PIANO & DANCER
(Paper)

Topics: Dance and Music

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Abstract
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Key words: Generative Music, Sensor Augmented Dance, Disklavier

Main References:
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PIANO & DANCER

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Abstract
PIANO & DANCER is an interactive piece for a dancer and an electromechanical acoustic piano. The piece presents the dancer and the piano as two performers on stage whose bodily movements are mutually interdependent. This interdependence reveals a close relationship between physical and musical gestures. Accordingly, the realization of the piece is characterised by a creative processes that merges choreographic and compositional methods. In order to relate the expressive movement qualities of a dancer to the creation of musical material, the piece employs a variety of techniques. These techniques include methods for movement tracking and analysis, generative algorithms for creating spatial and temporal structures, and the application of non-conventional scales and chord transformations to shape the modal characteristics of the music. The publication presents the artistic and technical aspects of this work and discusses some of the challenges that have shaped the creative outcome.

1. Introduction
PIANO & DANCER is a dance piece for a single human dancer and an electromechanical acoustic piano (Disklavier). This piece has been realised by the three authors of this publication. During the performance, both the dancer and the Disklavier are present on stage. The music of the performance is produced through the piano's mechanical movements. These movements are generated in real-time through a combination of compositional algorithms, stochastic functions, swarm simulations and modal mappings, all of which are influenced by the dancer's bodily movements. As a result, the piano and dancer are connected with each other through three levels of relationships: they are both physically present on stage and exhibit bodily movements, their respective movements are correlated through a generative intermediate layer, and they exhibit in the musical and bodily domain a clear correspondence in expressivity.
The realisation of *PIANO & DANCER* has been motivated mainly by our intention to create a performative situation in which dance and music are related not only through a correlation of

bodily and musical gestures but through a physical co-presence and interdependency. In particular, we wanted to establish an equal emphasis on the role of bodily movements for the dancer and the piano. This emphasis serves as a point of origin for shaping the visual and acoustic characteristics of the piece. Furthermore, by attributing the dancer and the piano a physical co-presence on stage, they both appear as performers and their relationship can be shaped through additional choreographic principles including movement synchronisation, distance correlations and haptic engagement. On a behavioural level, generative approaches provide the means to enable the piano to exhibit sensitivity to the dancer's activities and to exhibit both reactivity and autonomy in its response. By balancing the reactivity and autonomy of the generative system, the role of the piano shifts between that of a passive musical instrument and that of an autonomous entity. The sensing capabilities of the generative system are connected to an automated analysis of the expressive movement qualities of the dancer. This analysis not only frees the dancer in her interaction with the piano from the normal constraints of traditional piano playing but also connects the responsivity of the generative system to aspects of bodily movement that are perceptually meaningful for the dancer and the audience. This combination of physical co-presence, movement-based expressivity and artificial agency offers the opportunity to blend generative, compositional and choreographic approaches for the creation of the piece.

2. Background

This section provides a brief and by no means complete overview about some of the topics that are of relevance for this project. These topics include principles of applying choreographic and compositional methods beyond their original domains, the integration of machines as performers in dance, the application of algorithmic and generative approaches in music, and the analysis of high level movement features.

2.1. Extended Choreography

The principle of choreographing movement beyond the human body has been recently described by Mette with the term Expanded Choreography [1]. In her publication, the term refers to both the application of choreographic principles to nonhuman performers and the expansion of movement into an imaginary and virtual space. She exemplifies the latter principle by treating movement as a linguistic principle that becomes accessible to language- or word-choreography. In her publication [2], dance scholar Elswit formulates the notion of Extended Choreography in the context of reality television. Here, choreography takes over multiple roles in that it not only serves to define danced routines but also establishes the overarching narrative and viewing experience of the show. This latter understanding of Extended Choreography is clearly beyond the scope of our approach. Our focus lies on the establishment of formal relationships between body movement and music that permits the creation of musical material via the choreographing of bodily movements.

2.2. Extended Composition

While the term Extended Composition is rarely used, the application of compositional techniques within music and dance that go beyond the creation of sonic material is quite common. One of the most important extended techniques in musical composition deals with the distribution of sonic material not only in the temporal but also spatial domain. These approaches foreground the role of space as a aesthetic element in musical composition. A overview of sonic spatialisation techniques is provided in the PhD thesis by Bates [3]. Wishart's seminal text "On Sonic Art" [4] provides a thorough description of spatial motions for sonic objects. This text also highlights an interesting connection between what is regarded as a sonic gesture in the musical domain and Laban notation and movement analysis [5]. This connection is highly relevant for *PIANO & DANCER*, since it provides a conceptual and aesthetic inspiration for relating the spatial trajectories of the dancer's movements to musical gestures for the piano. The transfer of compositional principles into choreographic principles is also not uncommon in contemporary dance. A particularly popular technique is musical counterpoint. In music, this term refers to the establishment of harmonic relationships between two melodic lines whose rhythm and contour are different. In dance, the counterpoint principle can be applied to align and merge choreographed sections into coherent unities that differ in their use of space, time, or movement. This technique has been extensively used by choreographers such as William Forsythe, Marius Petipa, George Balanchine, Trisha Brown, Jonathan Burroughs, and Pablo Ventura [6]. More closely related to the context of this publication are approaches in composition that extend creative considerations into the domain of material objects. The creation of idiosyncratic physical interfaces for controlling live aspects of a musical performance is particularly popular, as is reflected by the many activities and research projects that are presented at the yearly New Interfaces for Musical Expression conference. Somewhat less prominent are compositional approaches that deal directly with the sonic qualities of custom designed physical objects. Among the most famous of these examples are the works by composer Alvin Lucier [7]. A very recent set of compositional approaches for working with physical objects is provided by Lähdeoja [8].

