The Network of Western Classical Music Composers

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Abstract. Network science focuses on the connections between the elements of a complex system in order to uncover the nature and the underlying patterns of interaction relationships inside the system. In this paper we apply network theory to understand associations between the composers of western classical music constructed from a comprehensive data of CD recordings. We study the properties of the network of composer-composer ties including the degree distribution, the component structure, clustering, and several types of centralities of the composers. We also investigate the nature of prominent modules found in the network, and show how the tastes of consumers of western classical music manifest themselves in the network. We believe that our work shows how network science can be a useful tool for studying arts and humanities.

1 Introduction

Recently network science has been instrumental in the modeling and understanding of various complex systems, ranging from technical systems such as the Internet and the Worldwide Web [1, 2] to social networks [3] and biological systems [4]. The success and the wide range of applicability of network science is based on the fact that by focusing on the connection patterns of a system's constituents it provides a unified framework for studying diverse systems, allowing developments in one area to quickly find use in others [5].

One area where network science as a methodology is garnering interest is arts and humanities [6, 7] including archaeology, history, and music. Coupled with an accelerating accumulation of so-called "Big Data," network science is advancing

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the field of humanities by helping us make sense of the patterns inherent in the data and their significance in the arts and humanities. Some notable large-scale data and network analyses in the field are as follows. Suarez, Sancho and Rosa [8] analyzed the data set of 11 443 works from Spain and Latin America and the linkage patterns of paintings with respect to genre and theme, finding that religious theme is the most dominant factor linking the paintings. Gleiser and Dan [9] studied the topology and the community structure of the collaboration network of Jazz musicians. Their analysis uncovered the presence of communities based on the recording locations of the bands correlated with the racial segregation between the musicians. Park *et al.* [10] highlighted the discrepancies between the network of collaboration and that of similarity in their study of contemporary popular musicians.

In this paper we analyze the network of composers of western classical music that covers its 700 years of development, constructed from a comprehensive data of CD recordings. We study the patterns of composer-composer associations including the degree distribution, the component structure, clustering, and the centralities of the composers. We also investigate the properties of prominent modules (communities) in the network that shed light on the nature of large-scale associations in western classical music, which we believe could prove useful for advances in traditional musicology that have often focused chiefly on understanding the individual composers.

2 Data

We utilized data sets from two prominent providers of information on classical music, ArkivMusic[1] and All Music Guide[2]. ArkivMusic is an online classical music retailer specializing in the distribution of CDs and DVDs. All Music Guide is an online music guide service website. As of early 2013, ArkivMusic lists a total of 96 911 classical music CDs along with their titles, release dates, labels, and the musicians involved, namely the composers of the pieces and the performers (conductors, soloists, and ensembles). The data can thus be represented as a bipartite network between CDs and the musicians in which an edge connects a CD and a musician if the musician has been featured on the CD (see Fig. 1). While there are several interesting possibilities of exploring the patterns of connections between different classes of musicians, in this paper we focus specifically on the network of composers obtained via the one-mode projection onto the set of composers. Therefore in our network an edge between two composers means that they were featured on at least one common CD.

We also processed the data to eliminate so-called "compilation CDs" that are essentially repackaged collections of previously issued CDs that are the root of undesirable effect of most well-known becoming connected to each other, resulting in an effective complete (full) network. We also trimmed out composers whose attribute data (periods and active years) were not available from All Music Guide,

[1] `http://www.arkivmusic.com`
[2] `http://www.allmusic.com`

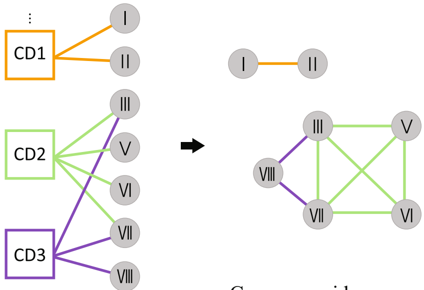

Fig. 1 The network representation of ArkivMusic data. The association between the CDs and performers or composer can be visualized as a bipartite network (left). A one-mode projection of the bipartite network onto the set of composers works by connecting two composers that are associated with a common CD (right).

as we would need them later when we investigate the relationship between node attributes and network properties [11].[3]

3 Network Properties

3.1 Small-World Property and Giant Component

Many networks exhibit the so-called "small-world property," meaning that the distance between two nodes of a network measured by the length of the geodesic (shortest path) connecting them is typically small. Also referred to as showing "six degrees of separation" in common parlance and made famous by Milgram's experiment in 1967 [12], it is now known to be true for many other networks. The average geodesic length between node pairs in our network is 2.6, and the longest geodesic length (also called the diameter of the network) is 7, showing that it also has the small-world property. A component in a network is a set of nodes between which at least one geodesic exists. Many networks possess one giant component that accounts for most of the nodes in the network, and it is true for our network as well: the largest component consists of 99.8% of the nodes.

