A SCHEME FOR MUSIC INTERACTION DESIGN AND NOTATION BASED ON DYNAMIC SOCIOMETRY

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ABSTRACT

A framework for musical interaction design and notation based on social network analysis is proposed. To this end, the affiliation network model, which comprises *actors* and *events*, is employed. Maintaining a sufficiently flexible definition of event can cater for both music improvisers and composers alike. If the (number of) events, their time occurrence and their action space (what happens in a given event) can be subjectively defined, then the concept of authorship and the continuum between improvisation and composition can be arbitrarily explored. The theoretical axioms of the affiliation network, along with methods for analysing its dynamics are presented. Furthermore, it is suggested that such analysis can provide a suitable strategy for notating emergent and/or composed musical interactions and, retrospectively, for designing some anew. Finally, a general scheme is illustrated, along with some speculative blends for its practical implementation.

1. INTRODUCTION

Networks can represent and study the interdependence, interaction and behavioural emergence of multi-agent systems, often a synonymous of complexity. Music ensembles, by virtue of the dynamical and complex interactions that define them, can also be considered as multi-agent systems, thus (socio-musical) networks. Improviser and researcher David Borgo, for example, states that "music, as an inherently social practice, thrives on network organization" [1, p. 11]. This characteristic has recently afforded ecological approaches and novel technological paradigms to music improvisation and composition, with contributions from practitioners, academics and researchers alike. In this paper a particular social network model, the affiliation network, is considered as a framework for both structuring and representing musical interactions.

1.1 Continuum

Musical composition is the strictest application of musical interaction, as it defines roles, times, content and expression for any given player in a music ensemble. Free musical improvisation sits at the opposite end of the spectrum, as it does not make a predefined commitment to any musical parameter, relying instead on the dynamic negotiation of the musical space and its organisation on behalf of the players, in real-time. Between these two extremes, there are countless hybrid tropes that blend improvisation and composition with varying degrees of integration, aimed at providing expressive opportunities and improvisational space to the players, while abiding by a top-down structural design. Amongst these, one can list *aleatoric* music [2] and *comprovisation* [3], although the contemporary and modern music composition practice abounds with examples of such blends. These, inevitably, require bespoke notation systems and methods.

1.2 Horizontal Time

There are innumerable approaches to notational systems developed to grant varying degrees of freedom to the performers. Amongst them, one could list proportional spatial notation (*e.g.*, Luciano Berio's *Sequenza I*), time-based pictographic scores (*e.g.*, Cage's *Waterwalk*), approximate pitch systems with (*e.g.*, tape-notation in Krzysztof Penderecki's *Threnody for the Victims of Hiroshima*) or without staves (*e.g.*, Schillinger graph-style notation [4]), altered (*e.g.*, Baude Cordler's *Belle, Bonne, Sage*) or specific notation systems (*e.g.*, Xenakis' *Psappha*), time-based abstract representation (*e.g.*, Hans-Cristoph Steiner's *Solitude*) or notation (*e.g.*, Rudolph Komorous' *Chanson*), free abstract representation (*e.g.*, Earle Brown's *December 1952*) or notation (*e.g.*, Mark Applebaum's *The Metaphysics of Notation*).

However, in the majority of the above, one cannot but notice the hegemony of linear time, which includes circular or periodic structures (*e.g*, George Crumb's *Songs, Drones, and Refrains of Death*). Temporal dependencies in (but not limited to) this particular musical domain are more often than not viewed as a serial procedure: event *A* happens before event *B*, and so forth.

Things do not seem too different in contemporary practices involving computer aided notation and/or composition for interactive musical performances. These include *screen scores* [5] and other scoring methods in the context of *networked performance* [6, 7] and laptop orchestras, sometimes referred to as responsive scores. Recent couplings of MaxScore [8] with node.js [1] have enabled be-

[1] URL: https://nodejs.org

spoke generation of scores for each client in networked performances comprising large numbers of players [9]. Nevertheless, systems as the latter, or such as *John* [10], *ZScore* [11], *Decibel ScorePlayer* [12] and so forth, are still primarily anchored to a horizontal viewpoint of time.

