prominently in earlier contexts of looting.

Further, dedicated efforts should be taken to identify not only the national origins of looted objects, but the specific former owners from whom works were either confiscated or purchased under duress. This would serve to support the ideological aims of the Washington Principles and undermine the “deeply ingrained and institutionalized historical amnesia”, to quote Manikowska (2023: 60), which is appropriating formerly looted art for the bolstering of contemporary national identity. While historical injustices can never truly be reconciled, the continued consolidation of available resources and the application of new analytical methods on these materials have the potential to achieve increasingly satisfactory results for those who were victim to a range of wartime losses, material and immaterial.

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Author contributions

Conceptualisation, R.G., M.L., S.F., M.D., and A.T.; methodology, R.G. and M.L.; software and data collection, R.G. and M.L.; formal analysis, R.G. and M.L.; writing—original draft preparation, R.G. and M.L.; writing—review and editing, S.F., M.D., and A.T.; visualisation, R.G.; supervision, M.D. and A.T.; project administration, M.D. and A.T.; funding acquisition, A.T. All authors have read and agreed to the published version of the manuscript.

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Data availability

The dataset analysed in this article was derived from the following publicly available resource: "Proveana", [<https://www.proveana.de/en/search>] (<https://www.proveana.de/en/search>). The dataset as extracted is not available because the Italian Institute of Technology does not have the right for data reproduction.

Declarations

Competing interests

The authors declare no competing interests.

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