Converge/Diverge: Collaborative Emergence in a Composition for Piano, Double Bass and Interactive Music System

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ABSTRACT

This paper describes a composition for piano, double bass and interactive music system exploring the concepts of collaborative emergence and joint agency. In Converge/Diverge, the computer monitors the degree of timbral similarity between the two audio inputs (piano and double bass), identifies instances of "convergence" and "divergence" between them and responds accordingly. In addition to responding to the interaction between the two musicians, the interactive music system can act proactively, by initiating two additional interaction scenarios: "compete" and "cooperate". During the performance, the intentions of human and non-human agents are being continuously negotiated and adapted to changing group dynamics, leading to varied musical outcomes. The compositional methods used in the creation of the piece are discussed with respect to the conceptual and practical challenges posed by the concept of interactive musical works and, particularly, the trade-off between musical authorship and interpretative freedom.

1. INTRODUCTION

Compositional strategies aiming to blur the boundaries between composition and improvisation and expand the space of possible interpretations of a musical work are many and diverse. Over the last century of music history, open, graphic and text scores have been employed to allow for a higher degree of freedom in interpretation, leading to a new understanding of the musical work as a space of possibilities, as opposed to a thoroughly composed structure of sounds. In the last few decades, interactive music systems, i.e., computer music systems that use machine listening and generative algorithmic processes to interact with human musicians, have added to the complexity of interactions that can take place as part of musical performance and, by extension, to the creative possibilities available to composers.

Performances shaped by decisions made in real-time, whether by human or virtual performers, share a common objective: allowing for emergent musical phenomena, resulting from collective and spontaneous creativity. In interactive compositions, in particular, real-time decision-making takes place in the context of concrete interaction scenarios and is guided both by the interaction affordances of the computer music system and some form of performance instructions. Comprising both composed and improvised musical actions, interactive musical works showcase yet another type of collective creativity: an asynchronous collaborative creativity between the composer and performers – both human and virtual.

The concept of 'collaborative emergence', which refers to emergent group behavior that arises in improvisatory contexts in which there is no structured plan or a 'leader' guiding the group [1], is the focus of the composition described in this paper. *Converge/Diverge* is a composition for piano, double bass and Interactive Music System (IMS) based on a dynamic form, shaped by decisions made by the musicians and the IMS in real-time. The dynamic form of the piece allows for emergent musical phenomena, resulting from collective spontaneous decisions. Another central concept in this work is that of joint agency. In order for any musical change to happen during a performance of the piece, all actors involved (i.e., both musicians and the IMS) have to act jointly. As a result of this "constraint", during the performance intentions are being continuously negotiated and adapted to group dynamics and momentary stimuli, leading to varied sonic interactions and musical outcomes.

2. CONVERGE/DIVERGE, FOR PIANO DOUBLE BASS AND INTERACTIVE MUSIC SYSTEM

In *Converge/Diverge*, the two musicians (pianist and double bassist) are free to explore three different states of the Interactive Music System: "converge", "diverge" and "negotiate". By playing spectrally similar or dissimilar sound material (i.e., "converging" or "diverging"), the musicians can initiate different interaction scenarios, entailing diverse sonic interaction affordances. The terms convergence and divergence in this context refer exclusively to the degree of timbral similarity between the two inputs (piano and double bass), measured by calculating the Euclidean distance between Mel Frequency Cepstral

Coefficients (MFCCs)[1] extracted from the input signals. The interaction dynamics between the musicians are both sonified and influenced by the IMS, which, in addition to monitoring the interaction between the two musicians and responding accordingly, can initiate two additional states: "cooperate" and "compete".

The default state of the IMS is "negotiation". In this interaction scenario the musicians take turns, choosing sound material from a pool of notated actions (Fig. 1). The response of the IMS consists in generating spectrally compressed variations of the input signal, using a series of band pass filters and envelope followers to analyze it and additive synthesis to resynthesize it. As only a small number of frequencies is used by the synthesis algorithm, the electronic sound resembles a resonance, rather than an exact resynthesis of the human input.