Motivated by the desire to break with a linear representation, notation and design of musical interactions, a method drawing from social network theory is proposed.

2. NETWORK THEORY

A network can be thought of as a systemic architecture within which elements connect and interact with each other. The bare minimum needed to describe a network is a definition of its topology and of its logical and operational affordances. In other words, it is necessary to know who/what is connected to whom/what, how these connections are formed or abandoned, and what are the eventual logical (or non) rules upon which these connections are contingent. A network can be represented as a system of connections (*edges*) between nodes (*vertices*). A basic understanding of network theory's terminology is assumed, however, the reader can refer to the Appendix, to this end.

2.1 Considerations

Many of the network model architectures developed in the context of graph and social network theory are difficult to port to a musical domain. The reasons are case-specific and embedded in their core axioms. For example, in the Erdös-Rényi random graph model [13], given a sufficiently large network, nearly all nodes will have the same *degree* (see Appendix). Furthermore, such model does not account for the instantiation of edges beyond randomness. Similarly, the Watts and Strogatz's *small-world* model [14], while it exhibits small average shortest *path* length (see Appendix), a large *clustering coefficient* (see Appendix) and addresses the absence of *hubs* (a node with atypically high degree), is still eminently stochastic. The *scale-free* model [15], on the other hand, abandons randomness as a potential way to explain large, complex social networks, thanks to the notion of *preferential attachment* [16]. However, a scale-free model is no less problematic when applied to music ensemble interaction or composition. In an ensemble of music performers and/or improvisers, the number of musicians is relatively small and each element (the musician) cannot be considered simpler than the system (the ensemble). Each musician is a complex decision-maker, evaluating strategies and responding not only to the local neighbourhood but also to the system as a whole. Furthermore, while it needn't be so, the prevailing norm in music performance and composition is to have a fixed number of players, while a scale-free network is dynamically growing and comprises a very large number of nodes (far exceeding the typical largest music orchestra). A candidate model for this paper's speculative framework is, instead, the affiliation network.

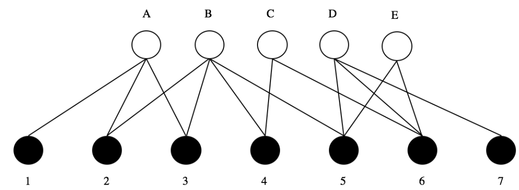

Figure 1. A bipartite graph representation on a two-mode network.

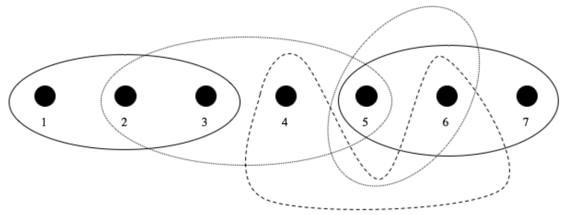

Figure 2. A hypergraph representation on a two-mode network.

3. AFFILIATION NETWORKS

An affiliation network, also called *two-mode* network, is described as "a network in which actors are joined together by common membership of groups or clubs of some kind" [17, p. 2570]. This model manages to introduce some non-trivial behaviours and a deviation from the low clustering coefficient of the random graph. A two-mode network can be represented as a *bipartite* graph or a *hypergraph*, as shown in Figure 1 and 2, respectively. Alternative ways exist to express the network concisely, without using a graphical representation, as it can be seen in the *incidence matrix* in Table 1. Rows represent the events and columns the actors, and their affiliation to any given event is expressed as a binary value. Based on the interaction strength, the edges in a bipartite network can be weighted, using a ratio scale (4 is twice 2, etc.). Figure 3 is an example of the same network with added weights.

Affiliation networks are relational and can show how actors and events are related, how events create ties amongst actors and how actors create ties amongst events. In general, affiliation networks can exhibit non-overlapping, nested or overlapping relations, as shown in Figure 4. Two-mode networks can include the synchronous existence of several events, which actors are free to choose from. This *modus operandi* can be useful for a musical interaction design that wants to expand and develop in time vertically, as well as horizontally (see Section 1.2). To design and notate musical interactions based on this model, it is worth describing its inner working a bit more in detail.

