Postprint: Spatiotemporal Network Structure Analysis of Ming Dynasty Jinshi Cohort from a Digital Humanities Perspective

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Abstract

[Purpose/Significance] Digital technologies are rapidly evolving and flourishing, providing new research perspectives and paradigms for humanities research through digital intelligent tools. [Methodology] By retrieving data on the Ming dynasty Jinshi elite group from the China Biographical Database (CBDB) and employing Social Network Analysis (SNA) and Geographic Information System (GIS) methods, we mapped the spatiotemporal network diagrams of the Jinshi group. [Results/Conclusions] From three dimensions—the spatiotemporal evolution patterns, kinship networks, and social relationship networks of the Ming dynasty imperial examination Jinshi group—we "distantly read" the historical phenomena reflected by this elite group. This assists humanities scholars in efficiently organizing historical factual materials from complex and voluminous information, accurately identifying research topics, and better exploring the overall spatiotemporal distribution patterns and network structures of the Ming dynasty Jinshi group from a bird' s-eye view, thereby demonstrating the hidden potential of digital technology in the field of digital humanities.

Full Text

Preamble

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Analysis of the Spatiotemporal Network Structure of Imperial Examination Jinshi Groups in the Ming Dynasty from the Perspective of Digital Humanities

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Abstract: [Purpose/Significance] Digital technology is undergoing rapid iteration and vigorous development, providing new research perspectives and paradigms for humanities studies through intelligent tools. [Method/Process] By retrieving data on the Ming dynasty Jinshi elite groups from the China Biographical Database (CBDB) and employing Social Network Analysis (SNA) and Geographic Information Systems (GIS) methods, this paper maps the spatiotemporal network of the Jinshi group. [Result/Conclusion] From three dimensions —the spatiotemporal evolution patterns of Ming dynasty imperial examination Jinshi groups, kinship networks, and social relationship networks—this study "distantly reads" the historical phenomena reflected behind the Ming dynasty Jinshi elite group. This assists humanities scholars in efficiently sorting through factual materials from complex information, accurately grasping research questions, and better exploring the overall spatiotemporal distribution patterns and network structures of the Ming dynasty Jinshi group from a bird' s-eye view, thereby demonstrating the hidden potential of digital technology in the field of digital humanities.

Keywords: digital humanities; Ming dynasty imperial examination Jinshi; spatiotemporal network structure

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Under the wave of digitalization, humanities activities are undergoing cross-boundary integration empowered by technology. By leveraging digital technology to cultivate and read humanities knowledge, traditional research paradigms are being transformed and infused with new vitality. Digital humanities evolved from humanities computing. J. Unsworth argued that humanities computing is a representational practice determined by the dual demands of efficient computation and humanistic communication—a form of knowledge modeling, a pathway for knowledge reasoning, and an ontological constraint [1]. Digital humanities broadens the extension and connotation of humanities computing, increasing research depth and breadth from multidimensional and wide-angle perspectives. Its significance lies in using intelligent tools to assist humanities scholars in defining concepts, solving humanistic problems [2], and returning to the essence of humanities. In the era of big data, digital literature is surging, with diverse types of data resources urgently requiring technological assistance to excavate the hidden humanistic connotations behind the data.

Digital humanities research cannot proceed without data support. Major data sources include literature databases, domain-specific biographical indexes, *Chronological Tables of Birth and Death Dates of Qing Dynasty Figures*, official biographies in standard histories, literary works such as funeral orations in collected writings, and official documents. These sources refine character information into databases, constructing relational databases. As of April 2019, the database contains approximately 427,000 biographical entries, including 28,311 Jinshi from the Ming dynasty—encompassing general imperial

examination Jinshi, military Jinshi, and regular-ranked Jinshi. This paper uses this as its data source, relying on Social Network Analysis (SNA) and Geographic Information Systems (GIS) methods, adopting a digital humanities perspective, and following digital humanities research paradigms to explore the network relationships and spatiotemporal evolution patterns of Ming dynasty imperial examination Jinshi groups. Technical tools are employed to visualize the spatiotemporal distribution architecture of this group, enabling "distant reading" of their spatiotemporal network relationships. This provides humanities scholars with a new perspective for fine-grained study of Ming dynasty Jinshi historical materials, rekindling the "warmth" of humanities research and stimulating new vitality in the field.

Data serves as a lens through which humans understand history, memory, and culture. Through "cold" data, human history and culture can be presented "vividly" before our eyes [3].