Convergence and divergence can only be initiated by both musicians jointly, making interaction with the IMS a matter of negotiation, collaboration and joint action between the two musicians. Two separate pools of synchronous actions are provided as sound material for "convergence" and "divergence". By playing sound material from one of these pools, a musician extends an invitation to their co-player to "converge" or "diverge". As such an invitation can either be accepted or rejected, joint agency plays a central role in shaping the form of the performance. If the second musician decides to accept the invitation and join their co-player (that is, if both musicians start playing simultaneously), the IMS begins to assess their current interaction with the purpose to determine whether they are in "convergence" or "divergence" with each other.

The IMS responds to convergence by generating spectrally richer responses (i.e., increasing the number of individual frequencies used by the synthesis algorithm) and updating synthesis parameters with a longer delay. The system remains in this state for as long as the spectral distance between the two inputs remains under a certain threshold – i.e., as long as the musicians remain in "convergence" – meaning that the duration of this state is up to the musicians.

When divergence is detected, the IMS responds by initiating one of two additional scenarios: "compete" or "cooperate". In the latter, the system responds by generating a static spectrum, essentially becoming unresponsive. In order for this spectrum to be dissolved, the musicians have to "cooperate" (i.e., "converge").

A pulsating electronic sound (the result of amplitude modulation with a square wave) is an indication that the system has entered the "compete" mode. In this scenario, the musicians compete for the computer's attention, which only responds to the musician currently playing the most "novel" sound material. "Novelty" in this context is judged by calculating the spectral distance between currently and previously played sound material for each musician. In this interaction scenario, the musicians can use the notated material as a starting point and/or improvise freely, introducing new sounds of their own choosing. The duration of this scenario is determined by the IMS.

The IMS has no preconception of convergence or divergence, meaning that there are no hand-coded thresholds or machine learning involved in identifying certain sonic interactions as convergent and others as divergent. These states are understood as relative to the overall sonic interaction between the two musicians. The computer is essentially "learning" on-the-fly, by observing the interaction between the two musicians and comparing the current spectral distance between the two audio inputs to previously observed values. Whether a certain sonic interaction constitutes a "convergence" or a "divergence" is determined by comparing the current distance value to the standard deviation of previously observed values. If the current value falls outside the standard deviation in either direction, the IMS responds accordingly, by activating either "converge" or "diverge".

This constitutes an additional interaction feature of the IMS, which though originally not intended as such, adds to the idiosyncracy of the piece. As convergence and divergence are understood and conceptualized in the context of a specific sonic interaction and determined with respect to previously observed values, the ability of the IMS to successfully identify these states is based on data collected during the performance. This means that for the first few minutes of the performance the response of the IMS might be less reliable and predictable, as its decisions are based on a small amount of collected data. This feature only comes into play if the musicians try to initiate "convergence" or "divergence" within the first few minutes of the performance and is irrelevant if they remain in "negotiation" during this time.

In their interpretation of the piece, Nikolaus Feinig and Florian Müller (Ensemble Klangforum) deliberately attempted to initiate "convergence" and "divergence" early into the performance, with the purpose to induce unpredictable responses. This interpretative choice is an interesting example of the degree of interpretative freedom involved in the performance of interactive musical works, as well as the interplay between intended and actual interaction affordances in them.

Besides interpretative freedom, another aspect of composed interactive music made evident by different instantiations (i.e., performances) of the piece is that of interpretative individuality. In the rehearsals leading to another performance of the piece in New York, pianist Jana Luksts and double bassist Evan Runyon suggested that they were interested in differentiating their performance from previous performances of the piece by ensembles *Schallfeld* and *Klangforum*[2] (Jana Luksts and Evan Runyon, in discussion with the author, October 2019). Jana Luksts, in particular, suggested that she intended to play exclusively on the piano keyboard (as opposed to inside the soundboard) in "compete", as means to demarcate this scenario from the other interaction scenarios involved in the piece.

[1] Mel Frequency Cepstral Coefficients (MFCCs): the coefficients of Mel-Frequency Cepstrum, which is used to analyze periodical structures in a frequency spectrum. In a Mel-Frequency Cepstrum, frequency bands are spaced on a Mel-frequency scale, which approximates human perception of frequency.