3.1 Measures and Metrics

The one-mode projection of the events (A, B, C, D, E) of the network in Figure 1 is obtained by constructing the 5-vertex network such that every event is connected to another if there is at least a member that participated to both.

1	1	1	0	0	0	0
0	1	1	1	1	0	0
0	0	0	1	0	1	0
0	0	0	0	1	1	1
0	0	0	0	1	1	0

Table 1. The same affiliation network in Figure 1, expressed as an incidence matrix.

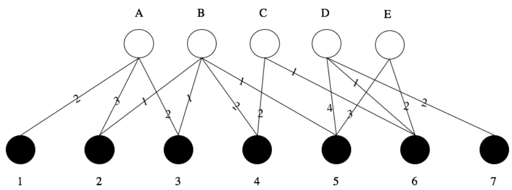

Figure 3. A weighted bipartite graph.

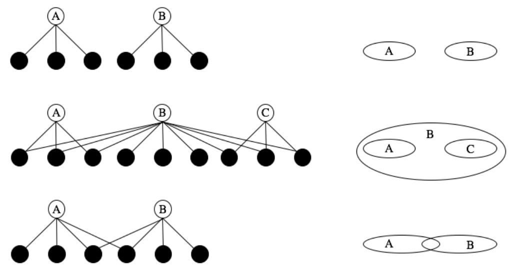

Figure 4. Non-overlapping, nested and overlapping relations (top to bottom).

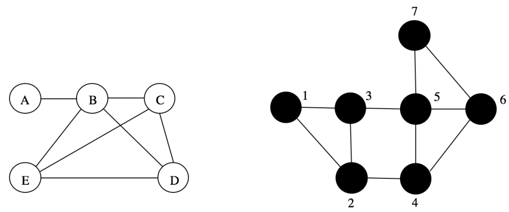

Figure 5. One-mode projections.

Conversely, the one-mode projection of the nodes (1, 2, 3, 4, 5, 6, 7) is obtained by connecting actors who have been part of the same event. The two one-mode projections are shown in Figure 5.

One-mode projections lose some of the information of the bipartite network, for example in the actors' projection, the number of events that any given two connected members have in common is not deducible. Things improve when using weighted edges, as shown above. However, neither hypergraphs nor bipartite graphs offer a comprehensive visualisation of the three layered structure consisting of actor-event, actor-actor and event-event. For this, Galois lattices have been proposed [18], but they are beyond the scope of this paper.

Despite the partial information loss, one-mode projections can be useful if one wishes, for example, to calculate shortest paths in the two-mode network, by simply projecting onto either actors or events and calculate path lengths as one would do in one-mode networks. A simple notion in a two-mode network is that of *co-affiliation*. An unnormalised measure of co-affiliation can be constructed by simply using a pairwise actor contingency table, as shown in Table 2, which refers to nodes 1 and 2 in the weighted bipartite graph of Figure 3.

In Table 2, the quantity a is a measure of the number of times that nodes 1 and 2 co-attended an event. To normalise this quantity, it is sufficient to divide a by n, which can be useful to compare other pairs of nodes. Alternatively, one can divide n by the $\min((a+b),(a+c))$, thus accounting for the maximum possible overlap given the number of events attended by both. Yet another normalisation would be to divide a by $(a+b+c)$, which expresses a in relation to the events that are possible to attend. Another important property in a network is that of *centrality*, which has been defined in a number of ways, for example based on *degree* (how active an actor is in the network), *eigenvectors* (if a central actor has ties with other central actors), *closeness* (how short are the potential paths to other actors), and *betweenness* (potential to mediate between other actors).

4. SOCIOMETRIC ANALYSIS

The measures discussed so far can be useful for the sociometric analysis of the network. For example, one could deduce who are the most central actors or events, how these relate to one another, the eventual overlaps of memberships and in general capture inner structures and behaviours. When thinking in musical terms, the actors being players, these insights can be used retrospectively for the design of structured musical interactions or for notating interaction dynamics which can be conveyed back to the performers.

