Network Analysis of Orchestral Concert Programming

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1 Introduction

Orchestral concert programming is one of the most important and challenging jobs for a symphony's artistic or musical director. Programs must be coherent both for a single concert and across an entire season, without the repetition of too many pieces from one season to the next. Musical directors must consider both the musical components of a concert, balancing the tone, style and lengths of the pieces performed, as well as more economic demands, such as the cost of the personnel required for the pieces performed. In addition to appealing to the musical tastes of the orchestra's subscribers, musical directors often look to push the boundaries of audience expectations through the performance of new works or rarely-performed pieces (Wittry (2007)). However, musical directors must also look to expand audience engagement beyond current subscribers, especially with the recent decline in orchestral attendance (Midgette (2005)). "Pops" concerts, thematic programs and famous soloists are common ways that musical directors seek to grow orchestral audiences.

While orchestras look to improve audience engagement for future and current subscribers, there is also the desire to balance new works with the standard repertoire. There has been criticism of the overly "conservative" programming of most large orchestras (Tommasini (2008)). Concert programs tend to follow the traditional format of an "overture, concerto and symphony" per concert and there is often little experimentation with non-traditional pairings of pieces or the performance of new works. Additionally, most new works are not performed again after their premiere.

Gilmore (1993) and Thuerauf (2005) studied concert programming across major orchestras for the 1969 - 1970 and 2003 - 2004 seasons, respectively, and both found that there were a limited number of composers (i.e. Mozart, Beethoven and Tchaikovsky) and a limited number of musical eras (i.e. Romantic era and 20th Century music) that dominated orchestral concert programming. Gilmore (1993) in particular used these findings to advocate for the performance of more new works and a shift away from the standard, established repertoire of pieces.

The goal of this project was to use network analysis methods to understand and explore the similarities and differences in the concert programming of five of the world's top professional orchestras. While there are established guidelines and suggestions for concert programming

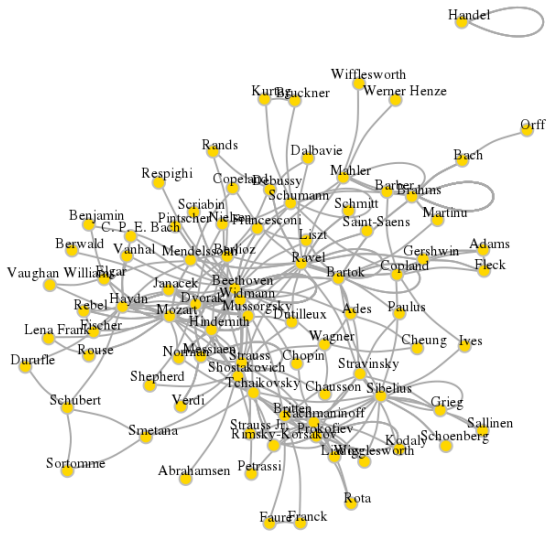

Figure 1: Concert programming network for the Cleveland Orchestra.

from a predominantly musical perspective (for example, Goza (2006) and Wittry (2007)) and Gilmore (1993) and Thuerauf (2005) provided summary statistics and performed ANOVA tests for concert programming, there does not appear to be any prior work on explicitly utilizing network analysis techniques to explore orchestral concert programming.

2 Methods

2.1 Data

The five orchestras considered for this project were the Boston Symphony Orchestra (BSO), the Cleveland Orchestra, the Royal Concertgebouw Orchestra of Amsterdam (RCO), the New York Philharmonic and the Vienna Philharmonic. All five orchestras maintain archives (BSO (2017a), Orchestra (2017b), RCO (2017b), Philharmonic (2017a), Philharmonic (2017c)) of previous performances and I scraped the concerts of each orchestra between 1/1/2012 and 12/31/2016. Since the networks over the past five years were too sparse if each piece performed was treated as a node, I considered the nodes in each of the five networks to correspond to the composer whose work was performed, with an edge representing the fact that two composer's works were performed together in the same concert. I treated the edges as unweighted, thus, I did not consider if two composers were performed in the same concert together multiple times. The network for the Cleveland Orchestra is plotted as an example (Figure 1). There were isolates in some of the networks. For example, every year Cleveland performs Handel's Messiah as a stand-alone concert around the holidays. This work is close to three hours in length and is thus not performed by the Cleveland Orchestra with any other works by different composers in concert.

Each of these five orchestras is considered among the top professional orchestras in the world.

Gramohphone (2009) published an article on the top 20 orchestras in the world and all five of these orchestras were ranked in the top 20. Table 1 lists the year that each orchestra was founded, the current musical directors and the Gramohphone (2009) ranking. Andris Nelsons began the role of musical director of the BSO in the 2014-2015 season and there was no appointed musical director between 2012 and 2014 (BSO (2017b)). Franz Wesler - Möst has been the musical director of the Cleveland Orchestra since 2002 and one of the stated missions of the Cleveland Orchestra is to perform new works and innovative programs (Orchestra (2017a)). Alan Gilbert has been the musical director of the NY Philharmonic since 2009 and this orchestra is the oldest in the US (Philharmonic (2017b)). Gilbert is additionally interested in the performance of new works (Tommasini (2008)).