2.3. Machines as Performers

The exploration of specific movement qualities of mechanical systems forms an interesting strand for artistic experimentation. Most of these approaches focus on robotics. The authors are not aware of any examples in which choreographers have staged musical instruments in order to highlight their capabilities for mechanical movements. Nevertheless, the application of robotics in dance provides a useful context for this publication. Among the artists who have most thoroughly experimented with the choreographing of robots are the performance artist Stelarc and choreographer Pablo Ventura. Stelarc usually treats his robots as mechanical extensions to the human body. His cyborg constructions serve to not only drastically alter the movement capabilities of the human body but to also shift the agency of the human performer partially or entirely towards the robotic system [9]. Pablo Ventura on the other hand employs robots a separate entities on stage whose juxtaposition and contrasting with human dancers serves to question the distinction between specific human and machine-like qualities [10]. The combination of robotics and dance is a popular phenomena, in particular among asian choreographers. Recent examples of human-robot choreographies include choreographies by taiwanese choreographer and dancer Huang Yi for a duet consisting of a human dancer and a KUKA industrial robot (http://huangyi.tw/) and the drone “augmented” dance performances by the Japanese dance troupe Eleven Play (http://elevenplay.net/).

2.4. Algorithmic and Generative Composition

The field of algorithmic composition is large and well established. Due to the formalised characteristics of western musical styles, their composition has exhibited an affinity to algorithmic techniques. While the usage of algorithmic methods for the creation of musical material pre-dates computers, computers have significantly expanded the potential of these techniques. A broad overview about algorithmic composition techniques is provided by Nierhaus [11]. The adoption of techniques from artificial intelligence (AI) and artificial life (ALife) is a more recent phenomena. Fernández and Vico [12] provide a very condensed overview about such techniques on the context of composition. This background section focuses on those approaches that are most closely related to *PIANO & DANCER*, that is the application of swarm simulations for real-time algorithmic composition. A very famous example is the work Swarm Music by Blackwell [13] that employs a swarm simulation in the role of an artificial musician that responds to the performance of three human musicians. For his thesis project, Albin [14] has studied the legibility of musical mappings and interaction principles in musical applications of swarm simulations. In particular, his experimentation with different types of swarm responses to interaction are interesting in the context of this publication. Finally, a publication by one of the authors [15] is relevant in that it highlights conceptual and practical techniques for situating the design of swarm simulations as core element within a composition process.

2.5. Movement Analysis

Interactive technology in dance is often based on sensor systems that are capable of tracking the movement of one or several dancers. Here, the most popular sensor systems are either cameras or inertial sensors. The former provide an allocentric and absolute frame of reference whereas the latter provide an egocentric and therefore relative frame of reference. Inertial sensors provide a number of benefits over camera-based systems: they detect more nuanced and small scale movements, they can be placed to monitor specific limb movements, they don't constrain the dancer's spatial position, they exhibit less latency, they are not affected by light conditions, and they don't exhibit visual occlusion effects. Therefore, these sensors can be employed in less controlled and more diverse performance environments than camera-based systems. Even more importantly, inertial sensors provide measurements that are closely related to a dancer's own kinaesthetic body awareness. This forms an important aspect for the extraction of high level movement features from these measurements. Such high level features are able to convey information about the expressivity of a dancer [16]. By integrating a high level feature analysis into an interactive system, this system becomes capable of detecting and subsequently responding to movement qualities that are also salient for the dancer and the human audience [17]. This alleviates one of the main problems of interactive technology in dance: the constraining of dance movements through technological prerequisites and the shifting of the dancer's body control away from intentionality and expressivity towards purely physical aspects of movement [18].

3. Realization

The following section describes in some detail the compositional, algorithmic and choreographic considerations and technical implementations that shaped the realization of *PIANO & DANCER.* At the core of the realization lies the attempt to establish of a close relationship between the visual and acoustic presence, behaviours, and expressivity of the dancer and the piano. Because of this, choreographic and compositional principles are tightly interconnected. One of the main challenges concerns the integration of these principles in a manner that not only respects the different properties of these two creative domains but that also establishes an aesthetic coherence and unity between them. An obvious first step in this direction is to enable the dancer to control the piano through other means than direct tangible interaction. By doing so, the functional constraints of sound producing gestures and the immediacy of their effects on the musical result are dissolved. This provides the opportunity to invent novel and diversified relationships between physical and musical gestures. As a result, the dancer's bodily movements can be shaped according to choreographic criteria and the relationship between movement and music can be expanded to involve interactive control of the compositional structure itself. By integrating algorithmic and generative methods as mediating layers between movement and music, both the choreographic and compositional aspects of the performance can exhibit their own respective levels of complexity while maintaining a strong causal relationship. From a musical point of view, these layers condition the composition of the work. There exist multiple algorithms that create itineraries, rotations, control densities, speeds, rhythms, motifs and relationships within a composed layer of predefined musical entities. These algorithmic abstractions are perturbed, controlled or affected in different ways by the bodily movements of the dancer.