1 Related Research

The Ming dynasty represents the peak period of China' s imperial examination system, with strict official selection procedures and rigid hierarchical ranks. The imperial examination system delivered a large number of elite talents to the court, giving rise to the saying "Only Jinshi may enter the Hanlin Academy" and "Only Hanlin scholars may enter the Grand Secretariat." As a social elite group, Jinshi were intimately connected with social and historical development. The China Biographical Database Project (CBDB) [4] uses biographical materials from Song, Yuan, and Ming dynasty figures as its primary data source, with official biographies in standard histories, literary works such as funeral orations, and official documents serving as main data sources. This information is refined into a relational database. As of April 2019, the database contains approximately 427,000 biographical entries, including 28,311 Ming dynasty Jinshi—encompassing general imperial examination Jinshi, military Jinshi, and regular-ranked Jinshi. This paper uses this as its data source, employing SNA and GIS methods from a digital humanities perspective to explore the network relationships and spatiotemporal evolution patterns of Ming dynasty imperial examination Jinshi groups.

Digital humanities is an emerging academic field. It is widely acknowledged to have originated from R. Busa's 1949 computer-compiled Latin index for Aquinas' s works [5], marking the first application of information technology to the humanities field. In the early 21st century, the establishment of the Alliance of Digital Humanities Organizations and the publication of related journals pushed digital humanities research to new heights. Today, in the era of big data and artificial intelligence, digital technology is rapidly iterating and flourishing, providing even greater opportunities for humanities research and enabling "distant reading" of phenomena and deconstruction of internal mechanisms from macro perspectives. Since F. Moretti proposed the concept of "distant reading" [6], quantitative research has taken root in the humanities field. For example, M.

Schich et al. collected birthplace and deathplace information for over 150,000 notable figures, using network tools and complexity theory to quantify cultural history research [7], representing a model of diachronic studies. Digital humanities scholar M.L. Jockers, in his work *Macroanalysis*, first analyzed the application of text mining technology in literary studies [8], interpreting humanities phenomena from a macro perspective. Additionally, scholars have used computational technology on large corpora to address issues such as work attribution [9], authorial style, and author sentiment tendencies [10-11]. Others have employed machine learning algorithms to mine entity information from ancient texts [12] and discover hidden new phenomena [13]. These examples demonstrate that computational technology assists humanities research in exploring corpora from a "bird' s-eye view," thereby discovering new questions, expanding research horizons, and transforming traditional paradigms that relied solely on speculative approaches. Such "distant reading" strategies can provide new ideas for humanities research and more intuitively reproduce the full picture of humanities studies.

Surveying current digital tools and methods, SNA and GIS offer possibilities for digital humanities research. SNA has diverse applications in the humanities field. In literary works, humanities scholar F. Moretti used character relationships in *Hamlet* to interpret Shakespeare' s tragic theme of "maintaining monarchical legitimacy"[14]; Zhao Wei used SNA to analyze the character relationship network in the *Da Bo* trilogy [15]; Wei Huiyang et al. analyzed character relationships in *White Deer Plain* [16]. These examples demonstrate that SNA is suitable for 梳理 ing complex character relationships in literary works. In historical research, C. Wetherell first introduced SNA into historiography, exploring how it promotes understanding of historical blood relationships [17]; other scholars have analyzed the overall and individual network characteristics of historical figure groups, attempting to clarify their network relationships. For example, Yan Chengxi et al. explored the overall network distribution characteristics, core figure status and structural topology, and temporal evolution patterns of Song dynasty political networks [18]; J. Novak et al. developed the histoGraph tool to assist historians in discovering and analyzing relationships between people, places, and events [19]. In arts and humanities, L. Weixuan constructed networks of artistic ideas in historical paintings [20], thereby 挖掘 ing their deep connotations.

Although GIS belongs to the field of geography, it has also been applied in historical and literary studies. In the 1990s, A.K. Knowles and I.N. Gregory introduced GIS into historical research [21-22], forming the HGIS concept and outlining a vision for historical studies, transforming research paradigms and providing spatial perspectives. The most typical historical GIS in China is CHGIS, which attempts to establish a continuous database of Chinese historical administrative units from 221 BCE to 1911 CE, providing researchers with a data platform and spatial analysis models. Additionally, some scholars have constructed a series of historical GIS platforms for specific historical events, such as the Silk Road Historical GIS Platform [23], the Chinese Genealogy GIS

Platform [24], and Ancient Books GIS [25]. In terms of research literature, some scholars have demonstrated the relationship between GIS and Chinese historical research [26], and designed a basic, universal historical GIS data model from geographical and historical dual perspectives [27], while others have visualized and interpreted the geographical distribution of poets [28].