The RCO has a tradition of performing Richard Strauss, Mahler and Bruckner, as well as new works, and the current chief conductor Daniele Gatti is particularly interested in "French repertoire, the Second Viennese School and contemporary music" (RCO (2017a)). The Vienna Philharmonic is one of the most famous orchestras in the world and has been since its founding, with Anton Bruckner calling the Vienna Philharmonic "the most superior musical association" and Richard Strauss commenting, "all praise of the Vienna Philharmonic reveals itself as understatement" (Philharmonic (2017d)). The Vienna Philharmonic only employs guest conductors and the musicians of the orchestra are in charge of many of the decisions which govern the orchestra (Philharmonic (2017d)), thus there is no listed musical director.

	Boston Symphony Orchestra	Cleveland Orchestra	Royal Concertgebouw Orchestra	New York Philharmonic	Vienna Philharmonic
Year Founded	1881	1918	1888	1842	1842
Musical Director	Andris Nelsons (2014 -)	Franz Wesler - Möst	Daniele Gatti	Alan Gilbert	N/A
Gramophone Ranking	11	7	1	12	3

Table 1: Date of founding, current musical director and Gramohphone (2009) ranking for the five orchestras studied.

2.2 Analysis

2.2.1 Exploratory Data Analysis

I performed an exploratory data analysis on each of the five networks as an initial analysis step, focusing on summary statistics like the number of nodes, edges, 2-stars, 3-stars and triangles in each network. I additionally explored trends for the nodes in each network that had the most edges and I compared these trends across networks.

2.2.2 Community Detection

Using the community detection algorithms in `igraph` (Csardi (2015)), I next analyzed the detected communities for each of the five networks and compared these communities across networks. Composers in the same community were interpreted as being programmed similarly to the other members of the community. I compared the communities found by the edge-betweeness (M. E. J. Newman (2003)), fast-greedy (Aaron Clauset (2004)), label propagation (Raghavan et al. (2007)), leading eigenvalue (Newman (2006)), Louvain (Blondel et al. (2008)) and random walk (Pons and Latapy (2005)) algorithms. For each network, I selected the community detection algorithm that resulted in the highest modularity (a number between -1 and 1), which measures how dense the edges within the communities are compared to the edges between communities (Blondel et al. (2008)).

The two community detection algorithms that had the highest modularity for the five networks were the fast greedy algorithm, which uses a greedy algorithm to approximately optimize the modularity (Aaron Clauset (2004)), and the Louvain algorithm, which iteratively places each node i in the community that maximizes the gain in modularity when node i is moved from its current community to a new community (Blondel et al. (2008)).

2.2.3 Social Relations Regression Model

Following Hoff (2015), various Social Relations Regression Models (SRRMs) were fit to each network separately and across all five networks simultaneously. For each network, a probit SRRM was fit and models with only row effects were fit, since the adjacency matrices for each network were symmetric. The era and nationality of the composer were included as nodal covariates. The SRRM with multiplicative effects could be written as

$$y_{i,j} = \beta^T \boldsymbol{x}_i + a_i + \boldsymbol{u}_i^T \boldsymbol{u}_i + \epsilon_{i,j}$$

where $y_{i,j} = 1$ if two composers were programmed together and 0 otherwise, $\boldsymbol{x}_i$ represented nodal covariates, β was the nodal coefficients, the a_i described row effects (equivalently, column effects), the $\boldsymbol{u}_i$ described multiplicative effects and $\epsilon_{i,j}$ was the model error for each node.

3 Results

3.1 Exploratory Data Analysis

Table 2 provides several summary statistics for each of the five networks. The BSO and the NY Philharmonic were the largest networks with the highest numbers of nodes (composers) performed, as well as the highest number of concerts over the period considered. The BSO had the highest ratio of triangles in the network as compared to the number of edges, while Cleveland had the lowest ratio. Thus, the BSO network exhibited more homophily than the Cleveland network. For the BSO, if one concert contained works by composer A and composer B and another concert contained works by composer A and composer C, it was likely that works by composers B and C would be performed in the same concert (thus

forming a triangle in the network between nodes A, B and C). This triangle formation was not as likely for the Cleveland Orchestra, which could be indicative of "innovative" programming, as it was not necessarily the case that just because composers B and C were separately performed with composer A, then composer B and C would also be performed together.

	Boston Symphony Orchestra	Cleveland Orchestra	Royal Concertgebouw Orchestra	New York Philharmonic	Vienna Philharmonic
Nodes	155	87	142	179	96
Edges	655	197	438	648	340
Concerts	1604	635	928	1713	1296
Two Stars	12802	1552	4690	10574	4957
Three Stars	128627	6665	25923	92139	35869
Triangles	1265	130	454	958	528

Table 2: Summary statistics for each of the five networks.

As an additional exploration of the five networks and as a comparison with the findings of Gilmore (1993) and Thuerauf (2005), I looked at the twenty nodes with the largest number of edges for each network. These "top twenty" nodes represented the composers in the network that were performed the most often, both alone and with other composers. For all five networks, Beethoven, Tchaikovsky, Mozart, Ravel and Richard Strauss were among the nodes with the most edges. Stravinsky, Prokofiev, Brahms, Shostakovich, Mendelssohn, Dvořák, Rachmaninoff and Bartók were among the top twenty nodes for four of the networks, while Bach, Haydn, Debussy, Copland, Sibelius and Wagner were in the top twenty for three of the networks. The composers John Williams and Samuel Barber appeared in the top twenty for the BSO only, while Britten, Hindemith and Berlioz were unique to the top twenty of the Cleveland Orchestra. Lutosławski, Gershwin, Ives and Saint-Saëns were unique to the top twenty of the RCO, Bernstein, Rimsky-Korsakov and Anthem (the US National Anthem) were unique to the NY Philharmonic and Schubert, Johan Strauss, Jr., Josef Strauss and Bruckner were unique to the top twenty of the Vienna Philharmonic. Figure 2 shows the distribution of the number of edges for the top twenty nodes for the BSO.