[3] This process leaves us with 6.5% of all composers in the ArkivMusic data, however, we find that most prominent classical composers – who turn out to be high-degree nodes – that we are most interested in are left intact. The average number of CDs in which the removed composers are featured on is 3.5, significantly lower than that for the composers who remain in our database, which is 64.8.

Table 1 Basic network properties

Number of nodes	878
Number of edges	13,667
Size of the largest component	876
Mean geodesic length	2.62
Diameter	7
Clustering coefficient (random expectation)	0.618 (0.035)

3.2 Clustering Coefficient

Clustering refers to the tendency for triangles to form in a network. It is most commonly quantified by the Clustering Coefficient $C \in [0,1]$ defined as

$$C = \frac{3 \times \text{number of triangles}}{\text{number of connected triples}}, \tag{1}$$

where a connected triple is a set of three nodes $\{u, v, w\}$ such that u and v are connected, and v and w are connected. C is the probability that two nodes connected to a common neighbor are neighbors themselves. C for a network is often compared with the expected value from a random graph of equal n (number of nodes) and m (number of edges), and social networks in particular exhibit a large C [13]. Our composer network exhibits $C = 0.62$, which is also significantly larger than the random expectation 0.035. Thus two composers who have been featured on a CD with a common composer are highly likely to have been featured on a common CD.

3.3 Degree Distribution

The number of a node's neighbors is called its degree, often written as k. It is often the most fundamental quantity underlying many features of a network [5]. The degrees of nodes in a network can sometimes vary widely, and it is represented by the degree distribution $p(k)$ or its cumulative distribution $P(k) = \sum_{k'=k}^{\infty} p(k)$. We show the $P(k)$ for our network in Fig. 2 on a log-log scale. The node degrees vary widely in the network, with Johann Sebastian Bach (1685–1750) having the highest degree with $k = 348$, approximately 11 times that of the average degree $\overline{k} = 31.1$, followed by Wolfgang Amadeus Mozart (1756–1791) with $k = 287$.

3.4 Centralities of Composers

The most outstanding characteristic of a network is the heterogeneity in the structures around each node, and the right-skewed degree distribution in Fig. 2 is one example of it. The differences between each node in a network are exemplified by the nodes' centralities. As its name suggests, centrality is a measure of the importance or influence of a node in a network. The degree is one type of a centrality; in

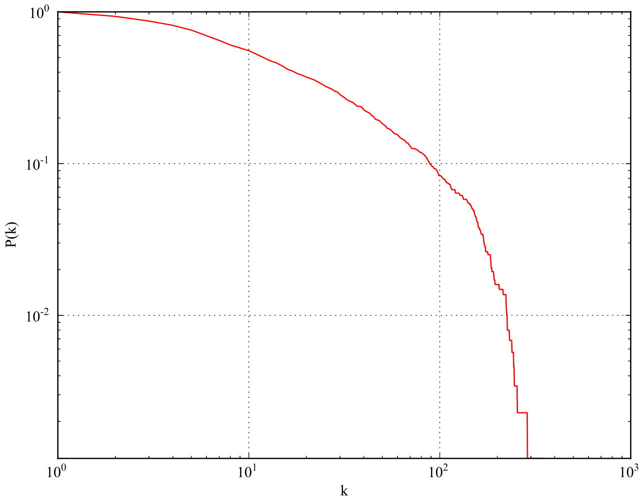

Fig. 2 The cumulative degree distribution $P(k)$ of the composers. The three highest-degree musicians in our network are Johann Sebastian Bach $(k = 348)$, Wolfgang Amadeus Mozart $(k = 287)$, and George Frideric Handel $(k = 254)$.

a social network, for instance, a high-degree person with many friends can be assumed to be more influential than one with few friends. In our network of classical music composers, the degree is the number of composers that one has been featured on a common CD. Since in a projected network the degree is bounded by $\sum_i B_{ij} n_j$ where B_{ij} is the number of connections (either 0 or 1) between a CD i and composer j, and the n_j is the number of composers featured with composer j on the CD, a high degree implies being featured in many CDs or with many composers, i.e. popularity or compatibility with many composers. The top-degree composers are shown in Table 2.