In summary, beyond the application of computational algorithms in the humanities, SNA and GIS methods have also gained researchers' favor. However, regarding the specific research question of "Ming dynasty Jinshi groups," applications of these two methods have not yet been seen. Although historical research on Ming dynasty Jinshi groups is numerous, it is primarily qualitative, lacking quantitative analysis. Research paradigms mainly focus on interpretation, summary, and induction, approaching Jinshi group studies from small-scale, narrow perspectives—for example, examining spatial distribution characteristics and influencing factors of a single province or county [29], or analyzing the rise and fall of a particular Jinshi family [30]. These approaches lack comprehensive analysis of the entire Ming dynasty Jinshi group. Regarding the spatiotemporal distribution of Jinshi numbers, existing studies often use tables to depict Jinshi numbers across periods and text to discuss distribution locations [31], lacking visual intuitiveness and hindering problem discovery. For Jinshi network relationships, studies often 阐述 kinship relationships in textual form [32], with minimal discussion of social relationships. Therefore, this paper introduces SNA and GIS into the study of Ming dynasty imperial examination Jinshi groups, exploring the historical phenomena reflected behind this group from temporal, spatial, and network perspectives, providing humanities scholars with an analytical pathway for in-depth interpretation of underlying causes.

2 Research Methods

2.1 Social Network Analysis (SNA)

Social networks are defined as sets of points connected by one or more types of relationships [33], with network structural characteristics measured through centrality, average degree, clustering coefficient, average path length, and network density. SNA primarily 挖掘 s blood, kinship, and social relationships among figures in the humanities field, and studies the social relationship configurations formed by participants interweaving in social scenes [34]. The Jinshi in this paper belong to the Ming dynasty elite group. Using SNA to study the network topology and characteristics of this group can clarify the group' s social relationship attributes from a network perspective, 梳理 multiple network relationships between figures, discover potential phenomena and characteristics from relationships, and provide references for humanities scholars to deeply interpret underlying mechanisms.

2.2 Geographic Information Systems (GIS)

GIS belongs to the field of geographical research and is also a method of great concern under the digital humanities wave. GIS integrates complex spatial techniques into humanities research, more richly interpreting humanistic connotations and expanding research perspectives. Ming dynasty Jinshi groups show significant differences in birthplace, with spatial distribution evolving dynamically over time. Therefore, introducing GIS methods can intuitively present the regional distribution of Jinshi from a spatial perspective, using map narratives to discover how distance factors influence Jinshi distribution, providing humanities scholars with pathways for thinking about phenomena.

3 Analysis of Spatiotemporal Distribution Patterns of Ming Dynasty Imperial Examination Jinshi Groups

3.1 Data Sources and Preprocessing

This paper retrieved Ming dynasty Jinshi information from the CBDB database, screening for general imperial examination Jinshi, military Jinshi, and regular-ranked Jinshi, totaling 28,311 Jinshi entries. After preprocessing, 17,408 Jinshi were obtained (see Table 1). The data were imported into the Chinese Civilization Spatiotemporal Framework - WMTS service framework [35] to extract the Ming dynasty territory map as a base map.

3.2 Temporal Sequence Analysis of Ming Dynasty Imperial Examination Jinshi Groups

The Ming dynasty had 17 emperors. Figure 1 [Figure 1: see original paper] shows that the Yongle-Hongxi and Wanli-Taichang periods are normalized. In August of the 22nd year of Yongle (1424), Emperor Renzong ascended the throne, and the following year (1425) changed the era name to Hongxi. Since Emperor Hongxi reigned for only 10 months, he is grouped with Emperor Yongle. Emperor Taichang reigned for only one month and had no Jinshi during his reign, so he is grouped with the Wanli period. Figure 1 displays four Jinshi peaks (Yongle-Hongxi, Chenghua, Jiajing, and Wanli-Taichang periods) and two troughs (Jianwen and Tianqi periods), with relatively stable numbers between Xuande and Tianshun. Obtaining large amounts of Jinshi data and visually presenting the peaks and troughs of Ming dynasty Jinshi admissions helps target historical materials and explore the phased developmental characteristics of the imperial examination system, considering Jinshi admissions across multiple dimensions and delving into historical records to investigate underlying causes.