Some interesting trends emerged through the comparison of the top twenty composers for each of the five networks. As might be expected, the Vienna Philharmonic frequently performed works by Austrian composers, more so than the other orchestras, and also frequently performed works by a wider range of Austrian composers as compared to the other orchestras. As a result, the Vienna Philharmonic had fewer Russian composers represented in the top twenty composers as compared to the other orchestras. Mahler and Schoenberg (both Austrian composers) were only represented among the top twenty composers of the European orchestras and not the American orchestras. Likewise, Copland (an American composer) was only in the top twenty for the US orchestras. Interestingly, however, Ives and Gershwin were only among the top twenty for the RCO and not for the US orchestras, indicating that American composers were frequently performed, even outside of the US. Finally,

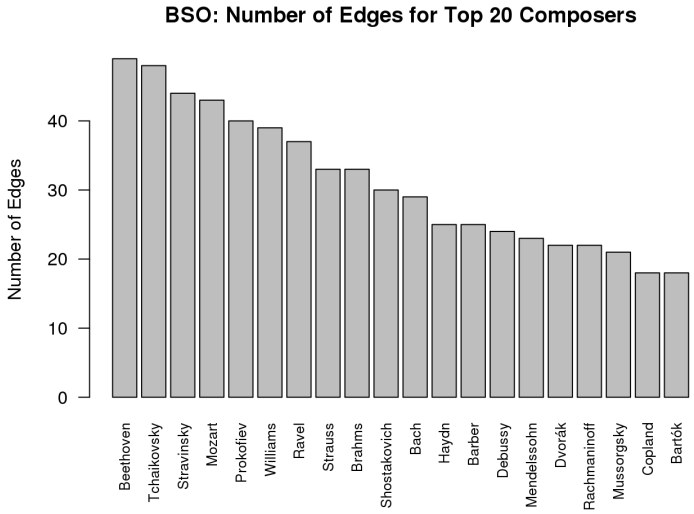

Figure 2: Histogram of the number of edges for the twenty composers with the most edges for the BSO.

special ties between specific composers and specific orchestras could be seen by looking at the top twenty composers. Bernstein used to be the conductor of the NY Philharmonic and was only represented among the top twenty composers for this orchestra. Similarly, John Williams used to be the conductor of the Boston Pops, an organization that is very closely affiliated with the BSO, and Williams was only in the top twenty composers for the BSO.

Overall, works by Austrian, German, Russian, American and French composers dominated the top twenty composers for each of the five orchestras. Apart from the wider range of Austrian composers and the fewer Russian composers performed in the top twenty by the Vienna Philharmonic, all five orchestras performed approximately the same number of composers in the top twenty for each of these nationalities. No US composers were in the top twenty for the Vienna Philharmonic and Mozart was the only Austrian composer in the top twenty for the NY Philharmonic. US composers were well represented in the top twenty for the RCO, even relative to US orchestras. Table 3 shows the top twenty composers by nationality for each of the five orchestras. Note: "Anthem" refers to the US National Anthem which is frequently performed at summer concerts by the NY Philharmonic and is in the "Other" category since it is a different type of composition than the other programmed pieces, as it is often programmed by default, regardless of what other pieces are to be performed in the same concert.

Overall, the top twenty composers were quite similar across all five networks in terms of the nationality of the composer, except for a few differences related to either the location or the history of the specific orchestra. There was a relatively small group of composers represented in these top twenty lists across the five orchestras and there was significant overlap between the specific composers represented and the findings of Gilmore (1993) and Thuerauf (2005).

Gilmore (1993) and Thuerauf (2005) additionally looked at the era of composers performed

Nationality	Boston Symphony Orchestra	Cleveland Orchestra	Royal Concertgebouw Orchestra	New York Philharmonic	Vienna Philharmonic
Austrian	Haydn Mozart	Haydn Mozart	Mahler Mozart Schoenberg	Mozart	Bruckner Haydn Mahler Mozart Schoenberg Schubert Strauss, Josef Strauss Jr., Johann
German	Bach Beethoven Brahms Mendelssohn Strauss, R.	Beethoven Hindemith Mendelssohn Schumann Strauss, R. Wagner	Beethoven Brahms Mendelssohn Strauss, R. Wagner	Bach Beethoven Brahms Schumann Strauss, R.	Bach Beethoven Brahms Mendelssohn Strauss, R. Wagner
Russian	Mussorgsky Prokofiev Rachmaninoff Shostakovich Stravinsky Tchaikovsky	Prokofiev Rachmaninoff Shostakovich Stravinsky Tchaikovsky	Prokofiev Rachmaninoff Shostakovich Stravinsky Tchaikovsky	Prokofiev Rachmaninoff Rimsky-Korsakov Shostakovich Stravinsky Tchaikovsky	Mussorgsky Tchaikovsky
American	Barber Copland Williams	Copland	Gershwin Ives	Bernstein Copland	
French	Debussy Ravel	Berlioz Ravel	Debussy Ravel Saint-Saëns	Debussy Ravel	Debussy Ravel
Other	Bartók Dvořák	Bartók Britten Dvořák Sibelius	Bartók Lutosławski	Anthem Bartók Dvořák Sibelius	Dvořák Sibelius
Overall # of Nationalities Performed	29	15	24	30	23