Different centralities capture different types of nodes' importance, and while they are often correlated, noticeable disagreements often point to some interesting aspects of the network. The **Eigenvector centrality** and the **(Freeman) Betweenness centrality** are two popular centrality measures besides the degree [14, 15]. Unlike the degree, the eigenvector centrality takes into consideration the "quality" of a connection. The idea behind it is that not all connections may be equal, and that being neighbors with an important node makes one more important. It is given as $x_i = \kappa^{-1} \sum_{ij} A_{ij} x_j$ which happens to be the definition of the eigenvector of the adjacency matrix $\mathbf{A} = \{A_{ij}\}$, and the eigenvector centrality means the components of the leading eigenvector of $\mathbf{A}$ [5]. This can be thought of as a generalization of the degree, and it often correlates highly with the degree centrality: In our network the Spearman rank correlation between the two is 0.940 ± 0.003, with seventeen common composers in the lists of top 20 composers of each centrality.

Another popular centrality is the (Freeman) betweenness centrality. It measures how often a node sits between two nodes, acting as an intermediary when the two nodes were to, say, exchange messages. It is given by $f_i \equiv \frac{1}{2}\sum_{jk} g_{jik}/g_{jk}$, where g_{jk} is the number of geodesics between j and k, and g_{jik} is the number of geodesics that go through i. The Spearman rank correlation between betweenness and degree centralities is 0.831 ± 0.009, and between betweenness and eigenvector centralities is 0.698 ± 0.012, respectively. While the correlations are positive, an inspection of Table 2 tells us that Modern composers are ranked extraordinarily high in betweenness centrality, whereas they were not so in other centralities. It turns out that modern composers who account for a majority of composers (70.3%) form a close-knit community between themselves, raising the betweenness centrality of the prominent ones such as Leonard Bernstein (1918–1990) and John Cage (1912–1992) despite their low degrees compared with those of composers from other periods. This tells us that investigating how composers in a common period are closely knit amongst themselves could be useful for understanding our network, the results of which we present next.

Table 2 Top 20 composers for the Degree, Eigenvector, and Betweenness centralities. Periods are abbreviated: Baroque (B), Classical (C), Romantic (R), and Modern (M).

Rank	Degree centrality		Eigenvector centrality		Betweenness centrality	
	Name	Period	Name	Period	Name	Period
1	Johann S. Bach	B	Johann S. Bach	B	Johann S. Bach	B
2	Wolfgang A. Mozart	C	Wolfgang A. Mozart	C	George Gershwin	M
3	George F. Handel	B	Claude Debussy	M	Wolfgang A. Mozart	C
4	Felix Mendelssohn	R	Beethoven	R	Leonard Bernstein	M
5	Franz Schubert	R	Franz Schubert	R	John Cage	M
6	Claude Debussy	M	Felix Mendelssohn	R	Ástor Piazzolla	M
7	Johannes Brahms	R	Johannes Brahms	R	Claude Debussy	M
8	Beethoven	R	Tchaikovsky	R	Beethoven	R
9	Tchaikovsky	R	Robert Schumann	R	Aaron Copland	M
10	Maurice Ravel	M	Maurice Ravel	M	Richard Rodgers	M
11	Gabriel Fauré	R	George F. Handel	B	Heitor Villa-Lobos	M
12	George Gershwin	M	Franz Liszt	R	Igor Stravinsky	M
13	Robert Schumann	R	Gabriel Fauré	R	George F. Handel	B
14	Franz Liszt	R	Camille Saint-Saëns	R	Johannes Brahms	R
15	Leonard Bernstein	M	George Gershwin	M	Maurice Ravel	M
16	Camille Saint-Saëns	R	Richard Strauss	R	Franz Schubert	R
17	Franz J. Haydn	C	Antonín Dvořák	R	Felix Mendelssohn	R
18	Igor Stravinsky	M	Franz J. Haydn	C	Alan Hovhaness	M
19	Frédéric Chopin	R	Igor Stravinsky	M	Irving Berlin	M
20	Samuel Barber	M	Sergei Rachmaninoff	M	Tchaikovsky	R

4 Mixing Patterns and Community Structures

Music is one of the oldest art forms created and enjoyed by humans, and accordingly has a rich history of development over time [16, 17, 18, 19]. Historians of music have attempted to break down the evolution of music into stages centered on distinguishable styles [20]. In network science, the study of commonalities between nodes is performed by investigating the mixing patterns between nodes and the community (modular) structures. For our network, in particular, this would allow us to see how well their connection patterns match with the conventional classification scheme.