3.1. Algorithmic Composition

The entire composition is implement in the Supercollider programming environment and is generated live during the performance. The algorithmic composition layer is composed of several abstractions that mediate between the dancer’s movements and several pre-defined harmonic fields and modal systems. During the piece, these harmonic fields change and evolve according to certain algorithms. Some of these compositional approaches explore the properties of finite groups. This for instance is the case for the automated creation of inverted transpositions on the same fundamental note. Other approaches make use of probability distributions such as Gaussian, Beta or Uniform distributions. These distributions are used for example for the creation of random walks. On a rhythmic level, an automated system for the creation of polyrhythms has been developed for the piece. Each of these algorithmic approaches is related to and selected for a specific type of dance movement, harmonic field or other musical structure. As an example, the application of automated transposed inversions depends on the rotation of the dancer's wrists. For each wrist rotation, the algorithm returns a new version of an array of numbers corresponding to an inverted transposition with the same fundamental note. Based on the direction of a wrist's rotation, the resulting chord is either in a closed or open position. Another example is the application of a one dimensional random walk over lists of discrete values that sonically convey the smoothness of the dancer's movements. The step size of the random walk is controlled by the jerkiness [19] of the current movement and the direction of the step is depended on the direction of the angular acceleration of the movement. A set of probability distributions are employed to shape the density of events and also to distribute them across different harmonic fields. For example, Cauchy, Gaussian or Poisson distributions are combined and superposed and ~~their~~ their mean is assigned to ~~the~~ a tonal centre ~~of an~~ associated to body joints whose computed energy perturb the parameters of these distributions.

3.2. Modal Scale and Chordal Systems

Different types of predefined modal systems or key chords shape the harmonic content of the piece. Some of these structures have been calculated algorithmically while others are obtained by hand. The most frequently employed structure is a set of notes extracted from a melody in the piece *Don Giovanni* by Wolfgang Amadeus Mozart. More specifically, this set corresponds to a fragment of a chromatic passage that is sung by the Commendatore during the last part of the opera.

This set of notes represents an impressive example of how a classic work can become renewed when listened to within a contemporary context. By bringing these notes into a vertical form, they create an extremely colourful and resonant chord. This chord is subjected to several algorithmic mutations during the piece. It is only at the very end of the piece that the melody is heard diachronically in its original disposition. Another harmonic field designed for the piece is a non-octavating scale. This structure represents an expansion to the tempered system of a microtonal scale in 48 parts of an octave. This structure has been previously designed by one of the authors in collaboration with the musician Mahmoud Turkmani for the piece *HIBR* for Oud and electronics.

A non-octavating scale does not repeat after covering the span of an octave; it possesses different sets of notes in each octave but maintains intervallic consistency. This offers the interesting possibility of assigning different sections of the scale to the movement of different joints of the dancer's body. Another palette of colours results from the juxtaposition or superposition of modes of limited transposition [20]. On several occasions throughout the piece, different modes and transpositions are assigned to the activity or movement quality of the dancer's body joints. The string of notes that is being played by the piano modulates to the mode and transposition associated to the joint that has the most prominent activity. Another approach involves the assignment of multiple modes to different body parts in order to create a polymodality. By carefully choosing rest positions in each mode, particular harmonic effects can be achieved. In a more sophisticated form, each of these modes and body joints can be associated to particular flock within a swarm simulation. The musical mapping of these flocks gives rise to a kaleidoscopic cascade effect.

3.3. Constraints and Capabilities of a Disklavier

Creating an interactive sonic performance for a physical acoustic instrument introduces additional challenges as compared to working with virtual instruments. The main issue of working with an acoustic piano whose keys are triggered by the dancer's movements without actually being touched concerns the delay time in the instrument's response. Latency is particularly problematic in sonic interaction situations that are supposed to create a quasi synaesthetic effect between visual and acoustic modalities. The disklavier exhibits two different types of latency. The first type of latency corresponds to the mechanical delay that any piano exhibits between the initiation of the finger-key contact and the resulting hammer-string contact [21]. This delay varies between 20ms for very high key velocities and 200ms for very low velocities. As a result, the playing of very short and quiet notes may lead to a mechanical actuation that doesn't bring a hammer in contact with its string. In order to avoid this effect in *PIANO & DANCER*, the control of the disklavier is either filtered or the interactive input is adjusted correspondingly. The second type of latency results from a pre-delay mechanism of the disklavier that serves to compensate travel time differences for different key velocities. This pre-delay has a duration of 500 ms which is too long for interactive situations. For this reason, the pre-delay mechanism has been deactivated for almost all of the scenes in the piece. A further limitation of the disklavier that has been used during rehearsal and performance is the inability of the piano controller to play more than 16 notes simultaneously.