In [19] it is posited that there are three main approaches to representation used in responsive scores. These are based on low-level audio, mid-level performance data, and high-level score data, respectively. In the same paper, a fourth approach is proposed, leveraging on machine learning to classify latent "musical agents" based on information retrieval methods and *telemetric* data. It is suggested that "technology can help us navigate this unknown territory through the transmission and generation of vital information and create new performance perspectives." In this paper, in agreement with the last statement, yet another approach is put forward, based on sociometric analysis, instead.

4.1 Dynamics

The principal motivation for using an affiliation network is to afford concurrent events and group memberships. This

		Node 2		
		1	**0**	
Node1	**1**	2 (a)	0 (b)	2 (a+b)
	0	2 (c)	0 (d)	2 (c+d)
		4 (a+c)	0 (b+d)	4 (n)

Table 2. Co-affiliation of nodes 1 and 2 in Figure 3's network.

property opens up design strategies for a multiplicity of musical interactions, which remain available to the players. However, this does not mean that one can entirely disregard sequential dependencies. Rather, the two viewpoints can coexist in the same conceptual space. An actor might be part of several events at different times in the performance, whether sequentially or periodically, although several events might be available at the same time. In a musical context it is reasonable to assume that a player can only be part of one event at the time, unless placing severe constraints on attention and focus which would reflect negatively on the quality of the music played. Therefore, to achieve dynamical re-configurations of the bipartite graph, a notion of sampling could be introduced. The rate at which players make changes in their outgoing ties could be also used as a further measure, *e.g.*, a 'rate function'. These repeated network snapshots could be regarded as discrete observations of a process developing in continuous time, where actors make changes in their evaluation of the state of the network, and constitute each other's changing environment. At each sampling step each player controls his/her membership and within each sampling period he/she (potentially) controls his/her behaviour in relation to the *clique* (in the current analogy: the musical cluster). Such discrete observations could be used to compute the measures described in Section 2.3, as well as for generating a time-explicit graph for visualisation purposes. Figure 6 illustrates two time steps in a hypothetical affiliation network (with only two events). Measures such as degree have to be redefined in relation to the network model. If considering a "one-mode" representation, then one will have measures for actor degree and for event degree. For an actor i and an event j these will be, respectively, the number of different actors who participate to the same event as actor i, and the number of different events which share an actor in common with the event j. As an example, Figure 7 shows the evolution of four player's degree over time [2]

5. SCHEME

The proposed framework is medium agnostic, and can be realised in whichever format is most congenial to the designer. For example, graphic scores could well be employed, as would any arbitrary blend of traditional notation techniques, abstract scores and technology-based representations. However, since we would like to benefit from the sociometric analysis described earlier, the specific

[2] This data is taken from one of the author's system's during a real performance.

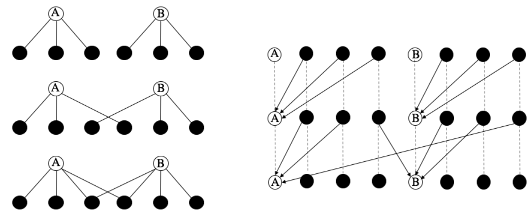

Figure 6. Cumulative graph after two periods (left) and corresponding time-explicit graph (right).

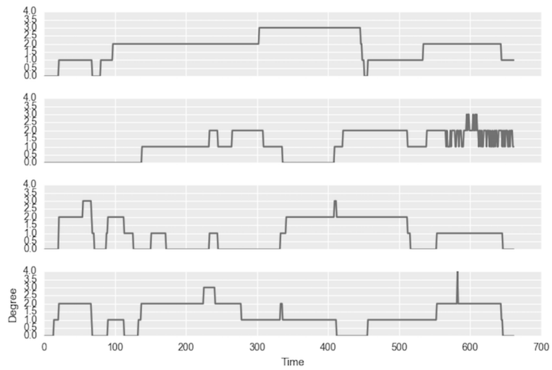

Figure 7. Example of four player's degree over time, from a "one-mode" perspective.