While any classification scheme of a system can show varying degrees of complexity, a common convention for composers in western classical music is to assign them to certain periods [21]. Here we adopt the period designations used by All Music Guide database that consist of Medieval, Renaissance, Baroque, Classical, Romantic, and Modern, whose musical characteristics are summarized as follows (all years are approximate):

- **Medieval** (500 CE – 1400 CE). It is generally assumed that the primeval shape of musical notation appeared in this period, and several advances over previous practice were shown in regard to tonal material, texture and rhythm. In terms of tonal material, polyphony took a shape, settled down in Renaissance period and has been used in a variety of pieces and even recent ones [16]. Notable composers from this period are Guillaume de Machaut (1300–1377) and Francesco Landini (1325–1397).
- **Renaissance** (1401 – 1600). The main features of music from this period are modes and rich textures in four or more parts that blend strands in the musical texture and harmony with a greater concern with the flow and progression of chords. Polyphony is one of the notable changes that mark the Renaissance from the Middle Ages musically [22]. Notable composers from this period are Thomas Tallis (1505–1585), William Byrd (1540–1623), and John Dowland (1563–1626).
- **Baroque** (1601 – 1750). The creation of tonality distinguishes Baroque music from previous periods. During this period, composers used more elaborate musical ornamentation and made changes in musical notation. Baroque music became more complex in comparison with the songs of earlier periods and expanded the size and range of instrumental performance [18]. Notable composers from this period are Henry Purcell (1659–1695), Antonio Vivaldi (1678–1741), Johann Sebastian Bach (1685–1750), and George Frideric Handel (1685–1759).
- **Classical** (1730 – 1820). Classical music is characterized by a lighter, clearer texture than Baroque music and is less complex. It is mainly homophonic, although counterpoint was used often in later periods. Importance was given to instrumental music. Variety and contrast within a piece became more pronounced than before, and melodies tended to be shorter than those of Baroque music, with clear-cut phrases and clearly marked cadences [23]. Notable composers from this period are Wolfgang Amadeus Mozart (1756–1791) and Franz Joseph Haydn (1732–1809).

- **Romantic** (1815 – 1910). Romanticism, the artistic and literary movement in Europe that occurred in the second half of the 18th century, is a closely-related term with Romantic music [24]. It is characterized by freedom of form, emotions, individuality, dynamic changes and nationalism, a reaction against German influence. It was more personal and emotional than before so there was more freedom in form. Lyrical melodies as well as chromatic harmonies and discords boosted up this situation more along with dramatic contrasts of dynamics and pitches and wide variety of pieces were popular at the same time. Notable composers from this period are Ludwig van Beethoven (1770–1827), Franz Schubert (1797–1828), Frédéric Chopin (1810–1849), Robert Schumann (1810–1856), Franz Liszt (1811–1886) and Pyotr Ilyich Tchaikovsky (1840–1893).
- **Modern** (1900 – current). Modern music is characterized by innovations in the ways of organizing and approaching harmonic, melodic, sonic, and rhythmic aspects of music. Changes in aesthetic views and developments in technology have led to many novel techniques and styles, often called expressionism, abstractionism, neoclassicism, futurism and etc. [25] Besides the aesthetic changes, the rise of American classical music broke the tradition of composers replicating the European classical music. Notable composers from this period are Claude Debussy (1862–1918), Maurice Ravel (1875–1937), Sergei Rachmaninoff (1873–1943), Igor Stravinsky (1882–1971), George Gershwin (1898–1937) and Leonard Bernstein (1918–1990).

4.1 Assortative Mixing

Assortative mixing measures the tendency for similar nodes to be connected, given by the following assortativity measure for discrete node characteristics [26]:

$$r \equiv \frac{\sum_i e_{ii} - \sum_i a_i b_i}{1 - \sum_i a_i b_i} = \frac{\mathrm{Tr}\,\mathbf{e} - \|\mathbf{e}^2\|}{1 - \|\mathbf{e}^2\|}, \tag{2}$$

where $\mathbf{e} = \{e_{ij}\}$ is a matrix whose elements e_{ij} is the fraction of edges in a network that connect a vertex of type i to one of type j, and $\|\mathbf{x}\|$ is the sum of all elements of the matrix $\mathbf{x}$, and a_i and b_i are the fraction of each type of end of an edge that is attached to nodes of type i. For the periods of composers, we have $r = 0.257 \pm 0.005$, meaning that composers belonging to a common period tend to be connected preferentially to one another. The Pearson Correlation Coefficient between connected composers' active years (the middle point between their birth and death years) is even higher, with $\rho = 0.451 \pm 0.009$.