3.3 Quantitative Discussion of the Impact of Ming Dynasty' s "North-South Division" System

In the 30th year of Hongwu (1397), the "North-South List" incident occurred, where southern Jinshi held absolute advantage, causing dissatisfaction among

northerners. This gradually led to the establishment of the division system. This paper quantifies Ming dynasty Jinshi data to reveal the system' s impact on north-south Jinshi admission quotas. Figures 2 [Figure 2: see original paper], 3, and 4 respectively show the temporal sequences of Jinshi numbers by province in the southern, northern, and central rolls. Overall, the division system did not significantly affect southern Jinshi numbers, which remained approximately double those of the north. However, Figures 3 [Figure 3: see original paper] and 4 show that in the early implementation period (Yongle-Hongxi), southern roll Jinshi numbers were about seven times those of the northern roll, indicating that the south still dominated initially. From the Xuande period onward, the southern roll remained about double the northern roll, maintaining this ratio. The reasons relate to population mobility, imperial examination policies, and other factors. In essence, the division system indeed provided northerners with opportunities to climb the social ladder, with their Jinshi numbers fluctuating and increasing, while the amplitude of change aligned with southern Jinshi evolution trends. The central roll shows Sichuan maintaining a leading position from the Yongle period, but even its peak in Jiajing reached only 250 Jinshi, while other provinces had fewer than 50 due to sparse populations and slow economic development.

3.4 Thematic River Chart of Provincial Jinshi Quantity Evolution

Figure 5 [Figure 5: see original paper] clearly distinguishes the number of Jinshi in each province during specific periods and the evolution of provincial Jinshi throughout the Ming dynasty. The evolution trend of provincial Jinshi numbers in Figure 5 almost matches the overall Jinshi quantity changes in Figure 1, showing four peaks and two troughs. Among these, Jiangxi had the largest proportion during the Yongle period. The Jiajing period saw the highest number of Jinshi across provinces. Historical research on differential factors influencing Jinshi periods is rare, and detailed reasons require further examination of historical materials. Overall, Nanjing, Zhejiang, Jiangxi, and Fujian have the widest river coverage, ranking top in Jinshi numbers, corresponding with the provincial total Jinshi bar chart in Figure 6 [Figure 6: see original paper]. The thematic river chart can intuitively highlight surface problems, helping humanities scholars deepen research from phenomenon to essence and from surface to depth, saving time and energy to more efficiently 挖掘 underlying historical connotations.

3.5 Spatial Distribution of Jinshi by Province, Prefecture, and County

Space is an indispensable factor in the evolution of historical events. The mapping of historical events onto spatial maps carries historical memory, and seeking potential historical phenomena from a spatial perspective can 催生 new research paradigms. Based on Figure 6, Jinshi group regional distribution can be divided into three gradients: Nanjing, Zhejiang, Jiangxi, and Fujian in the first gradient; Shandong, the capital region, Shanxi, Henan, Huguang, Sichuan, Shanxi,

and Guangdong in the second gradient; and Guangxi, Guizhou, and Yunnan in the third gradient, with decreasing Jinshi numbers. Research on regional distribution differentiation is rich, with historical scholars in nearly every province having provided detailed explanations [36-37].

Using GIS technology to visualize Jinshi distribution presents the distribution across Ming dynasty provinces, prefectures, and counties in finer granularity. Figure 7 [Figure 7: see original paper] shows extreme imbalance in provincial Jinshi distribution, with more in southeastern coastal regions and very few in southwestern and northwestern areas. This allows 论证 of the necessary and contingent factors behind Jinshi clusters and the influencing factors of spatial distribution differentiation. These factors can be explored by obtaining historical data and using GIS layer overlay functions to 重现 elements affecting Jinshi group distribution on maps, such as population distribution and Jinshi quotas, thereby discovering hidden patterns and providing new growth points for historical research.

Focusing on Nanjing, Zhejiang, Jiangxi, and Fujian as examples, the spatial distribution within prefectures is presented in finer granularity. Figures 8 [Figure 8: see original paper], 9, 10, and 11 clearly show that Jinshi are concentrated in specific prefectures: in Zhejiang, the northeastern coastal prefectures of Jiaxing, Huzhou, Hangzhou, Shaoxing, Ningbo, and Taizhou; in southern Nanjing, the prefectures of Suzhou, Songjiang, Changzhou, Zhenjiang, Yingtian, and Huizhou; in central and northern Jiangxi, the prefectures of Ji' an, Linjiang, Fuzhou, and Nanchang; and in eastern Fujian, the prefectures of Fuzhou, Xinghua, Quanzhou, and Zhangzhou. These match exactly with the regions of flourishing imperial examinations summarized by Ho Ping-ti from historical materials [38]. From a shallow spatial distribution perspective, areas with many Jinshi are mainly concentrated in coastal provinces and prefectures, suggesting that economic factors profoundly influenced Jinshi numbers. From a deeper analysis, Jinshi distribution within these provinces is extremely unbalanced, with more Jinshi in southern Nanjing and northern Zhejiang border areas, and the distance between prefectures with high Jinshi numbers within each province is relatively close, indicating that spatial distance factors significantly affected Jinshi admission rates. Figure 10 [Figure 10: see original paper] shows that Jiangxi, as an inland region, ranked top in Jinshi numbers, with specific reasons awaiting further investigation. Graphics can intuitively reproduce the spatial distribution patterns of Jinshi across Ming dynasty provinces and prefectures, breaking through traditional humanities research paradigms and bringing convenience to humanities studies.