[2] Videos of the two performances are available at: https://www.artemigioti.com/demos/Converge_Diverge.html.

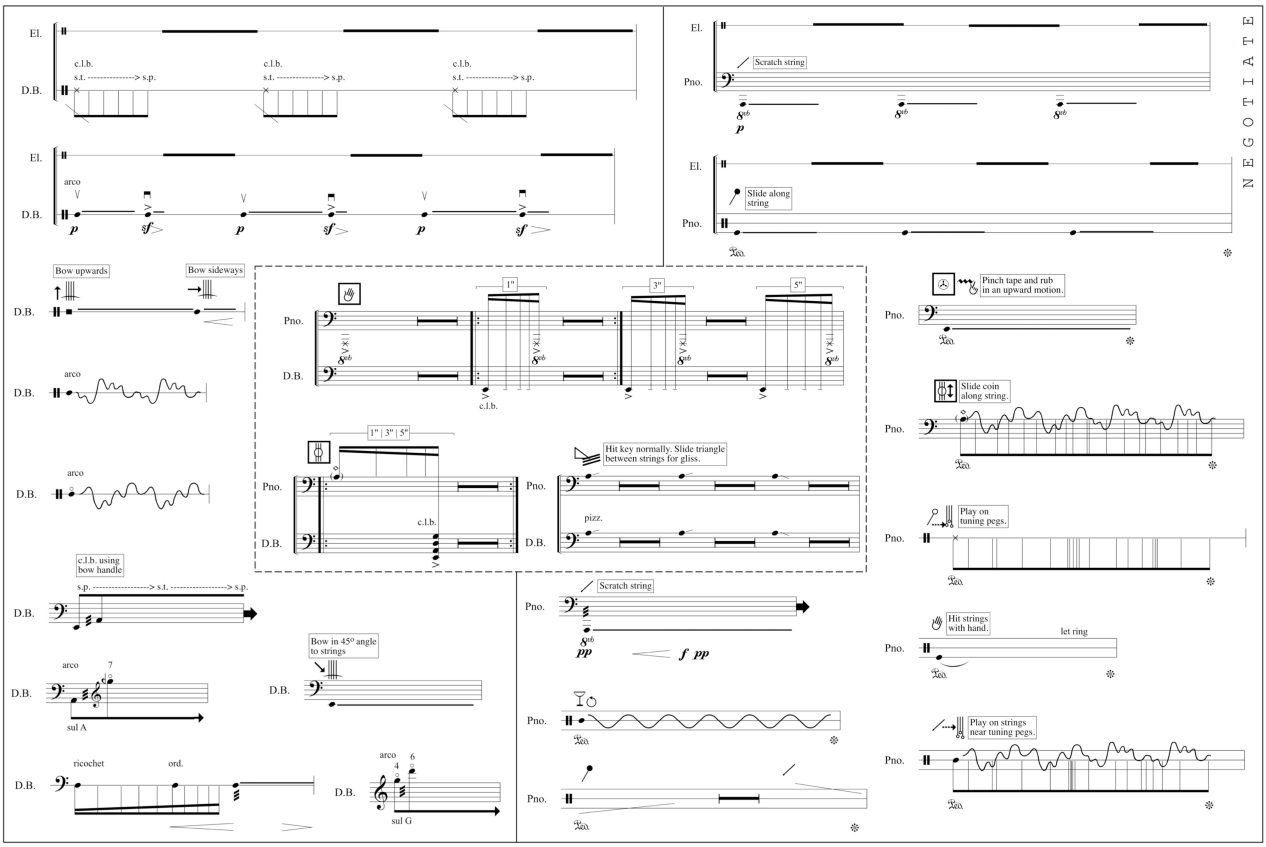

Figure 1. *Converge/Diverge*: score excerpt.

This interpretative choice reveals another way in which the creative responsibility delegated to the performers manifests itself in the piece: by informing and influencing its future performances. The work seems to evolve as different musicians develop diverse interpretative strategies and explore new areas of the action spaces available to them. Of course, the documentation and dissemination of different performances of the piece in the form of video or audio recordings is instrumental to this process.