choice would depend on having a way for actors to route membership decisions back to the network. To this end, computer-aided systems, and in particular the networked performance paradigm, whereby the design and/or compositional parameters (*e.g.*, the timeline of scheduled event, the content specifics, etc.) are shared over a co-located or remote computer network, are an obvious choice. Practically, the system could be configured as a many-to-one topology, where each player receives and visualises the available information about the affiliation network state on his/her terminal. A central server would host the 'score' or the sequence of available events that are presented to the actors, along with arbitrarily complex descriptions of what any given event musically entails. Affiliation decisions' routing could be done in many different ways, for example, a foot-pedal array, a numerical keypad, a graphical user interface, and so forth. The server could thus perform some of the analysis discussed in Section 4 and this information could feedback into the system, at some level. For example, if it was the case that a particular event was consistently poorly attended, the system could choose to replace it [3] with a suitable alternative.

In exploring this model speculatively, two extremes can be considered to illustrate the potential flexibility of the system. In the first case, the framework would be used by ensembles of improvising musicians, thus the specifications on both actors and events would be assumed to be minimal and/or consensually agreed amongst the constituent players. In the second case, the framework would be used by composers who can have complete agency over

[3] stochastically or according to specific rules.

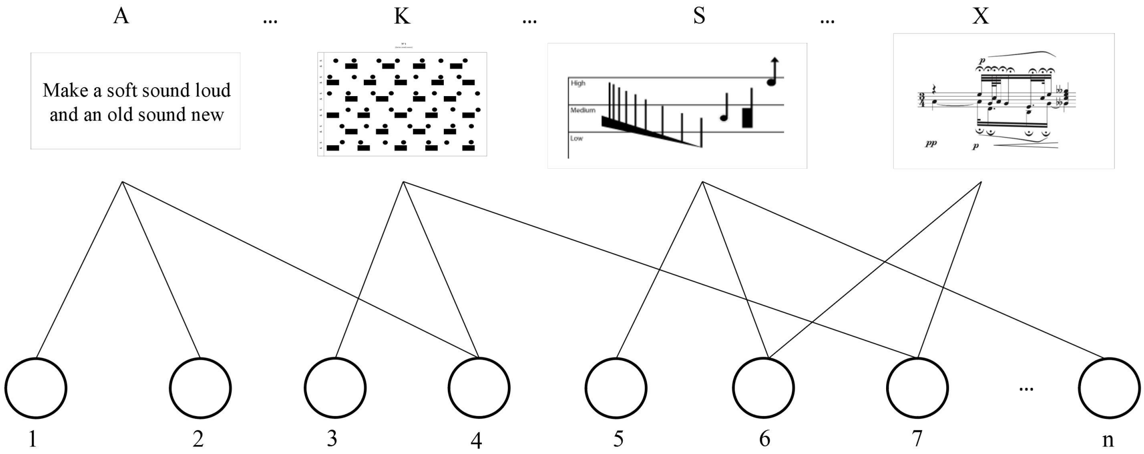

Figure 8. A speculative score, for illustration purposes only, with events ranging from abstract/aleatoric to conventional notation. Event *A* is borrowed from Oliveiros' *Klickitat Ride, 108 possibilities 54 opposites*, in [20]. Event *K* is Kirkpatrick's The Book of Musical Patterns No1 [21]. Event *S* is an example of relative pitch notation [22], and event *X* is a detail from Verheul's Nocturne No.14 [23].