Table 3: Top twenty composers by nationality for each of the five orchestras. In the "Other" category, Bartók is a Hungarian composer, Dvořák is Czech, Britten is English, Sibelius is Finnish and Lutosławski is Polish. "Anthem" refers to the US National Anthem.

and found that Classical, Romantic and 20th Century pieces are performed the most often, while Contemporary pieces were performed the least. Table 4 summarizes the count and proportion of composers performed by era for each of the five orchestras considered. There was some overlap between the categories of 20th Century and Modern composers, in particular, as the styles of some composers could fall into multiple eras. Approximately 40% of all of the composers performed by each orchestra were 20th Century composers. The NY Philharmonic performed the highest proportion of Modern composers (27%), while the Vienna Philharmonic performed the lowest proportion of Modern composers. However, the composers in the top twenty performed by all five orchestras were dominated by Romantic and 20th Century composers (Table 5), as found by Gilmore (1993) and Thuerauf (2005). While there were many Modern composers performed by each orchestra, these composers were not performed with as many other composers or as frequently as more traditional, repertoire composers.

	BSO		Cleveland		RCO		NY		Vienna	
Era	n	Freq.	n	Freq.	n	Freq.	n	Freq.	n	Freq.
Renaissance	1	0.0065	1	0.0115	1	0.0070	2	0.0112		
Baroque	1	0.0065	2	0.0230	4	0.0282	5	0.0279	1	0.0104
Classical	7	0.0452	6	0.0690	7	0.0493	6	0.0335	8	0.0833
Romantic	38	0.2452	25	0.2874	32	0.2253	38	0.2123	33	0.3438
20th Century	77	0.4968	39	0.4483	66	0.4648	79	0.4414	43	0.4479
Modern	31	0.2000	14	0.1609	32	0.2254	49	0.2737	11	0.1146

Table 4: Counts and frequencies for the number of composers performed by era for the five orchestras.

3.2 Community Detection

For all five orchestras, the community detection algorithms edge-betweeness (M. E. J. Newman (2003)), fast-greedy (Aaron Clauset (2004)), label propagation (Raghavan et al. (2007)), leading eigenvalue (Newman (2006)), Louvain (Blondel et al. (2008)) and random walk (Pons and Latapy (2005)) were applied to the five networks. The algorithm resulting in the highest modularity for each network was selected as the community detection method considered below. Composers in the same community corresponded to composers that were programmed similarly for each orchestra.

3.2.1 Boston Symphony Orchestra

For the BSO, the fast-greedy algorithm (Aaron Clauset (2004)) resulted in the highest modularity for the network (0.3358). This algorithm found 8 communities of sizes 12, 36, 16, 22, 37, 30, 1 and 1 node each. As noted in Aaron Clauset (2004), a modularity above about 0.3 indicates significant community structure in a network.

Era	Boston Symphony Orchestra	Cleveland Orchestra	Royal Concertgebouw Orchestra	New York Philharmonic	Vienna Philharmonic
Baroque	Bach			Bach	Bach
Classical	Beethoven Haydn Mozart	Beethoven Haydn Mozart	Beethoven Mozart	Beethoven Mozart	Beethoven Haydn Mozart
Romantic	Brahms Dvořák Mendelssohn Mussorgsky Tchaikovsky	Berlioz Dvořák Mendelssohn Schumann Tchaikovsky Wagner	Brahms Mendelssohn Saint-Saëns Tchaikovsky Wagner	Brahms Dvořák Rimsky-Korsakov Schumann Tchaikovsky	Brahms Bruckner Dvořák Mendelssohn Mussorgsky Schubert Strauss, Josef Strauss Jr., Johann Tchaikovsky Wagner
20th Century	Barber Bartók Copland Debussy Prokofiev Rachmaninoff Ravel Shostakovich Strauss, R. Stravinsky Williams	Bartók Britten Copland Hindemith Prokofiev Rachmaninoff Ravel Shostakovich Sibelius Stravinsky Strauss, R.	Bartók Debussy Gershwin Ives Lutosławski Mahler Prokofiev Rachmaninoff Ravel Schoenberg Shostakovich Stravinsky Strauss, R.	Anthem Bartók Bernstein Copland Debussy Prokofiev Rachmaninoff Ravel Shostakovich Sibelius Stravinsky Strauss, R.	Debussy Mahler Ravel Schoenberg Sibelius Strauss, R.

Table 5: Top twenty composers by era for each of the five orchestras.

There were trends within the found communities that aligned with a purely musical view of concert programming. The French composers Dutilleux, Debussy, Ravel, Berlioz, Roussel, Saint-Saëns, Bizet and Canteloube were all in the same community (2) and all of these composers were composing in either the Romantic era or the 20th Century. This suggests that the most well-known French composers were programmed similarly by the BSO. Several Russian composers (Tchaikovsky, Rachmaninoff, Prokofiev, Rimsky-Korsakov, Glinka) were also in the same community as these French composers, indicating that these Romantic and 20th Century popular Russian composers were programmed similarly to popular Romantic and 20th Century French composers. The third community was almost exclusively 20th Cen-

tury or Modern composers and 9 out of the 19 composers were American (Copland, Barber, Schwanter, Adams, Rodgers, Gershwin, Cohen, Bolcom and Ellington), again suggesting that US composers were programmed similarly to each other. Three primarily operatic composers (Wagner, Puccini and Verdi) were all placed in the fourth community, while several of the most performed composers (Beethoven, Mozart, Brahms, Schubert, Mendelssohn, Bach, Schoenberg, Mahler, Sibelius, Bruckner and Chopin) were together in the fifth community (Table 6).