Finally, central to any performance of this piece is the aural and visual communication taking place between the musicians and their interpretation of each other's intentions. In order for any musical change to happen during the performance, the intentions of all agents involved have to be aligned. Not only do both musicians need to be on the same page – both metaphorically and literally, as the pool of sound material for each interaction scenario occupies a single page – but also the IMS needs to correctly interpret their interaction. "Misunderstandings", both on behalf of the IMS and the musicians, are rare but possible, while intentions are constantly negotiated, modified and adapted to the current interaction.

3. COMPOSITIONAL PROCESS AND METHODS

The compositional process for this work involved a series of experiments based on guided improvisation tasks and conducted with the help of double bassist Margarethe Maierhofer-Lischka and pianist Patrick Skrilecz (Ensemble Schallfeld). In these experiments, improvisation was used to explore and refine both abstract compositional ideas and concrete interaction scenarios. Exploratory, 'naïve' and 'informed' rehearsals [2] were used in different stages of the compositional process and data from them was collected through observation, questionnaires and semi-structured interviews with the musicians.

3.1. Exploratory rehearsals: defining convergence and divergence

The purpose of exploratory rehearsals was to explore the evocative power of the concepts of convergence and divergence as metaphors for musical interaction, as well as the degree of intersubjectivity involved in their interpretation by the musicians. The musicians were given a total of 4 different improvisation tasks and were asked to reflect on various aspects of their improvisation (e.g., form, sound material, interaction etc.) in semi-structured group interviews following each task.

In the first task, the musicians were asked to improvise freely for an approximate duration of 10 minutes. They were then asked to reflect on their interaction during the improvisation and try to identify any moments of convergence and divergence. This was the first instance in which the concepts of convergence and divergence were

introduced to the musicians (i.e., the musicians were asked to reflect on these concepts only after the improvisation, rather than take them into account while improvising). Both musicians agreed that their actions were highly convergent and could not identify any moments of divergence in the session. When asked which element of the improvisation was most suggestive of convergence, they responded that their playing was centered around specific pitch centers.

In the second task, the musicians were instructed to explore the concept of convergence in an improvisation of approximately 10 minutes. In the discussion following this session, they commented that their actions were convergent with respect to pitch, timbre ('playing techniques') and loudness. Elements of musical form, such as different textures and musical gestures were also mentioned as aspects suggestive of convergence. The musicians agreed that both aural and visual communication played an important role in their interaction and pointed out that they perceived not only similar but also complementary actions as convergent, citing as an example a section of the improvisation in which loud chords on the piano were followed by sustained tones on the double bass, creating an artificial 'resonance'.

In the third improvisation task, the musicians were asked to explore the concepts of divergence and competition. When asked to describe this session, they mentioned that it was characterized by a higher level of activity, more frequent musical changes and a wider range of dynamics, pitch and rhythms. They commented that they consciously tried to avoid imitating each other's actions, but disagreed on which musical parameter was most characteristic of divergence, with opinion being split between rhythm and dynamics. Both musicians agreed that their interaction was not antagonistic and pointed out that they still tried to 'make music together'. Reflecting on their reluctance to explore more antagonistic forms of interaction, the musicians suggested that instructions to 'play faster or louder' than their co-player could potentially be helpful. Similarly to the previous improvisation task, visual communication was considered a crucial part of music-making.

Overall, the musicians repeatedly used the terms 'harmony' and 'harmonic' to describe the session exploring the concept of convergence and the term 'counterpoint' to describe the session on the topic of divergence, while they associated complementarity with both convergence and divergence.

Finally, the musicians were asked to improvise for another 10 minutes, this time incorporating both concepts in their improvisation. They were later asked to listen to a recording of this session and assess the degree of convergence between their actions on a scale from 1 (very low) to 5 (very high) for every 15" of the improvisation. Their responses were very similar, as shown in Figures 2 and 3.

These exploratory rehearsals helped shed some light on the concepts explored by the piece and the challenges involved in their adaptation into sonic interaction scenarios. The two main challenges identified through this process were:

1) the musicians' reluctance to explore antagonistic forms of interaction, a concept that was central to the compositional idea, and

2) that convergence and divergence can potentially be understood with respect to a variety of musical parameters (e.g., pitch, rhythm, timbre etc.) and behaviors (e.g., complementarity can be associated with both convergence and divergence).