3.4. Choreographic Structures

The choreographic material developed for *PIANO & DANCER* emerges in many ways from the sensory motor coupling with the mechanical piano. The choreography explores on one hand the possibility that each quality of the dancer's movements becomes sonically mirrored by the piano. For the audience, this mirroring corresponds to a cross-modal transfer from the visual domain of movement into the acoustic domain of listening. On the other hand, the choreography also experiments with the reverse approach, that is, to adjust the dancer's movements in order to meet a specific musical result. The choreographic strategies for relating movement qualities and music have been developed within the framework of the EU-H2020 ICT project Wholodance. One of these techniques is based on the movement qualities smoothness and fluidity and employs the metaphor of a sound wave. For a sound wave, it is not the particles themselves that travel through the elastic medium but their perturbation patterns. Similarly, in dance we distinguish between **i)** a pattern which is propagated from within the body and travelling through the kinematic chain of adjacent joints, or **ii)** the propagation travels from a pro-active body part through the external medium surrounding the dancer and affecting the re-active behaviours of other body parts. In addition to these approaches, the choreography is based on abstract transformations of trajectories performed with imaginary inscriptors associated to body parts. These spatial paths are fragmented, rotated, and inverted along different axes (vertical, sagittal, and horizontal) and planes (front, middle, and rear). The spatial transformations can be related to chord inversions or permutations of strings of notes.

3.5. Swarm Simulation

The swarm simulation for this piece has been implemented using the ISO generic programming library [22]. The repertory of swarm behaviours that are provided by the programming library has been expanded with several additional behaviours (see Figure 1, top row). These behaviours have been developed to meet the specific requirements to provide control data for the creation of discrete and note based musical forms.
The most important of these behaviours are:

- A simple discretisation behaviour that maps any continuous agent parameter such as position or velocity to a set of discretised values. These values can for instance be directly representative of pitch classes or note values (see Figure 1, top left).
- A cohesion behaviour that permits the specification of axis aligned offsets among the positions of neighbouring agents. The cohesion behaviour causes neighbouring agents to converge on spatial positions whose relative distances among each other correspond to those offsets. This effect permits the realising of chord-like groupings within a swarm (see Figure 1, top middle).
- A neighbourhood behaviour that encodes the positions of neighbouring agents in spherical coordinates in order to simplify the distinction between distance and orientation relationships within a swarm. The distance can affect for instance the intervallic relationships between notes whereas the orientation could give rise to chord permutations.
- A sequencing behaviour that triggers a timed series of modifications to a particular agent parameter. If the parameter is directly related to the agent’s movement, then the sequencing behaviour causes the agent to move along a specific trajectory in space. Depending on the type of parameter, the invariance of this trajectory is different. If the parameter is the agent’s position, the trajectory is always identical in shape, scale and position. If the parameter is the agent’s velocity, the trajectory will have a fixed shape but its scale depends on the mass of the agent and its position can be anywhere in space. If the parameter is the force acting on the agent, the trajectory can be varied in shape, scale and position depending on the other forces that are also acting on the agent. The purpose of the sequencing behaviour is to generate control data that exhibits a motivic form (see Figure 1, top right).

The swarm simulation comprises four different swarms, each of which consists of five agents only (see Figure 1, bottom row). The numbers of swarms corresponds to the numbers of internal sensors that are placed on the dancer’s body. The number of agents in each swarm is motivated by the desire to directly relate agent parameters to chord structures that consists of up to five notes. By using multiple swarms instead of a single swarm within which subgroups of agents are assigned to different inertial sensors offers several benefits. First of all, the behaviours and parameters for each swarm can be configured independently. This provides the possibility to create an interactive system in which each joint movement gives raise to a different response within the swarm simulation. As an additional benefit, multiple swarms can exhibit more complex neighbourhood relationships than a single swarm, since the neighbourhood dependent behaviours such as cohesion, evasion and alignment can be specified differently for neighbourhoods that span across multiple swarms. Finally, each swarm in a multi-swarm simulation can be equipped with different spatial bounding behaviours and thereby be confined to different regions within simulation space. These regions could for instance be mapped to different registers on the piano.