both the actors (*e.g.*, orchestration) and the events (*e.g.*, event 1 = play specified musical material/score/ideas, event 2 = . . .). However, this very case would collapse the affiliation network into a sequence of pre-established memberships to groups on behalf of given actors. Notwithstanding this caveat, all continuous options in between free improvisation and highly constrained network parameters could be considered. Whatever the case, it is assumed that actors are free to join any given event available. This affordance will be dependent on how the time sampling is implemented, whereby, at given time occurrences, the players are presented with the opportunity to change their group membership. Of course, it is possible to introduce arbitrary flexibility regarding the sampling period. For example, this could be stipulated a priori by the composer (*e.g.*, regular or periodic time frames, time-line score, etc.) or negotiated in real-time by the improvisers, for example by means of a voting system or by cueing. Similarly, the events available at any given sampling step could be invariant or changing (both in action space and in number). These options could be chosen/fixed by the composer, stochastically determined (*e.g.*, using a probabilistic automaton), or even negotiated as above. In general, the network dynamics could depend on endogenous (*e.g.*, intrinsic in the design or resulting from reciprocity, transitivity, etc.), exogenous (*e.g.*, actor variables) and dependent (*e.g.*, ego-by-proxy, network position of strongest personalities) factors. The attendance to a given event in a musical framework of this type will then likely be a function of the willingness to cooperate with a given set of players (for a wide range of motivations) and of the appeal that a given event has for a player. Regarding the events' content, it is ultimately up to the end users or music designers to make specific choices in this regard. Figure 8 illustrates some of these options along the continuum, from abstract to notated. The overall scheme derived from this speculative application of affiliation networks to musical interaction is thus very simple, and can be summarised as a parametric space spanning a continuous domain ranging from designed to emergent, as seen in Table 3.

SAMPLING	EVENTS			ACTORS		
	Number	Content	Membership	Individual	Sectional	Mixed
Fixed						
⋮						
Mutable						

Table 3. A simple scheme.

6. CONCLUSIONS & FUTURE WORK

Graph models can be useful for exploring modalities of musical communication, interaction and creation, whether more composition-oriented or more improvised. However, to harness the potential of the network's notion in the context of finite music ensembles (which normally do not grow or shrink arbitrarily during the course of a given performance), considerations regarding structural and dynamic characteristics of the chosen graph model are paramount. Affiliation networks can offer an interesting viewpoint in that they allow concurrent options for the players to choose from. Thus, they challenge the well-established paradigm of sequential time normally used for interpreting, experiencing, and designing or composing musical interaction. Providing that non-intrusive and seemingly integrated ways to route membership decisions are implemented in this context, sociometric data analysis can be fed back into the network, thus injecting the musical interaction design process with real-time opportunities to morph and adapt, if one so wishes. However, since this model is purely speculative at this point, it remains to be seen whether or not it constitutes a valid scheme that can be flexible enough to accommodate a wide range of musical organisation level needs. Thus, the author endeavours to implement a working prototype in the near future and to test it in a real-performance environment.

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Appendix

The *degree* of a vertex is the number of edges ending in that very vertex. *Directed* and *undirected* graphs are defined based on whether the edges can be traversed in both directions or not, respectively. *Walks* are ways to get from one vertex to another, for example, a walk $(ahkjs \dots z)$ is a walk between *a* and *z*. A *path* is defined as a walk where all edges and nodes are different and a *cycle* is a closed path. The shortest path from one vertex to another is called a *geodesic path*, whereas the *average distance* is the average of the minimal path length between all pairs of vertices. The *coordination number* is the average degree in a graph, and the *network diameter* represents the maximum degree of separation between all pairs of vertices. In other words, is the longest geodesic path between any two vertices. A *clique* is a fully connected sub-graph. More formally, a clique is a set of nodes where every node is connected to every other in the set and where no node outside of it is connected to all the nodes that are members of it. Further essential definitions include the *clustering coefficient* of a vertex, defined as the average ratio between the vertex's degree and the number of neighbours that are also connected to each other, and the degree distribution p_k which, for a graph with N nodes and X_k being the number of nodes having degree k, is equal to $\frac{X_k}{N}$. A *complete graph* is such that each pair of vertices are adjacent, which means there is an edge joining them and the vertices are incident with such an edge. Finally, two graphs are *isomorphic* if there is an injective mapping (one-to-one) between the vertices on one graph and the vertices of the other, such that the number of edges linking any two vertices in one graph is equal to the number of edges linking the corresponding vertices in the other graph.