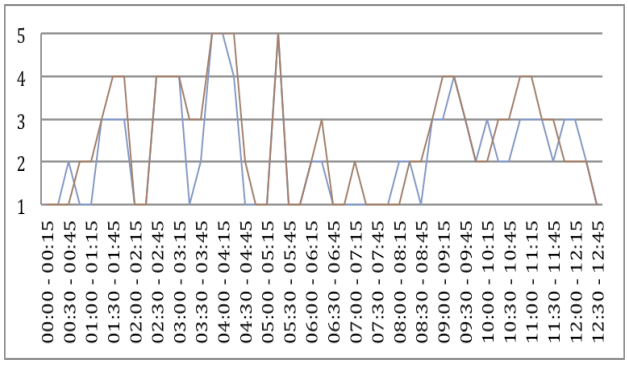

Figure 2. Degree of perceived convergence from 1 ("very low") to 5 ("very high"): individual responses.

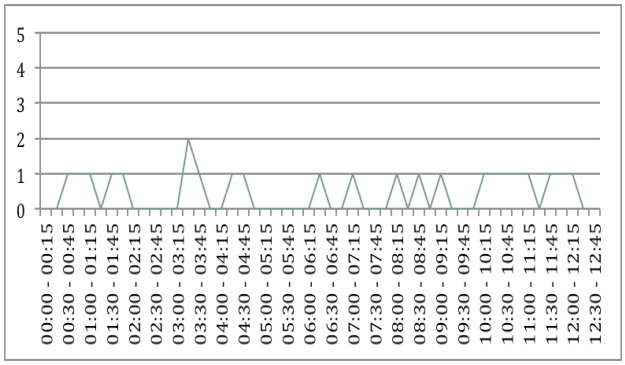

Figure 3. Absolute difference between the musicians' responses.

The first point was addressed by designing responses that reward musicians for exploring divergent sonic interactions. While the response of the IMS to convergence is hardly distinguishable from its default mode, consisting solely in increasing the number of frequencies and response time of the additive synthesis algorithm, divergence can initiate more diverse and less predictable sonic interactions. Concretely, when divergence is detected, the IMS can initiate either "compete" or "cooperate", a decision over which the musicians have no control. And while "cooperate" consists in a simple error-like behavior (i.e., a "spectral freeze" effect), which can be resolved through prescribed actions, the sound material for "compete" is effectively left to the musicians, who can choose to use (some of) the notated actions or improvise freely. Additionally, the IMS only responds to the musician currently playing the most novel sound material, a feature that was implemented specifically to encourage the musicians to experiment sonically.

While "convergence" and "divergence" can be understood in relation to a variety of musical parameters (e.g., pitch, rhythm, timbre etc.), in *Converge/Diverge* the focus lies on timbre. This was partly a sound-driven deci-

sion, dictated by the broader aesthetic context of the piece (i.e., sound-based as opposed to note-based music), and partly a form-driven decision, aiming to make different interaction scenarios and behaviors more distinguishable.

The decision to use the Euclidean distance between MFCC vectors as a measure of timbral similarity, as opposed to machine learning models built from human-labeled data, had some interesting implications for the sound material used in the composition. First experiments with this approach revealed significant differences between human perception of timbral similarity and the system's perception of spectral convergence and divergence. Spectral convergence was identified rarely by the IMS and seemed to be correlated with high-pitched, sine-wave-like sounds – i.e., overtones, lacking the characteristic timbre of the instrument. This led to the use of a number of unconventional playing techniques, such as rotating a glass on top of the piano strings or sliding a triangular ruler between them (Fig. 4). As the system's estimation of spectral similarity can, at times, deviate from human perception, the IMS has the potential to surprise the musicians, by behaving in unpredictable ways, a feature that adds to its idiosyncracy.

Figure 4. *Converge/Diverge*: extended playing techniques.