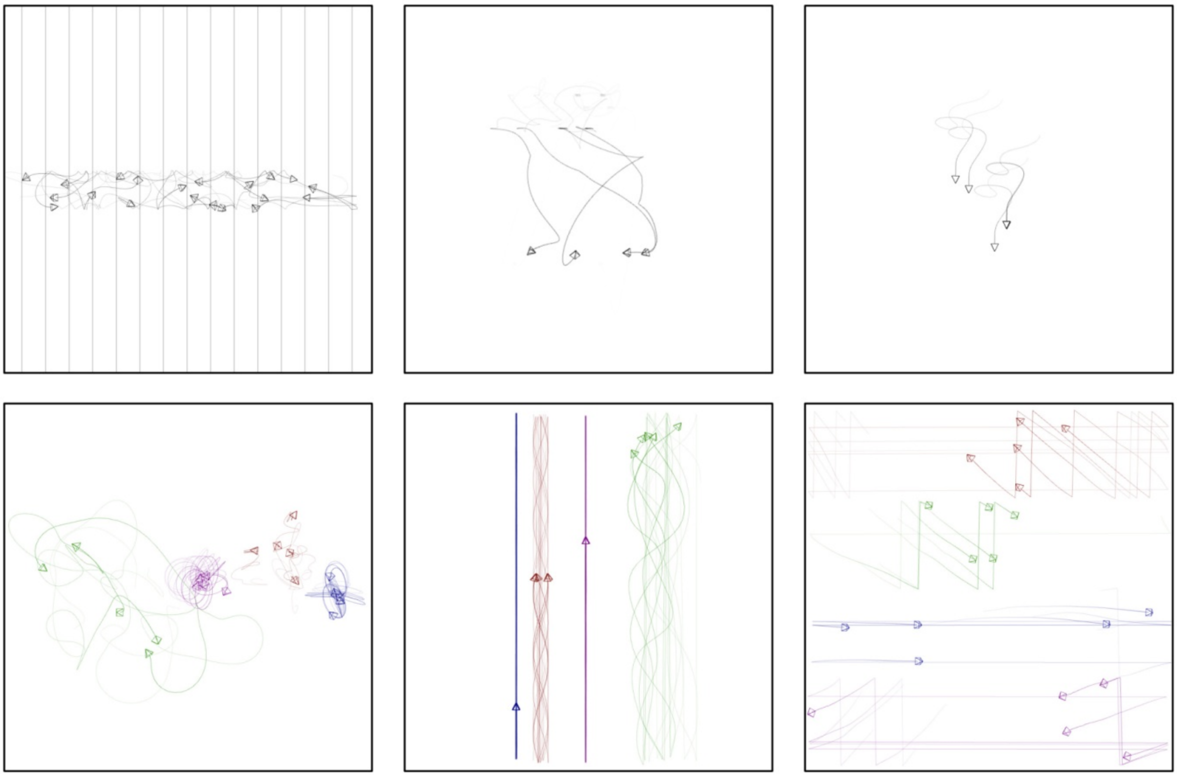

Figure 1: Swarm behaviours and multi-swarms. The top three images depict different swarm behaviours. From left to right: discretisation behaviour, axis aligned offset behaviour, sequencing behaviour. The bottom three images show different multi-swarm simulations. From left to right: the evasion distance among agents within each swarm increases for low levels of dynamic symmetry among the dancer's joint movements, the amount of alignment among agents within each swarm changes depending on the velocity of each of the dancer's joint movements, the amount of alignment within a swarm and across different swarm is manually changed.

3.6 Movement Sensing

For almost all the scenes in *PIANO & DANCER,* interactivity is based on sensing the dancer's movements with inertial measurement units (imu) that are attached to the dancer's body. This technique is complemented only during particular moments by a camera-based tracking system. This complementary system permits the dancer to ~~trigger of notes~~set into motion the piano keys or to accentuate notes~~s~~ with any part of her body regardless of whether an imu is attached to it or not. The imu devices that are used for the piece are named *Xosc* and are provided by the company *x-io Technologies*. These devices integrate a gyroscope, an accelerometer and a magnetometer, each of them providing~~es~~ three degrees of freedom. Furthermore, these devices offer a Wifi-based wireless connectivity whose communication frequency and latency is of very good quality even when multiple devices are used concurrently. For the piece, four of these devices are employed to track the movements of four joints on the dancer's body (two wrists and two ankles). Interactivity is based on both the acquisition of raw sensorial movement data as well as higher level movement features such as fluidity, smoothness, weight, energy and dynamic symmetry [23]. The conceptualization of these movement features is inspired by the definition proposed by choreographer Rudolf Laban [5] but occasionally deviates in its implementation from this definition. The computation of these higher level features is implemented in the *EyesWeb* programming environment. As part of two EU ICT H2020 projects (Dance and

WholoDance) in which the authors of this paper are participating, a custom *EyesWeb*-based software application has been developed. This application processes the raw imu data and extracts ~~low and~~ higher level movement features. These features are sent via the open sound communication protocol (OSC) to the composition and piano control software. This latter software has been developed in the Supercollider programming environment.
Some of these qualities, as defined within the framework of the Wholodance project are:

- Energy: The kinetic energy of moving joints weighted by masses taken from biometric tables [19].
- Smoothness: A concept from biomechanics defined as minimum jerk. The movement of a joint is considered smooth when no abrupt changes in acceleration occur. When taking into consideration the activity of multiple joints, fluid movement would correspond to a smooth and coordinated wave-like propagation pattern through several body joints [24].

- Dynamic Symmetry: This higher level feature differs from static symmetry in that it includes dynamic and temporal aspects. Dynamic symmetry is based on the analysis of the coordination and dynamics of multiple parts of the body [23]. In *PIANO & DANCER*, dynamic symmetry is derived for example from a comparison of the smoothness of movement between pairs of joints.

3.7 Technical Integration

The integration of all the technical components is depicted in Figure 2. The four imu devices that are attached to the dancer's body communicate via Wifi with an industrial Gigabit Wifi router over a private network. The router, one Mac Mini and two Macbook Pros are connected to a Gigabit switch. The Mac Mini runs an *EyesWeb* patch that extracts low, mid and high level movement features from raw imu data. The first Macbook Pro run musical algorithms within the Supercollider programming environment. This computer is also connected to an audio interface that communicates via the Midi protocol with the control unit of the disklavier. A second Macbook Pro runs the swarm simulation software. The *Eyesweb* patch, the musical algorithms, and the swarm simulation exchange data via OSC. The *EyesWeb* patch sends quantified high level movement features to the musical algorithms. These algorithms translate the movement features into OSC commands that modify the configuration of the swarm simulation. Vice versa, the swarm simulation sends via OSC specific properties of the individual agents back to the musical algorithms. These properties include: the position and velocity of the agents, the level of alignment between these velocities, and the properties of the neighbourhood relationships in spherical coordinates. The playback of the piano is controlled by the musical algorithms via Midi commands. These commands control NoteOn and NoteOff events, the piano pedal, the mute pedal, and the activation and de-activation of the piano key synchronisation delay. Furthermore, the musical algorithms pass Midi information about keys that are being depressed by the dancer as positional events to the swarm simulation.