4.2 Communities

A positive assortative mixing that we see above is a symptom of the existence of **communities** or **modules** in a network. A community is commonly defined as a group of nodes of a network where connections between the nodes are denser than to the rest of the network. Algorithms that seek to find communities inside a network are deeply related to the graph partitioning problem, and have seen much development in recent years [27, 28, 29, 30]. Here we used the Louvain algorithm of Blondel *et al.* [31], which returned six communities of which the five largest were studied in more detail that account for 99.4% of the composers in our network. In Fig. 3 we show the period compositions of the member nodes of each module (1A and 1B are submodules of module 1 found by re-running the algorithm on the module, which we discuss later).

We find that the modules represent certain aspects in the history of developments in classical music. First, we see that each module corresponds reasonably well to one single period except for Module 1, which contains composers from four distinct periods – Medieval, Renaissance, Baroque, and Classical. In each of other modules (2 to 5), the majority of nodes belong to a specific period: Module 2 are mainly Romantic, while Modules 3, 4, and 5 are mainly Modern.

To further break down Module 1 we applied the Louvain algorithm one more time, after which we obtained two sizable submodules 1A and 1B. The division along the periods of the nodes is clearer now: Module 1A represents mainly Renaissance and early Baroque composers, while Module 1B represents later composers of Baroque and Classical periods. The Modern composers in 1B, while they appear to be many, are rather insignificant ones with average degree 19.9 in comparison to 77.8, the average degree of later Baroque and Classical composers. They are therefore nicely separated in chronological order. Notable composers in Module 1A

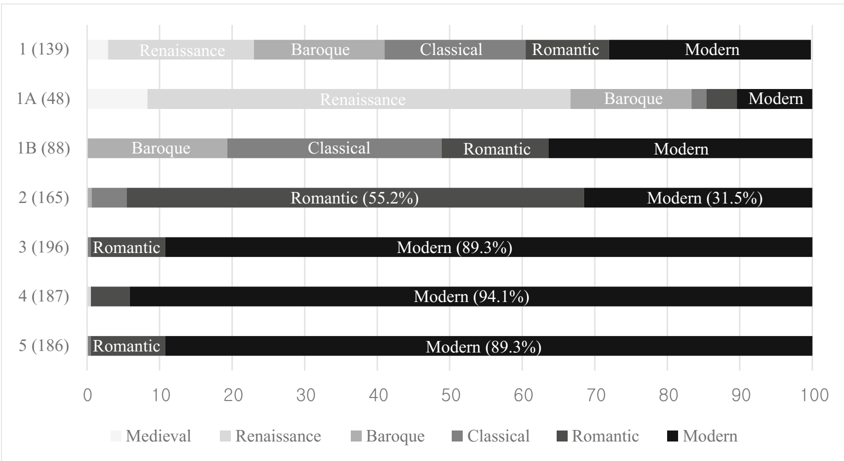

Fig. 3 Period compositions of the network communities. The numbers in parentheses are the modules' sizes. The grayscale color bars show the relative fractions of the periods. Module 1 includes composers from periods between Medieval and Classical. Module 2 represents the Romantic period, while Modules 3, 4, and 5 represent Modern composers. Modules 1A and 1B are submodules of Module 1, and correspond to the earlier and the later periods of Medieval and Classical.

include William Byrd (1540–1623, Renaissance) and Henry Purcell (1659–1695, Baroque). Notable composers in Module 1B include Antonio Vivaldi (1678–1741, Baroque), Johann Sebastian Bach (1685–1750, Baroque), George Frideric Handel (1685–1759, Baroque) from the Baroque period, and Wolfgang Amadeus Mozart (1756–1791, Classical), and Franz Joseph Haydn (1732–1809, Classical) from the Classical period.