3.2. Naive rehearsals: balancing authorial responsibility and interpretative freedom

The exploratory rehearsals described in the previous section informed the compositional process, by playing a decisive role in both compositional and design choices. The use of qualitative research methods in their context (e.g., interviews with the musicians) enabled a more systematic and productive composer-performer collaboration and helped explore an abstract compositional concept and gain insight into some of the challenges relating to its implementation. Both the interaction affordances of the IMS and the sound material used in the composition were greatly influenced by insight gained through these sessions.

Exploratory rehearsals informed mainly the conceptual stage of the compositional process. Later in the creative process, when first drafts of the score and code were written, the musicians were asked to participate in a 'naïve rehearsal' [2], a format meant to explore the *perceived* – as opposed to *intended* – interaction affordances of the IMS and inform further compositional decisions. In this session, the musicians were asked to improvise with the IMS without being given any information regarding its interaction affordances prior to the improvisation – although at this point the musicians already knew that the concepts of "convergence" and "divergence" would play a central role in the piece. The purpose of this experiment was to identify unintended affordances of the IMS and explore strategies for balancing the trade-off between authorship and interpretative freedom in the piece.

After this improvisation session, the musicians were asked to fill-in a questionnaire regarding the system's behavior and responsiveness. Interestingly, the musicians failed to identify most interaction scenarios, with only one of them identifying amplitude modulation (i.e., "compete") as a response to 'divergent and chaotic sounds'. When asked to describe the system's various behaviors, they focused mainly on its response to different dynamics and registers, rather than the degree of timbral similarity between the sounds they played. They correctly observed that in some parts of the improvisation the IMS was listening to both of them, while in others it was only listening to one musician at a time. They agreed that the system was able to act independently of their actions, but thought that the influence its actions had on the course of the improvisation was limited. Overall, the musicians' responses suggested that the system's interaction affordances alone were ineffective in communicating compositional intent and that further performance instructions and knowledge of its capabilities would be needed in order to guide their actions towards the intended action spaces.

After filling-in the questionnaire, the musicians were given some general information regarding the system's sonic interaction affordances and capabilities and were asked to improvise with it for another 10 minutes. Data from this 'informed rehearsal' [2] was collected through observation and video analysis, as the focus in this session shifted from the musicians' to the composer's perception of the improvisation. Observing and analyzing the musicians' 'informed' interaction with the IMS helped compare the intended and perceived affordances of the IMS and devise performance instructions that bridge the gap between the two. This compositional method is described by Marko Ciciliani as 'subtractive composition' and involves starting from an action space that is as open as possible and gradually introducing performance instructions until it is reduced to an aesthetically narrower, yet, as far as concrete musical actions are concerned, still open space of sonic possibilities (Marko Ciciliani, in discussion with the author, March 2019).

The purpose of this method was to balance the trade-off between authorial responsibility and interpretative free-

dom in the work through revisions of the score and/or code. For instance, one of the main discrepancies between the intended interaction scenarios and the way the musicians chose to interact with each other and the IMS during the informed rehearsal concerned interaction timing. Concretely, the musicians played simultaneously for most of the improvisation and opted for textures of high density, which meant that there were virtually no moments of silence. While this is in no way meant as criticism, these choices deviated significantly from the interaction concept of *Converge/Diverge*, namely a dialogue-like, call-and-response interaction in which synchronous interaction would be the exception rather than the rule and would signify specific states (i.e., convergence and divergence). The reasons behind this compositional decision were both conceptual and aesthetic. As the piece is based on a conversational metaphor, the call-and-response paradigm seemed more fitting, inviting the musicians to listen and respond to each other in a dialogue-like way. From an aesthetic viewpoint, this interaction paradigm allowed more space for the electronics, as well as for silence, a concept of central importance in the author's work.

4. COMPOSITION AND IMPROVISATION

The tension between authorial responsibility and interpretative freedom in interactive musical works points towards the complex and dynamic relationship between composition and improvisation in them; a relationship that goes far beyond the composition/improvisation binary. Admittedly, the use of improvisation in composed music is not specific to interactive works and can take various forms depending on the composer's artistic goals and aesthetic stance. For instance, Scelsi famously used improvisation as a compositional method, by recording his own improvisations on tape and then transcribing them with the help of musicians [3]. In Scelsi's practice, improvisation was a means rather than an end in itself; it was a method used to produce scores that would ensure the reproducibility of the notated material.