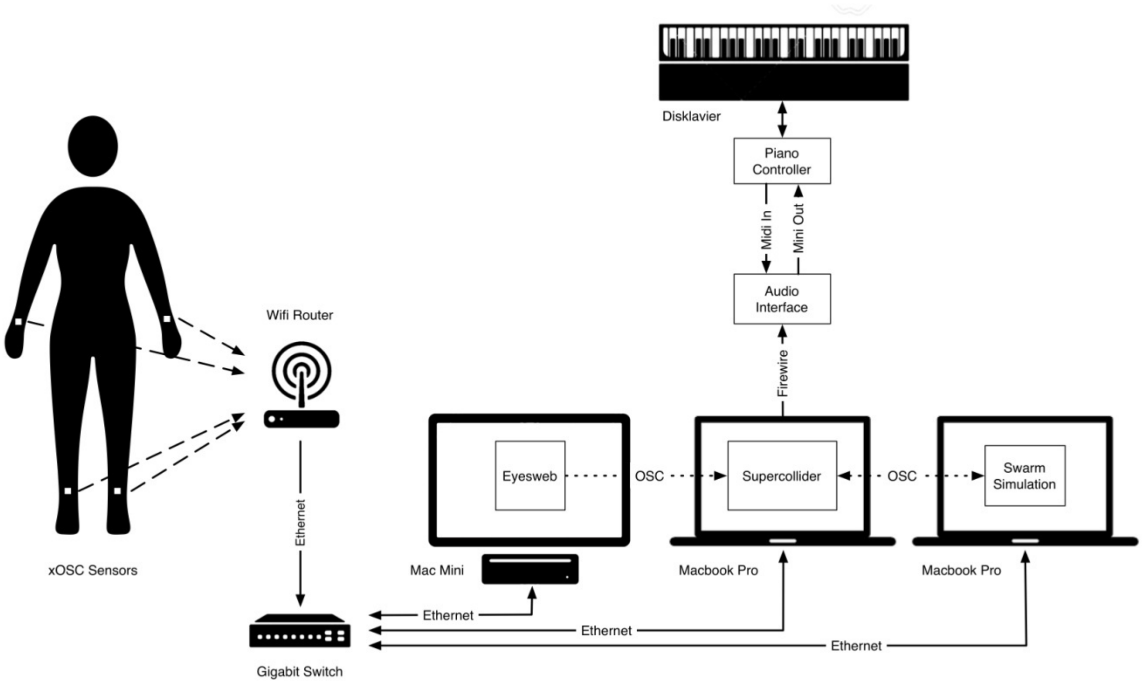

Figure 2: Technical integration of the sensing, communication, computation and piano control systems.

4. Performance

Each of the composed scenes in *PIANO & DANCER* develops a particular musical material or algorithmic approach to composition, a certain movement quality or choreographic structure ~~connected to~~associated to certain body parts and how these are connected to the actuation of piano keys. Narratively, the piece is conceived as a stroll of a dancer through a musical garden that is formed by the sonic entities emerging from the piano. These sonic entities serve most of the times as acoustic extensions of the dancer's behaviour, but at other times, they respond proactively and transform the dancer's sensorial input. The dancer experiences the piece as a magical itinerary composed of unstructured fragments tossed together as in dreams, and in which her movement capabilities have been expanded to another sensory domain. This domain is that of the piano which does not possess a unitary sound but rather creates a multitude of sonic aspects and timbers which flourish along the dancer's path. Some of these multimodal situations will now be briefly described.

The beginning of the piece establishes the connection between the dancer's body activities and the motion of the piano keys. The subtle and shaky movements of the dancer's feet cause the keys to move in the low register but the hammers only hit the strings when a critical movement energy is exceeded (see Figure 3 bottom right). This relationship is complemented with a series of clustering chords activated by the dancer's right hand vertical movement (see Figure 3 bottom left). The left hand vertical movement controls a simulated swarm that sweeps across the full piano keyboard and bounces off at the end of the keyboard. The scene ends with a “grand plié” step in which the right arm's vertical descent causes a spread chord that introduces the next situation

Figure 3: Scenes from the performance.

Another scene develops with the dancer sitting on the piano chair and performing a long compositional improvisation as if she was a normal pianist but without touching the piano keys (see Figure 3 top right). As the scene evolves, her movements deviate from the usual pianist's gestures and cover a larger space that is not restricted to the area above the piano keyboard. Also, the movements of the dancer's feet become involved in the control of the musical score. From now on, the dancer generates a series of chord rotations (see Figure 4) combined with horizontal lines of varying density (monodic, diadic and parallel chord lines) that move across compartmented registers of the piano based on algorithmic transformations of a motif from the piece *Don Giovanni*.