Community	Composers
1	Schroeder, Dvořák, Kodály, Schumann, Saariaho, Liszt, Tippet, Stucky, Dorman, Chin, Martinu, Sciarrino
2	Tchaikovsky, Dutilleux, Debussy, Rachmaninoff, Ravel, Berlioz, Fucik, Prokofiev, Anderson, Naughtin, Sousa, Meye, Gandolfi, Saint-Saëns, Sierra, MacMillan, Roussel, Hindemith, Thomas, Rimsky-Korsakov, Gabrieli, Vaughan Williams, Rands, Glinka, Bizet, Martinsson, Szymanowski, Tarrega, Canteloube, Tsontakis, Orff, Smith, Nicolai, Copland, Tomasi, Jacob
3	Elgar, Barber, Previn, Paganini, Penderecki, Schwantner, Adams, Rodgers, Gershwin, Loewe, Cohen, Bolcom, Barlow, Ellington, Walton, Holst
4	Haydn, Shostakovich, Lutosławski, Ewald, Berezovsky, Respighi, Bernstein, Wagner, Schumann, Puccini, Falla, Neikrug, Verdi, Mascagni, Dean, Ešenvalds, Boito, Berg, Abrahamsen, Hartmann, Kancheli, Ponce
5	Turnage, R. Strauss, Weber, Beethoven, Harbison, Mozart, Brahms, Schubert, Mendelssohn, Bach, Poulenc, Françaix, Adès, Schoenberg, Ives, Villa-Lobos, Sibelius, Bruckner, Chopin, Mahler, Carter, Franck, Rouse, Lalo, Nielsen, Milhaud, Schuller, Currier, Gossec, Henze, McTee, Bruch, Corigliano, Rossini, Widmann, Nathan, Andres
6	Stravinsky, Williams, Gubaidulina, Lyadov, Salonen, Britten, Gluck, Handel, Delius, Martin, Stanford, Mussorgsky, Lindberg, Messiaen, Varèse, Grofé, Bartók, Miaskovsky, Knussen, Ginastera, Grieg, Bates, Birtwistle, Glazunov, Neuburger, Smetana, Higdon, Grainger, Ponchielli, Janácek
7	Golijov
8	Szymanowski

Table 6: Communities found by the fast-greedy algorithm for the Boston Symphony Orchestra.

3.2.2 Cleveland Orchestra

The Louvain community detection algorithm resulted in the highest modularity for the Cleveland network (0.5091), indicating significant community structure in the network. Eight

communities were again found, of sizes 15, 8, 11, 18, 10, 16, 8 and 1. Several French composers were again in the same community for this network (Community 1, composers Ravel, Debussy, Berlioz, Dalbavie, Saint-Saëns), again suggesting that most French composers were programmed similarly by the Cleveland Orchestra. Interestingly, Mozart and Mendelssohn, both composers in the "top twenty" for the Cleveland Orchestra, were also in this community and were programmed similarly to the French composers. The popular composers Mussorgsky, Shostakovich and Dvořák were all in the same community (2) and Respighi, Wagner and Verdi were in the same community both for the Cleveland Orchestra (4) and for the BSO. Several well-known composers or top twenty composers for the Cleveland Orchestra were also in this fourth community: Beethoven, Hindemith, R. Strauss, Chopin, Liszt and Johann Strauss, Jr. Similar to the BSO, American composers dominated one community (5) and thus were programmed similarly, with Ives, Copland, Gershwin, Barber, Adams and Fleck all in this community. The Russian composers Prokofiev, Rimsky-Korsakov, Tchaikovsky, Stravinsky, Rachmaninoff and Liadov primarily made up another community (6) (Table 7).

Community	Composers
1	Ravel, Mozart, Elgar, Vaughan Williams, Mendelssohn, Debussy, Rands, Berlioz, Dalbavie, Saint-Saëns, Schmitt, Rouse, Lena Frank, Copland, Paulus
2	Mussorgsky, Shostakovich, Dutilleux, Petrassi, Abrahamsen, Berwald, Dvořák, Shepherd
3	Haydn, Schubert, Durufle, Benjamin, Smetana, Sortomme, Janácek, C. P. E. Bach, Vanhal, Fischer, Rebel
4	Beethoven, Respighi, Adès, Norman, Hindemith, R. Strauss, Messiaen, Verdi, Cheung, Wagner, Chopin, Chausson, Liszt, Francesconi, Widmann, Strauss Jr., Pintscher, Scriabin
5	Ives, Copland, Gershwin, Schumann, Nielsen, Kurtag, Bruckner, Barber, Adams, Fleck
6	Sibelius, Prokofiev, Britten, Rimsky-Korsakov, Tchaikovsky, Stravinsky, Grieg, Rachmaninoff, Kodály, Schoenberg, Lyadov, Faure, Franck, Wigglesworth, Sallinen, Rota
7	Martinu, Bartók, Brahms, Mahler, Bach, Werner, Henze, Orff
8	Handel

Table 7: Communities found by the Louvain algorithm for the Cleveland Orchestra.