Regarding spatial factors, we can reflect on whether Ming dynasty road transportation factors affected Jinshi mobility. Zipf' s "principle of least effort" can also be clearly mapped in Jinshi distribution patterns. The "proximity principle" may have influenced cultural dissemination and exchange, thereby transforming the knowledge structure of personnel within fixed domains. Under cultural influence, this might even have promoted upward mobility for commoner classes

and changed their destinies—this is the potential of digital humanities.

To further examine Jinshi distribution from the county perspective, Table 2 lists counties with more than 100 Jinshi in the Ming dynasty. The table shows that Ming dynasty Jinshi were mainly concentrated in Fujian, Zhejiang, Jiangxi, and Nanjing provinces, with Xiangfu County in Henan Province having 102 Jinshi and Nanhai in Guangdong having 103. These results can drive historical scholars to multi-dimensionally 论证 reasons for county-level Jinshi clusters. Figure 12 [Figure 12: see original paper] shows that counties with higher Jinshi numbers generally exhibit "clustering" distribution characteristics, with obvious spatial agglomeration effects. Within provinces, Jinshi cluster locations are relatively close in spatial distance, enabling quantitative analysis of spatial distance and rigorous examination.

4 Network Relationship Structure of Ming Dynasty Imperial Examination Jinshi Groups

4.1 Kinship Relations

In ancient society, people typically lived in communities based on blood, geographical, and religious ties. Friedman argued that genealogical and kinship issues closely related to Chinese life must be considered when studying Chinese culture and society [39]. The kinship networks of Ming dynasty Jinshi elite groups deserve in-depth exploration. Guo Peigui defined Jinshi families as those with two or more Jinshi within five generations of direct relatives, and discussed the political and social impact of Ming dynasty Jinshi families [40]. Humanities scholars have conducted related research from qualitative perspectives on Jinshi family profiles, reasons for prosperity, and political influence [41]. This paper quantitatively explores the impact of direct ancestors on Jinshi admission rates and presents the network topology of China' s number one imperial examination family—the Changzhou Zhuang family—more intuitively demonstrating the topological structure of Jinshi family groups and providing methodological references for humanities researchers.

4.1.1 Impact of Direct Ancestors' Official Positions on Ming Dynasty Jinshi Admission Figure 13 [Figure 13: see original paper] shows that the proportion of Jinshi with no official positions among direct ancestors accounts for 45.74%, while those with official positions account for 54.28%. Overall, each occupies about half, indicating that nearly half of Jinshi came from non-bureaucratic strata, providing opportunities for humble individuals to climb the academic ladder and playing a role in Ming dynasty social mobility and structural change. Direct ancestors with official positions may have influenced Jinshi advancement through social relationships and family cultural 熏陶.

Figure 14 [Figure 14: see original paper] shows that the proportion of Jinshi with official positions among direct ancestors was not large in early Ming but surged from the Yongle period, reaching its highest proportion of about 65% during

the Zhengde and Jiajing periods. Comparing this with Figure 1, which shows the highest Jinshi numbers in Jiajing (4,287), we can speculate that there may be some connection between high Jinshi numbers and official positions among direct ancestors, further verifying that beyond policy, culture, geography, and population factors, direct ancestors' official positions influenced Jinshi admission proportions.

4.1.2 Presentation of Genealogical Relationships in "China's Number One Imperial Examination Family: Changzhou Zhuang" Family trees are the most intuitive presentation method. When dealing with large data volumes, drawing family trees facilitates 梳理 ing family relationships, intuitively presenting blood kinship, improving research efficiency, and enabling examination of family rise and fall histories in combination with genealogies and biographies. Such applications are rare in humanities, which often rely on qualitative enumeration. Here, using only Ming dynasty Zhuang family data from CBDB as an example, a tree diagram is presented (see Figure 15 [Figure 15: see original paper]). During the Ming and Qing dynasties, "Changzhou Zhuang" —China's number one imperial examination family—flourished with 79 successful candidates and 35 Jinshi. Taking as a starting point the eighth-generation brothers Zhuang Qiyuan and Zhuang Tingchen who both passed the Jinshi examination, this tree diagram is briefly drawn from database queries for reference. It can also be combined with the Zhuang family genealogy to expand data sources, collect partial character relationships, and display them in 图谱 form. Integrating marriage relationships and consulting the Zhuang family genealogy can fully present the family genealogical relationships. Using digital tools to represent genealogical relationships is more convenient and intuitive than traditional methods, with relationships immediately clear.