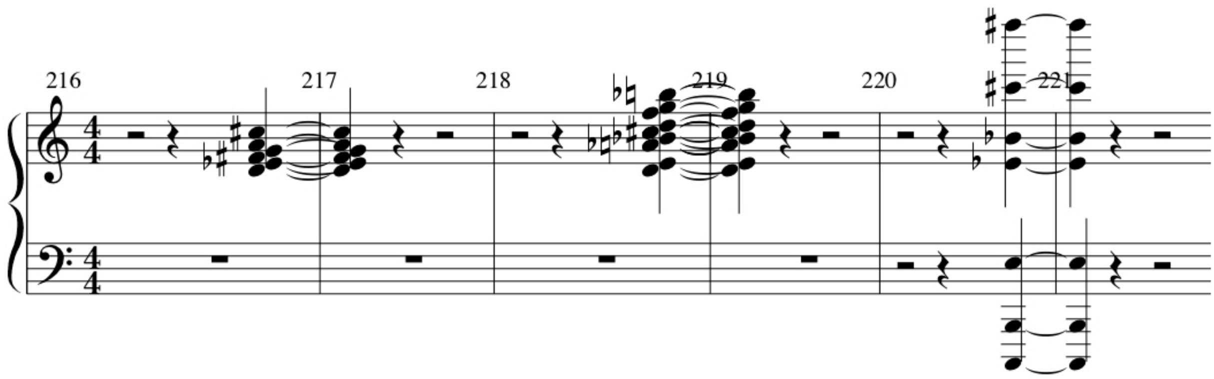

Figure 4: Score chord rotations.

A recurrent formal approach in this work is to confine both the choreography and musical activity to particular parts of the dancer and piano, respectively. For example, one of the scenes develops a sequence of feet variations in which the extracted weight and energy movement qualities are orchestrated in specific registers of the piano.

A contrasting section develops with the dancer lying on top of the piano and extending one arm to press a particular piano key (see Figure 3 top right). This is the only moment during the piece in which the dancer enters in physical contact with the instrument. The key depression triggers an attraction of the simulated swarms towards a position that corresponds to a spatial mapping of the key. As soon as the key is released, the strength of the swarms' evasion behaviours increases, thereby causing them to spread away and to trigger glissandi along its wake.

In another section, the dancer stands behind and above the piano (see Figure 3 top middle). An analysis of the smoothness of her wrist movements is used as basis for creating a gamut of contrasting musical entities ranging from smooth glissandi to jumps across distant degrees of non-octavating scales and superimposed modes (see Figure 5). At the end of the scene, the smoothness -based approach is complemented with an analysis of the wrists' movement energies that control the density of note events.

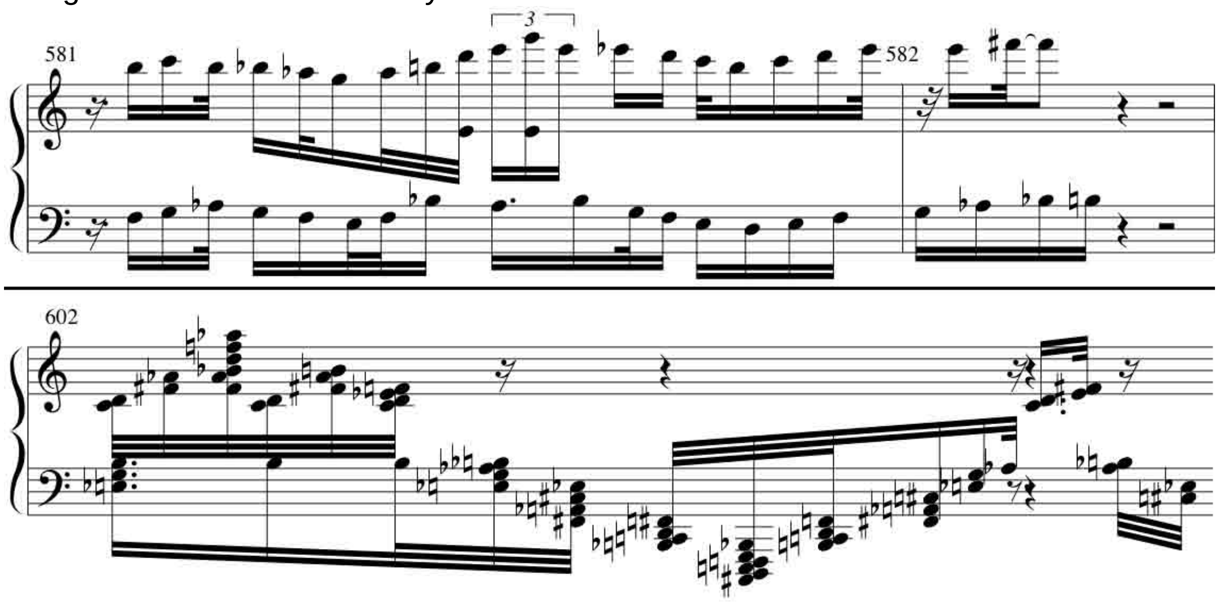

Figure 5: Contrasting score sections corresponding to low (top image) and high (bottom image) movement smoothness.

The dynamic symmetry of the smoothness between both wrists controls the cohesion of a swarm that is mapped to piano keys according to mode 6 of limited transposition by Olivier Messiaen (see Figure 3 bottom middle). The piano behaviour mirrors visually and acoustically the dancer's level of dynamic symmetry (see Figure 6). The choreography is restricted to the hands which oscillate between high and low degrees of dynamic symmetry.