3.2.3 Royal Concertgebouw Orchestra

The Louvain algorithm also gave the highest modularity for the RCO and again, the modularity for the network was high (0.4957), indicating significant community structure in the network. Eleven communities were found, of sizes 26, 17, 15, 16, 17, 13, 24, 12, 1, 1 and 1. Similar to the networks for the BSO and the Cleveland Orchestra, the first community was primarily made up of well-known and often-performed composers (Mozart, Beethoven,

Brahms, Mendelssohn, Bruckner, Haydn, R. Strauss, Handel, Dvořák, Schumann, Bach and Rossini) and both J. S. Bach and his son C. P. E Bach were in this community. Five of these composers were among the top twenty composers with the most edges for the RCO network. The second community was made up almost exclusively of 20th Century and Modern composers. The third community contained many well-known composers (Tchaikovsky, Rimsky-Korsakov, Puccini, Verdi, Vivaldi and Respighi), as well as the brothers Josef Strauss and Johann Strauss, Jr. 20th Century and Modern composers also dominated the fourth community and French (Ravel, Berlioz, Fauré, Messiaen, Chabrier, Dukas, Boulez) and American (Adams, Gershwin, Harbison, James, Bernstein) primarily made up the fifth community. It is interesting that the "French" and "American" communities that were also seen in the BSO and Cleveland networks were joined into one community for the RCO, as opposed to forming separate communities like for the BSO and Cleveland. Finally, 20th Century and Modern composers primarily made up the sixth, seventh and eighth communities (Table 8).

Community	Composers
1	Mozart, Walton, Beethoven, Brahms, Bruch, Weber, Kodály, Mendelssohn, Bruckner, Haydn, R. Strauss, Wagenaar, Widmann, Handel, Bloch, Dvořák, Bach, Benzecry, Lieberson, Rosetti, Schumann, Webern, Andriessen, C. P. E. Bach, Rossini, Rijnvos
2	Barber, Varèse, Henze, Nono, Shostakovich, Aa, Benjamin, Grime, Ligeti, Ockeghem, Zuidam, Flothuis, Janácek, Lyadov, Casals, Anderson, Smetana
3	Schubert, Anrooy, Tchaikovsky, Rimsky-Korsakov, Goemans, Lara, Massenet, Puccini, Verdi, Johann Strauss Jr., Piazzolla, Vivaldi, Falla, Respighi, Josef Strauss
4	Debussy, Britten, Dutilleux, Sibelius, Fink, Roussel, Turnage, Rachmaninoff, Nielsen, Szymanowski, Scriabin, Tan Dun, Copland, Woud, Diepenbrock, Schürmann
5	Adams, Ravel, Gershwin, Harbison, James, Bernstein, Buuren, Berlioz, Defoort, Liszt, Fauré, Messiaen, Chabrier, Martinu, Dukas, MacMillan, Adès
6	Boulez, Lindberg, Stravinsky, Hindemith, Wassenaer, Berg, Jeths, Zemlinsky, Holliger, Zimmermann, Enescu, Bizet, Villa-Lobos
7	Schoenberg, Arnold, Vries, Wagner, Bartók, Prokofiev, Saint-Saëns, Mahler, Lutosławski, Zimmerman, Witold, Herrmann, Merkies, Roukens, Warmerdam, Fröst, Glanert, Hillborg, Penderecki, Honegger, Lalo, Clementine, Ibert, Satie
8	Ives, Purcell, Rouse, Murail, Brewaeys, Devreese, Keuris, Nas, Crumb, Lott, Norman, Son
9	Martin
10	Humperdinck
11	Mussorgsky

Table 8: Communities found by the Louvain algorithm for the Royal Concertgebouw Orchestra.

3.2.4 New York Philharmonic

The fast-greedy community detection algorithm resulted in the highest modularity (0.4087) for the NY Philharmonic. Eleven communities were found of sizes 13, 25, 37, 50, 14, 14, 21, 1, 1, 1 and 1. The second community was dominated by American composers (Williams, Barber, Anthem, Rodgers, Mostel, Norman, Bernstein, Anderson, Sousa, Adams and Sandidge). Interestingly, both Richard Strauss and Johann Strauss, Jr. were also in this community, and these two composers were not in the same communities for any of the other networks. Several popular and often-performed composers were together in the third (Dvořák, Bach, Wagner, Brahms, Haydn, Schubert, Bartók, Schumann, Bruckner, Mendelssohn, Bizet and Schoenberg) and fourth (Mozart, Beethoven, Liszt, Tchaikovsky, Ravel, Prokofiev, Stravinsky, Berlioz, Debussy, Saint-Saëns, Rossini, Mahler and Chopin) communities. Russian composers (Rachmaninoff, Mussorgsky, Shostakovich, Glinka, Trifanov and Tcherepnin) largely made up the seventh community. There did not appear to be any primarily French composer communities as could be found in the other networks (Table 9).