4.2 Social Relationships—A Case Study of the Social Relations of the "Donglin Jinshi Eight Gentlemen"

According to the *Chinese Historical Dictionary* entry on "Donglin Academy": Donglin scholars discussed court politics, evaluated figures, participated in politics, and opposed empty talk. Court officials echoed them from afar, known as the Donglin Eight Gentlemen [42]. These eight figures—Gu Xiancheng, Gu Yuncheng, Gao Panlong, An Xifan, Liu Yuanzhen, Qian Yiben, Xue Fujiao, and Ye Maocai—were all Ming dynasty Jinshi. This section takes the "Donglin Eight Gentlemen" as a core case study to deconstruct their social relationship network topology. CBDB includes social relationship types such as friendship, academic, political, and 著述 relationships.

By retrieving the "Donglin Eight Gentlemen" from CBDB using ID numbers with a distance setting of 2, 635 figures and 2,170 relationships were retrieved to construct a social network knowledge 图谱 for the "Donglin Eight Gentlemen."

To better understand the overall network structural characteristics of the Ming dynasty "Donglin Eight Gentlemen" social relationship network from a holistic

level, network analysis indicators were introduced for comprehensive structural analysis. Calculations yielded an average degree of 5.153, average clustering coefficient of 0.277, average path length of 3.392, density of 0.008, and network diameter of 5. The relatively large average clustering coefficient and small average path length—meaning connectivity can be achieved through 3-4 people on average—demonstrate significant small-world effects [43].

In a double logarithmic coordinate axis, a scatter plot was drawn (Figure 16 [Figure 16: see original paper]), yielding a fitted line y = 0.3203x - 1.409 with R^2 = 0.8521. The closer R^2 is to 1, the more obvious the linear trend. The degree distribution diagram in Figure 16 shows that the network conforms to power-law distribution characteristics, making it a scale-free network [44]. This means the connection status (degree) among nodes is severely unevenly distributed, with a few Hub nodes having numerous connections while most nodes have few connections. A small number of Hub nodes dominate scale-free network operations, showing long-tail characteristics. The Ming dynasty "Donglin Eight Gentlemen" social relationship network shares structural similarities with contemporary social media networks, highlighting the potential of SNA methods from a digital humanities perspective.

4.2.1 Analysis of Core Figures in the "Donglin Eight Gentlemen" Social Relationship Network Degree centrality refers to the number of nodes adjacent to a given node and is one indicator for measuring network node core status. In human interactions, points with higher degrees are "cores" to some extent, possessing strong control in communication activities. Figure 17 [Figure 17: see original paper] shows the late Ming "Donglin Eight Gentlemen" social relationship network, with figures sorted by centrality from large to small and distinguished by font size. Table 3 lists the top 30 figures according to node degree in the network structure. Figures with centrality above 30 include Qian Qianyi, Yao Ximeng, Luo Qinshun, Li Weizhen, Wang Shizhen, Zou Yuanbiao, Xu Xuemo, Gu Qiyuan, Wang Shouren, Lu Shusheng, Gu Xiancheng, Chen Yidian, Xu Jie, Mao Xian, Ye Xianggao, Xue Chu, and Feng Congwu. First, these are all elite Jinshi figures who were famous at the time. Represented by Qian Qianyi, Zou Yuanbiao, Gu Xiancheng, Ye Xianggao, and Gao Panlong, the Donglin school promoted historiographical trends through Confucian classics and historical 著述. Second, Grand Secretariat members such as Yao Ximeng, Lu Shusheng, Xu Jie, and Ye Xianggao criticized current affairs and offered suggestions, stabilizing the political situation. Additionally, the network includes literary leaders and thinkers such as the "Guanzhong School" represented by Xue Chu and Feng Congwu, Wang Shouren' s "Yangming School of Mind," and Luo Qinshun' s "School of Qi," which promoted the evolution of Ming dynasty philosophical thought. These core figures, to some extent, interpret the immense social influence of the "Donglin Eight Gentlemen" at the time, encompassing numerous celebrities.

4.2.2 Analysis of Small Group Phenomena in the "Donglin Eight Gentlemen" Social Relationship Network The modularity algorithm proposed by M.E.J. Newman et al. [45] was used to measure network community clustering degree and evaluate clustering effectiveness. Modularity values range from [-1, 1], with values closer to 1 indicating stronger network community structure intensity. Generally, modularity values >0.3 indicate obvious community structure, while this network' s modularity value is 0.541, indicating strong community structure and intensity. Figure 18 [Figure 18: see original paper] and Table 4 show nine communities centered on Luo Qinshun, Yao Ximeng, Li Weizhen, Qian Qianyi, Wang Shizhen, Lu Shusheng, Xu Xuemo, Zou Yuanbiao, and Xue Chu, with node size representing degree value and lines indicating relationships. According to Table 5 , which lists the number of people in each of the nine communities, the differences are not significant except for the first category having more members.