Composers such as Mauricio Kagel and, most notably, Cornelius Cardew, on the other hand, viewed improvisation as a compositional strategy and incorporated it in their work in varying degrees. The use of ambiguous graphic notation by composers such as Cardew is a compositional strategy aiming to increase interpretative freedom [4]. Composer Cat Hope [4] uses graphic and animated scores to allow musicians to make decisions on how to engage with their instruments (both acoustic and electronic), in an approach that views improvisation as part of interpretation. In her works, some aspects of the performance are left to the musicians while others are clearly defined, ensuring that, despite the high degree of interpretative freedom involved in them, they are always identifiable as the same work.

Similarly, Richard Barrett [5] views notation and improvisation as compositional strategies and often combines precise notation with free improvisation within the same work. He uses the term 'seeded improvisation' to describe works in which precisely notated passages are interspersed with improvisatory passages, providing a form of overall structural context, while allowing the musicians to focus on spontaneous improvisatory actions. The argument behind this approach is that it can give rise to emergent musical phenomena, which would not have resulted from notation or free improvisation alone.

In *Converge/Diverge*, improvisation was used both as a compositional strategy and as a method for artistic experimentation during the compositional process. The combination of action-based notation with what could be partly described as a 'mobile' score, i.e., a score in which the order of notated material is decided during the performance [6] suggests that improvisation is an essential aspect of the interpretation of the work. However, "improvisation" in this context is not synonymous with "free improvisation", but rather improvisatory musical actions and decisions within "composed" interaction scenarios.

Additionally, in the work described here improvisation was integrated in a series of experiments designed to explore and refine an abstract compositional idea and, later on, identify the perceived interaction affordances of the IMS and inform compositional decisions. As interactive musical works challenge the composition/improvisation binary and, along with it, traditional compositional practices, such experiments can be helpful in dealing with the high degree of unpredictability involved in composed interactive music and deciding which aspects of the performance should be determined through performance instructions and which should be left to the performers.

5. COMPOSER-PERFORMER COLLABORATION

Hayden and Windsor [7] identify three different and, at times, overlapping types of composer-performer partnership: *directive*, *interactive* and *collaborative*. In the *directive* paradigm, the performance is completely determined through the score, while the relationship between composer and performer is hierarchical, with any collaboration between them being limited to issues of technical nature. In an *interactive* partnership, compositional decisions are informed by the performers' and/or technicians' input while some aspects of the performance might be open, but the composer is still the single author. Finally, the *collaborative* approach involves co-authorship and collective decision-making. In pieces created through the collaborative approach, the macro-structure of the performance is not determined by a single composer, but rather by group decisions made in real-time.

The type of composer-performer collaboration described here falls under the *interactive*, rather than the *collaborative* paradigm, even though the form of the piece is the result of group decisions and can vary from one performance to another. While compositional decisions were made by the author, each performance of the piece is a unique and unrepeatable event resulting from collaborative and distributed creativity. Creativity is distributed across actors (composer, performers, computer music system), different types of activities (composing,

programming, performing) and in time, as compositional decisions are made offline and interpretative decisions in real-time.

6. DISCUSSION

The concept of the interactive musical work poses a number of conceptual and technical challenges, not the least of which is reconciling its ontological status as the product of a co-creative process involving human and non-human actors with traditional compositional strategies. In interactive musical works compositional intentions, interpretative freedom and machine agency stand in a discursive relation to each other, as is evidenced by their widely varied instantiations in different performances.

This paper presented a series of methods used to navigate the tension between work identity and interpretative freedom in an interactive composition for piano, double bass and computer music system. These experiments aimed at exploring compositional ideas and their early implementations and informing further compositional and design decisions. Admittedly, these experiments were designed for a specific composition and are far from universally applicable. Nevertheless, similar experimentation frameworks could provide a fertile ground for composer-performer collaboration and creative experimentation within a broader range of 'open work' [8] musical practices.

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