3.2.5 Vienna Philharmonic

Finally, the Louvain algorithm had the highest modularity (0.3402) for the Vienna Philharmonic network, with community sizes of 16, 13, 5, 14, 18, 7, 22 and 1 for the eight communities found. Several well-known and popular composers made up the first community (Chopin, Bach, Mendelssohn and Saint-Saëns) and three of these well-known composers were Russian (Prokofiev, Tchaikovsky, Rimsky-Korsakov). Josef Strauss and Johann Strauss, Jr. were both in this first community and they were in the top twenty composers with the most edges for the Vienna Philharmonic. Several of these top twenty composers were also in the second community (R. Strauss, Dvořák, Debussy and Mussorgsky). Four out of the five composers in community three were Russian (Stravinsky, Shostakovich, Glinka and Blumenfeld). The fourth community was comprised of several Austrian composers (Mozart, Mahler, Staud, Neuwirth and Schoenberg). The seventh community was again dominated by popular and top twenty composers (Wagner, Brahms, Haydn, Schubert, Liszt, Bartók and Verdi) and five of the composers in this community were French (Ravel, Bizet, Berlioz, Boulez and Poulenc) (Table 10).

3.3 Social Relations Regression Models

A simple ANOVA revealed significant heterogeneity across the rows (equivalently, across the columns) of the adjacency matrices for each of the five networks and thus Social Relations Regression Models (SRRM) with and without multiplicative effects were considered. The era and nationality of each composer were added as nodal covariates for the SRRMs. For all five of the networks, an SRRM with only additive effects was not able to capture triadic dependencies well. Adding multiplicative effects improved the model fits for triadic dependence, but there was still room for model fit improvement of triadic dependencies, even with the addition of multiplicative effects. When nodal covariates that were not significant were excluded from the models, the triadic dependence in each network was well fit by an SRRM with multiplicative effects.

Community	Composers
1	Grieg, Våren, Piazzolla, Vivaldi, Sibelius, Harris, Juarez, Rankin, Paunio, Rodine, Villegas, Egan, Braunfels
2	Anthem, Barber, R. Strauss, Holst, Williams, Suppè, Massenet, Rodgers, Mostel, Norman, Bernstein, Anderson, Sousa, Paganini, Johann Strauss Jr., Fernandez, Lyadov, Adams, Smetana, Franck, Hamelin, Offenbach, Tovey, Hesketh, Sandidge
3	Dvořák, Hindemith, Pierpont, Bach, Wagner, Adolphe, Brahms, Shankar, Haydn, Schubert, Bartók, Bruch, Busoni, Schumann, Ligeti, Krawczyk, Falla, Westhoff, Bruckner, Lindberg, Mendelssohn, Glanert, Harvey, Eötvös, Rouse, Wagenaar, Korngold, Vivier, Golijov, Bizet, Traditional, Lalo, Bloch, Sarasate, Schoenberg, Schnittke, Henze
4	Mozart, Beethoven, Janácek, Faurè, Liszt, Tchaikovsky, Medtner, Ravel, Prokofiev, Stravinsky, Berlioz, Gershwin, Elgar, Debussy, Dukas, Ponchielli, Saint-Saëns, Rossini, Mahler, Kodály, Chopin, Horowitz, Britten, Neikrug, Adès, MacMillan, Nielsen, Ives, Glazunov, Chin, Shepherd, Cheung, Szymanowski, Webern, Berg, Weill, Ward, Zemlinsky, Pachelbel, Pärt, Poulenc, Turnage, Duery, Dallapiccola, Messiaen, Murail, Kurtág, Youmans, Gluck, Hartmann
5	Copland, Bolcom, Marsalis, Corigliano, Kander, Valongo, Poniewozik, Alexander, Sifuentes, Garcia, Collings, Brooks, Peterson, Landau
6	Ellington, Rimsky-Korsakov, LeFrak, Sakho, Liao, Rissmann, Fig, Stevens, Espiritusanto, Hanson, Micic, Braun, Irfan, Gulielmetti
7	Gabrieli, Handel, Nørgård, Boulez, Stucky, Orff, Rachmaninoff, Mussorgsky, Salonen, Shostakovich, Respighi, Albinoni, Glinka, Pollack, Trifonov, Escaich, Tcherepnin, Penderecki, Hillborg, Lutosławski, Weber
8	Dutilleux
9	Westlake
10	Chaplin
11	Verdi

Table 9: Communities found by the fast-greedy algorithm for the New York Philharmonic.

The regression coefficients for the model fit to each network are summarized in Table 11, Table 12, Table 13, Table 14 and Table 15. Overall, the nodal coefficients from the SRRM fits were small for all five networks, with only the RCO and the Vienna Philharmonic having any coefficients that were significant. Both the RCO and the Vienna Philharmonic had significant coefficients for the composer era, indicating that for these two orchestras, the era of the composer did play a role in concert programming. While the results of the community detection above seemed to show that composers of the same nationality were programmed

Community	Composers
1	Prokofiev, Tchaikovsky, Chopin, Bach, Rimsky-Korsakov, Shchedrin, Josef Strauss, Johann Strauss Jr., Mendelssohn, Bruch, Saint-Saëns, Ponce, Dutilleux, Dun, Takemitsu, Smetana
2	Freiberg, R. Strauss, Dvořák, Debussy, Mussorgsky, Borodin, Ponchielli, Giménez, Suppé, Staar, Penderecki, Suk, Larcher
3	Stravinsky, Cerha, Shostakovich, Glinka, Blumenfeld
4	Schoenberg, Mozart, Ibert, Paganini, Mahler, Janácek, Pärt, Staud, Vanhal, Bottesini, Cassadó, Carter, Neuwirth, Eötvös
5	Hindemith, Beethoven, Schumann, Webern, Bruckner, Messiaen, Pintscher, Salonen, Gluck, Reimann, Reger, Ligeti, Marx, Martinú, Eröd, Rachmaninoff, Kodály, Vieuxtemps
6	Sibelius, Lutosławski, Nørgård, Nielsen, Grieg, Sinding, Lumbye
7	Wagner, Brahms, Haydn, Widmann, Salieri, Schubert, Ravel, Bizet, Berg, Liszt, Bartók, Verdi, Berlioz, Weber, Schmidt, Šestic, Boulez, Elgar, Vivier, Enescu, Poulenc, Cherubini
8	Handel