The most influential group is the first community represented by Luo Qinshun, Wang Shouren, and Mao Xian, with 19 nodes having degree values above 10 and the largest total number. This group is mainly composed of thinkers and philosophers, led by Wang Shouren and Zhan Ruoshui, known as the "Wang-Zhan School," whose disciples spread across the country. Luo Qinshun developed Cheng-Zhu Neo-Confucianism and created the "School of Qi."Although Yan Song is listed as a treacherous minister, before gaining high power he widely associated with Wang Yangming and other celebrities, was erudite, and achieved profound literary accomplishments. This community has the greatest influence, revealing to some extent the broad transmission and inheritance of Cheng-Zhu Neo-Confucianism and Yangming School of Mind within the Ming dynasty "Donglin School" social circle.

The second community, led by Yao Ximeng, Gu Xiancheng, Gao Panlong, and Zhao Nanxing, ranks second in size with relatively high core figure degree values. As leaders of the Donglin school with numerous followers, this demonstrates the school' s high prestige in Ming dynasty society. This category also includes many renowned Donglin figures such as Tang Xianzu, Yang Lian, An Xifan, Ye Maocai, Li Sancai, Gu Yuncheng, Yu Kongjian, Qian Yiben, Xue Fujiao, Yang Tingyun, and Liu Yuanzhen. Moreover, the "Donglin Eight Gentlemen" cluster here, validating the accuracy of the modularity algorithm. Figure 18 also shows that some figures from the second category blend into the community centered on Zou Yuanbiao, so the eighth category could be merged with the second.

The third and fifth communities show 融合 characteristics of literary figures and politicians. Late Ming literary leader Li Weizhen, epigraphist and calligrapher Gu Qiyuan, the "Later Seven Masters" literary school represented by Wang Shizhen and Li Panlong, painter Chen Jiru, and Grand Secretariat leaders Ye Xianggao, Li Chunfang, Wang Xijue, Shen Yiguan, and Wang Jiaping are included.

The fourth community led by Qian Qianyi and the seventh led by Xu Xuemo show similar distribution characteristics: core figures have the highest degree

values, but associated figures have lower influence.

The "Guanzhong School" led by Xue Chu and Feng Congwu is aggregated into one category. Feng Congwu was a synthesizer who integrated Cheng-Zhu Neo-Confucianism and Lu-Wang School of Mind, and as a leader of the Donglin school in northwest China, he was close to Zou Yuanbiao. Additionally, within small groups, there exist phenomena of multi-dimensional social relationship interweaving. Historical figures were not isolated individuals; their relationship ties served as significant channels for transmitting information and knowledge. The social network of "Donglin Eight Gentlemen" includes figures with multi-dimensional attributes, with various social relationships interweaving and 融合—such as 著述 relationships, political relationships, and friendships—implying complex and variable social relationships among Donglin figures that played 不可忽视 roles in spreading Donglin school thought and culture.

4.2.3 Spatial Distribution Patterns of "Donglin Eight Gentlemen" Social Relations Figures Drawing the spatial distribution map of figures in the "Donglin Eight Gentlemen" social relationship network (Figure 19 [Figure 19: see original paper]) shows that figures are mainly distributed in three regions: southern Nanjing, northern Zhejiang, and central Jiangxi, with the capital region (Beizhili) as the core spreading to surrounding areas, and the Guanzhong region in Shaanxi. Spatial distribution characteristics map the spatial dimensions of Donglin school thought dissemination. The Donglin Academy was located in Wuxi, Nanjing, with many leaders such as Gu Xiancheng and Gao Panlong being Wuxi natives. Using this as an axis, the surrounding areas reflect the spatial distribution patterns. Comparing this with the Jinshi spatial distribution map (Figure 7) reveals that Jinshi cluster locations are also gathering places for "Donglin Eight Gentlemen" social relations figures, 侧面验证 ing the immense social influence of Donglin figures.

Overall, the "Donglin Eight Gentlemen" social network exhibits small-world effects and scale-free distribution characteristics, similar to modern social media network structures. From three dimensions—core figures, small group phenomena, and spatial distribution patterns—the network's characteristics and implied historical phenomena are clarified. The social relations figures encompass many renowned individuals, including multiple Grand Secretariat leaders and famous thinkers, whose significant roles in the network profoundly influenced the development trends of the Donglin school and its thought, highlighting the potential value of social network analysis.