During the end of the piece, the dancer performs with different parts of her body a melody that is composed from the pitch classes that have provided the material for the musical garden scenes of the piece. The melody consists of arrayed cascades, chords and inverted transpositions that surround permutations of the sequences of notes that are created by the dancer.

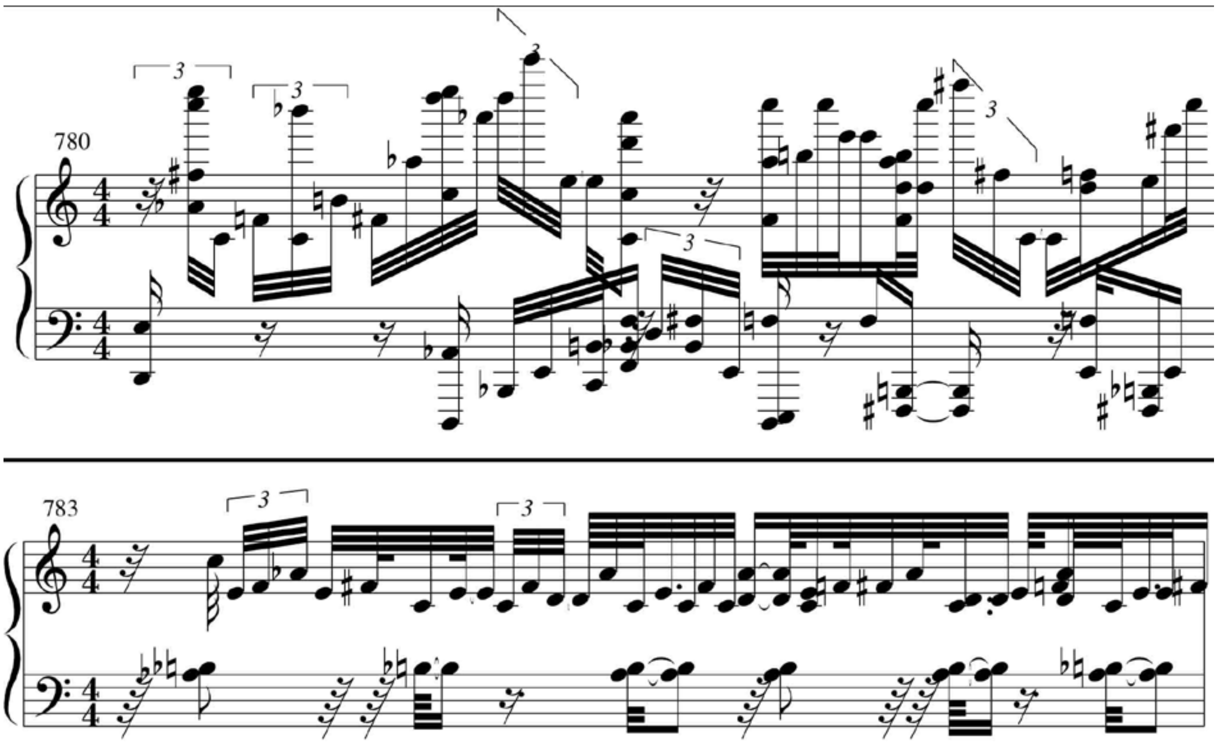

Figure 6: Contrasting score sections showing low (top image) and high (bottom image) movement symmetry.

5. Conclusions

All of the earlier dance works that have been realised by the authors of this paper have employed exclusively computer-based synthetic musical instruments for creating the interactive musical aspects of the performance. Accordingly, the decision to work with an acoustic instrument only in *PIANO & DANCER* constitutes a bold step away from this former approach. One of the main purposes of this publication is to clarify the artistic motivation and aesthetic consequences of this decision. A second focus of the paper deals with the merging of choreographic and compositional methods within the creative process that led to the realization of this piece. This merging has been made possible by a number of decisions, the most prominent of which are the abolishment of a direct touch-based interaction with the piano and the extraction of higher level qualities from the dancer's movements and their application as control features for the creation of musical material. These two aspects can be considered to constitute a minimum requirement for allowing choreography to free itself from the constraints of normal musical playing gestures while at the same time to maintain a clear correlation between physical gesture and musical gesture. It is clear that many more options exist that are worthwhile to explore for composers and choreographers. One of the more obvious options involves the application of machine learning techniques in order to train an interactive system to recognise idiosyncratic movement techniques of the dancer. The paper has also introduced a combination of algorithmic and swarm-based generative techniques for creating note-based musical structures. Such a combination is attractive since it provides both precise compositional control over the musical result while also offering the possibility for the emergence of complex and surprising musical patterns. For the creation of *PIANO & DANCER*, the potential of this combined approach has been exploited only to some extent. It is clear, that the transfer of formal musical principles into intrinsic aspects of a swarm-simulation is far from trivial and offers a much wider range of possibilities than has been addressed in this first version of the piece.

The authors are very eager to further explore these possibilities for future revisions of the piece. Overall, the authors hope that this publication provides an interesting starting point for other choreographers and composers to experiment with the fusion of dance and acoustic instrumental performance within the context of interactive generate art.

6. References

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