Table 10: Communities found by the Louvain algorithm for the Vienna Philharmonic.

similarly by all five orchestras, the results of these SRRMs revealed that the composer era played a more significant role in concert programming, at least for the RCO and the Vienna Philharmonic.

BSO	Posterior Mean	Posterior SD	z-stat	p-val
Intercept	-2.893	0.265	-10.911	0.000
Era	0.029	0.027	1.082	0.279
Nationality	0.005	0.006	0.763	0.446

Table 11: Summary of the SRRM fit to the BSO network with order $R = 2$ multiplicative effects. Composer era and nationality were nodal covariates.

Cleveland	Posterior Mean	Posterior SD	z-stat	p-val
Intercept	-3.234	0.328	-9.854	0.000
Era	-0.004	0.030	-0.148	0.882
Nationality	0.011	0.010	1.083	0.279

Table 12: Summary of the SRRM fit to the Cleveland network with order $R = 7$ multiplicative effects. Composer era and nationality were nodal covariates.

Additionally, a SRRM for replicated data was fit across all five networks, indicating a shared latent space among the five different orchestras. Again, for all of the models considered, even with multiplicative effects, the triad dependence fit could still be improved. However, for a SRRM with order $R = 5$ multiplicative effects and the nodal covariates of composer

RCO	Posterior Mean	Posterior SD	z-stat	p-val
Intercept	-3.104	0.250	-12.394	0.000
Era	-0.036	0.019	-1.948	0.051
Nationality	0.004	0.004	0.983	0.326

Table 13: Summary of the SRRM fit to the RCO network with order $R = 9$ multiplicative effects. Composer era and nationality were nodal covariates.

NY	Posterior Mean	Posterior SD	z-stat	p-val
Intercept	-3.143	0.244	-12.889	0.000
Era	0.009	0.020	0.428	0.669
Nationality	0.000	0.004	0.108	0.914

Table 14: Summary of the SRRM fit to the NY Philharmonic network with order $R = 8$ multiplicative effects. Composer era and nationality were nodal covariates.

Vienna	Posterior Mean	Posterior SD	z-stat	p-val
Intercept	-2.811	0.517	-5.438	0.000
Era	0.062	0.037	1.675	0.094
Nationality	-0.012	0.010	-1.214	0.225

Table 15: Summary of the SRRM fit to the Vienna Philharmonic network with order $R = 7$ multiplicative effects. Composer era and nationality were nodal covariates.

era and nationality (Table 16), both the coefficients for the composer era and nationality were significant. The coefficient estimate for the composer era was about five times larger than the coefficient estimate for the composer nationality. However, across all networks, both composer nationality and era played a significant role in determining concert programming, though composer era played a larger role than the nationality. This result makes sense from a musical standpoint, as it is often the era in which a piece was composed that determines the style, form and tone of a piece. Additionally, while composers in the established repertoire are primarily from only a few different countries, modern composers hail from a much wider range of countries, so perhaps composer nationality is less important for modern compositions than for pieces from the Baroque, Classical and Romantic eras.

	Posterior Mean	Posterior SD	z-stat	p-val
Intercept	-3.613	0.103	-35.177	0
Era	0.110	0.009	11.837	0
Nationality	0.020	0.001	16.044	0

Table 16: Summary of a SRRM replicated relational data model fit to all five of the networks with order $R = 5$ multiplicative effects. Composer era and nationality were nodal covariates.

4 Conclusions and Future Work

Overall, the concert programming of the BSO, Cleveland Orchestra, RCO, NY Philharmonic and Vienna Philharmonic was similar, with several composers performed much more often than other composers across all five orchestras, and composers of the same nationality programmed similarly, based on community detection. There were some trends that differed between orchestras, for example, the Vienna Philharmonic performed more works by Austrian composers than the other orchestras considered, but in general, the programming trends were quite similar. When SRRMs with nodal covariates of the composer nationality and era were fit, only the RCO and the Vienna Philharmonic had significant coefficients for the era of the composer in determining concert programming. However, across all five of the orchestras, both the nationality of the composer and the era of the composer had a significant effect in concert programming.

In the future, I would like to repeat this analysis with the nodes of each network representing the actual pieces performed, not the composers. Conventional wisdom holds that most concert programs follow the "overture, concerto, symphony" model (Tommasini (2008), Wittry (2007)) and I would like to explore the extent to which this programming model holds for different orchestras. Several additional nodal covariates, such as the key, performance length, orchestration, type (i.e. symphony or concerto), era and composer of the pieces, as well as the performance date, conductor and any soloists for the concert could be included. To ensure that the networks are not too sparse, several more years of programs would need to be included. Most of these orchestras maintain concert archives back to their founding in the 1800s, so in addition to collecting more data, it would be interesting to consider dynamic models that compare programming over time for each of these orchestras.

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