5 Conclusions and Prospects

In the big data era, digital humanities has expanded its living space, and intelligent tools can break barriers between technology and humanities. Traditional humanities research paradigms often involve manually organizing humanities data, 梳理 ing, interpreting, summarizing, and concluding research questions, and carefully reading historical materials combined with independent thinking

to explore existing historical issues—relatively inefficient. Digital technology enables "bird' s-eye view" approaches to propose new research questions, driving humanities research from surface textual phenomena to underlying essential connotations, being "problem-oriented"and "humanities-based"[46], 开拓创新 ing and 构思 ing new research propositions to more efficiently 挖掘 internal mechanisms from vast historical materials and expand research 思路.

This paper takes the Ming dynasty Jinshi elite group as its research object, introducing SNA and GIS methods from a digital humanities perspective to explore historical phenomena and essences reflected behind the Jinshi group from three dimensions: spatiotemporal distribution patterns, kinship relations, and social network relationships:

(1) In studying Jinshi group spatiotemporal distribution patterns, visual graphics represent Ming dynasty Jinshi spatiotemporal distribution. The temporal sequence distribution line chart reveals four peaks and two troughs in Ming dynasty Jinshi numbers, with the highest number in the Jiajing period. This helps historians quickly 梳理 historical data and provides new 思路 for multi-dimensionally considering temporal change reasons. Additionally, from a quantitative perspective, the "north-south division" system' s impact on north-south Jinshi spatiotemporal changes was explored, finding that while the system indeed provided opportunities for northerners, southern Jinshi maintained overwhelming advantages. The thematic river chart depicts provincial-period distribution characteristics, intuitively showing Jiangxi' s largest proportion during Yongle and Jiajing as the period with most provincial Jinshi, thereby enabling more efficient proposition formulation for humanities scholars. The Ming dynasty Jinshi group spatial distribution map clearly shows regional differences, presenting distribution patterns from coarse to fine granularity, revealing large variations in Jinshi numbers across provinces and prefectures and obvious spatial agglomeration effects within the same province/prefecture. This raises the question of whether Jinshi spatial distribution was influenced by spatial distance factors, enabling quantitative analysis of distance elements and deep exploration of their impact degree, while the "principle of least effort" can also reflect reasons for Jinshi distribution clustering.

(2) In kinship research, from a quantitative perspective, the impact of direct ancestors on Jinshi admission rates was explored, finding that about 45% had no official ancestors, suggesting significant opportunities for commoner children to become Jinshi. Additionally, this paper only uses the "Changzhou Zhuang" family tree as an example to 绘制 kinship relationships. Although data is limited, it provides a technical perspective research paradigm for historical studies. Scholars can collect relevant historical data and genealogies to construct similar kinship networks from macro or diachronic perspectives.

(3) In social relationship network research, taking the "Donglin Jinshi Eight

Gentlemen" as an example, the network structural attributes, core figures, small group phenomena, and spatial distribution characteristics were explored, finding that the network exhibits small-world effects and scale-free distribution characteristics similar to modern social media networks. The gathering places of "Donglin Eight Gentlemen" social relations figures are also Jinshi cluster locations, reflecting their immense social influence at the time. This study provides a 思考方式 for comprehensively interpreting the "Donglin Eight Gentlemen" group, enabling historical scholars to use Ming dynasty Jinshi data to construct similar network structures from diachronic perspectives, such as building period-based social network diagrams to parse social network relationships of Jinshi groups in each period and discover hidden patterns.

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Analysis of the Spatiotemporal Network Structure of Imperial Examination Jinshi Groups in the Ming Dynasty from the Perspective of Digital Humanities

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Abstract: [Purpose/Significance] Digital technology is renewed and iteratively developed. Digital intelligent tools provide new research perspectives and paradigms for humanities research. [Method/Process] By searching data of the elite group of Jinshi in the Ming Dynasty in CBDB, using SNA and GIS methods, this paper draws the space-time network diagram of the Jinshi group. [Result/Conclusion] From three levels of the evolution law of time and space, the kinship network and the social relationship network, "distant reading" the historical phenomenon refracted behind the elite group of Jinshi in the Ming Dynasty, helping humanists to efficiently sort out historical facts from complicated information, accurately grasp research propositions, and better discuss the overall spatiotemporal distribution law and network structure of the Jinshi group in the Ming Dynasty from a bird' s-eye view, highlighting the huge potential of digital technology in the field of digital humanities.

Keywords: digital humanities; imperial Jinshi of Ming Dynasty; spatiotemporal network structure

Note: Figure translations are in progress. See original paper for figures.