Module 2 represents a later time in history, consisting mainly of Romantic (55.2%) and Modern (31.5%) composers. Among these, Romantic composers are generally more prominent (the average degree of the Romantic composers in this module is 104.4, and that of the Modern composers is 38.2), including Robert Schumann (1810–1856, Romantic), Frédéric Chopin (1810–1849, Romantic), Franz Liszt (1811–1886, Romantic), Johannes Brahms (1833–1897, Romantic), and Pyotr Ilyich Tchaikovsky (1840–1893, Romantic). We also note the existence of transitional composers between the Classical and Romantic periods, Ludwig van Beethoven (1770–1827) and Franz Schubert (1797–1828).

Modules 3, 4, and 5 represent the Modern period. In Module 3, the fraction of the Modern composers is 89.3%. The two highest-degree Modern composers are George Gershwin (1898–1937, Modern) of *Rhapsody in Blue* and *Porgy and Bess* and Leonard Bernstein (1918–1990, Modern) of *West Side Story*. Module 3 also includes Jazz composers such as Scott Joplin (1867–1917, Modern) and Billy Strayhorn (1915–1967, Modern), and Broadway composers such as Richard Rodgers (1902–1979, Modern) and Irving Berlin (1888–1989, Modern), reflecting the variety of musical styles of the 20th century.

Module 4 include Charles Ives (1874–1954, Modern) of *The Unanswered Question*, Aaron Copland (1900–1990, Modern) of *Appalachian Spring*, Samuel Barber (1910–1981, Modern) of *Adagio for Strings* and John Cage (1912–1992) of *4'33"*. In fact, composers from the United States account for 86.8% of composers in this module with the average degree of 25.53. Non-US composers have the average degree of 7.33. This module thus represents the growth of American vernacular style of classical music in the 20th century [32]. Ernest Bloch (1880–1959, Modern), Alan Hovhaness (1911–2000, Modern), Ned Rorem (1923–current, Modern), Terry Riley (1935–current, Modern), Steve Reich (1936–current, Modern) and Philip Glass (1937–current, Modern), all from the US, are also in this module.

Module 5 comprises of Modern (89.3%) and Romantic (10.2%) composers. Transitional figures between the periods – e.g. Gabriel Fauré (1845–1924, Romantic), impressionists such as Claude Debussy (1862–1918, Modern), Maurice Ravel (1875–1937, Modern) – are found in this module. In a nice contrast with Module 4, Module 5 appears to represent the non-US branch of modern music, with non-US Modern composers accounting for 79.1% of the composers. The average degree of non-US Modern composers is 41.8, noticeably larger than that of American composers in the module, 8.0. Notable composers include Arnold Schoenberg (1874–1951, Modern) from Austria, Manuel de Falla (1876–1946, Modern) from Spain, Béla Bartók (1881–1945, Modern) from Hungary, Igor Stravinsky (1882–1971, Modern) from Russia, Heitor Villa-Lobos (1887–1959, Modern) from Brazil, Paul Hindemith (1895–1963, Modern) from Germany, Francis Poulenc (1899–1963, Modern) from France, Ástor Piazzolla (1921–1992, Modern) from Argentina, and Luciano Berio (1925–2003, Modern) from Italy.

In summary, the modules we find algorithmically correspond reasonably well to the developmental history of western classical music. This shows that the associations between composers originally constructed in the academic (musicological) tradition are also reflected deeply in the music recording business, suggesting that a more in-depth exploration of the modular structures could potentially yield new and helpful insights into understanding the landscape of classical music.

5 Conclusion and Discussions

In this paper, we studied the properties of the network of classical music composers. We started by conducting a basic analysis of the structural properties of the network, finding that our network exhibits characteristics common to many real-world networks, including the small-world property, the existence of a giant component, and a high level of clustering. The centrality measurements of the composers showed a reasonable agreement with a common perception of the popularity of the composers. We also explored the global association patterns of composers via assortative mixing and community structure analysis, which showed us the extent to which our network reflected our musicological understanding of the western classical music tradition.

Directions for further research are as follows. First, we note that our work is based on a commercial data archive of classical music, and we believe a similar work based on academic data sources may yield interesting and complementary findings. Since artistic creations serve multiple purposes, as objects of appreciation (consumption) as well as of scholarly study by scholars, both are necessary for a proper understanding for art and culture. Second, we can ask the temporal aspects of the networks in music to understand how a musical style emerges, evolves, and fades in popularity. We believe that our work highlights the potential of network science coupled with advanced data analytics in answering many such pertinent questions in the arts and humanities, playing an instrumental role in the developing field of “digital humanities.”

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