Neural Narratives1: Phantom Limb. ***Connecting cognitive neurosciences, sound synthesis, generative video and dance.***

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Abstract

Neural Narratives1: Phantom Limb is the first part of a trans-disciplinary research project that combines mathematical models from cognitive neuroscience with choreography, music and visual arts. The ultimate goal of this project is to produce a music and dance performance that serves as an artistic form of dissemination of this research. Towards this goal, we developed software tools that operate as simulation-based meta-instruments to control the creation of synthesized sounds, visual imagery and choreographic structures.

In this publication, we focus on the description of the sound synthesis models employed in the piece and the musical structures that emerge from the activities of the artificial neural networks and mass-spring structures. A detailed description of the simulation, the video tracking system and the visualization techniques can be found in a previous publication[1]

1.Introduction

Neural Narratives1: Phantom Limb is a collaboration between the two authors of this publication and the choreographer and dancer Muriel Romero. The work was produced by *Instituto Stocos* in the context of the *Metabody* EU Culture project)[2]. In Phantom Limb, we experiment with simulation-based extensions of the human body. These artificial body parts operate as meta instruments which connect the generation of music and imagery to the dancer's bodies, thus modifying their morphological appearance and expanding their behavioral capabilities (see Image 1).

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1) BISIG, Daniel, and PALACIO, Pablo. "Phantom Limb – Hybrid Embodiments for Dance". In Proceedings of the *Generative Art Conference*. Rome, Italy, 2015.

2) Metabody Project, http://metabody.eu/en/, accessed November 9 2015.

Image 1. Artificial body extensions in the Neural Narratives project.

These modifications are based on the representation of a dancer's natural bodily properties via the same computational abstractions that are employed for the simulation of the artificial body structures. In Neural Narratives1: Phantom Limb, we employ artificial neural networks and mass spring systems as basis for the simulation of imaginary body parts and as representations of the dancers' physical bodies. This abstraction integrates the structural and behavioral properties of natural and simulated body parts into a unified form of hybrid embodiment. The idiosyncratic qualities and capabilities of a particular hybrid embodiment is then as much the result of the dancer's subjective properties and activities as it is of the peculiarities of the simulated body parts. As a result, the simulated body extensions enter into different situations of co-determinacy with the physical bodies on stage (see Image1).

2. CONTEXT

The Neural Narratives series follow several historical lines in the fields of music, biology, cognitive neuroscience and performing arts.

Along one line, Phantom Limb relates to approaches in music that create sonic material from visual elements and vice-versa, the generation of music for the eye from musical abstractions [3]. For example, we find an intuitive connection and inspiration for Phantom Limb in the

[3]) XENAKIS, Iannis. *Music and Architecture*. Compilation, translation and commenatary by Sharon Kanach. Hillsdale, New York: Pendragon Press, 2008.

arborescences theory of Iannis Xenakis[4] (see Image 2). In this system, abstractions of branching structures present in nature such as blood vessels, trees, rivers or lighting bolts are plotted on millimeter paper and rotated and transformed on a pitch versus time axis. We recall Xenakis's words in relation to this topic in his conversation with Varga.

> Starting out of a point we have reached a bush or even a tree. This can occur freely or according to rules and can be as complicated as lighting or the veins of the body.

Another quotation of this conversation inspires and defines the conception of the sonification processes carried out in our work:

> The drawing and thinking of the sound-image go hand in hand, the two can't be separated. It would be silly to leave out of account, when drawing, what will sound in reality. We have to be able to find on paper the visual equivalent of the musical idea. Any changes and modifications can be carried out on the drawing itself. This feedback has to operate all time.

Also related to this line of works, the authors of this publication have recently produced a work named *Stocos.* This work connects dynamic stochastic sound synthesis, graphical renderings, interactive swarm simulations, and body gestures based on a continuous feedback among all these elements[5].

In Phantom limb, we developed a model to produce music and imagery from structures that are based on artificial neural networks and mass spring simulatons. This model may be regarded as a real time, automated, interactive, and open ended approach to this theory. The artificial neural networks and mass spring simulation generate, articulate, and animate similar kinds of branching configurations which are indeed so powerful in musical terms.

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4) VARGA, Bálint András. *Conversations with Iannis Xenakis.* Faber and Faber, London, 1996.

5) BISIG, Daniel, and PALACIO, Pablo. "STOCOS - Dance in a Synergistic Environment". In Proceedings of the *Generative Art Conference*. Lucca, Italy, 2012.

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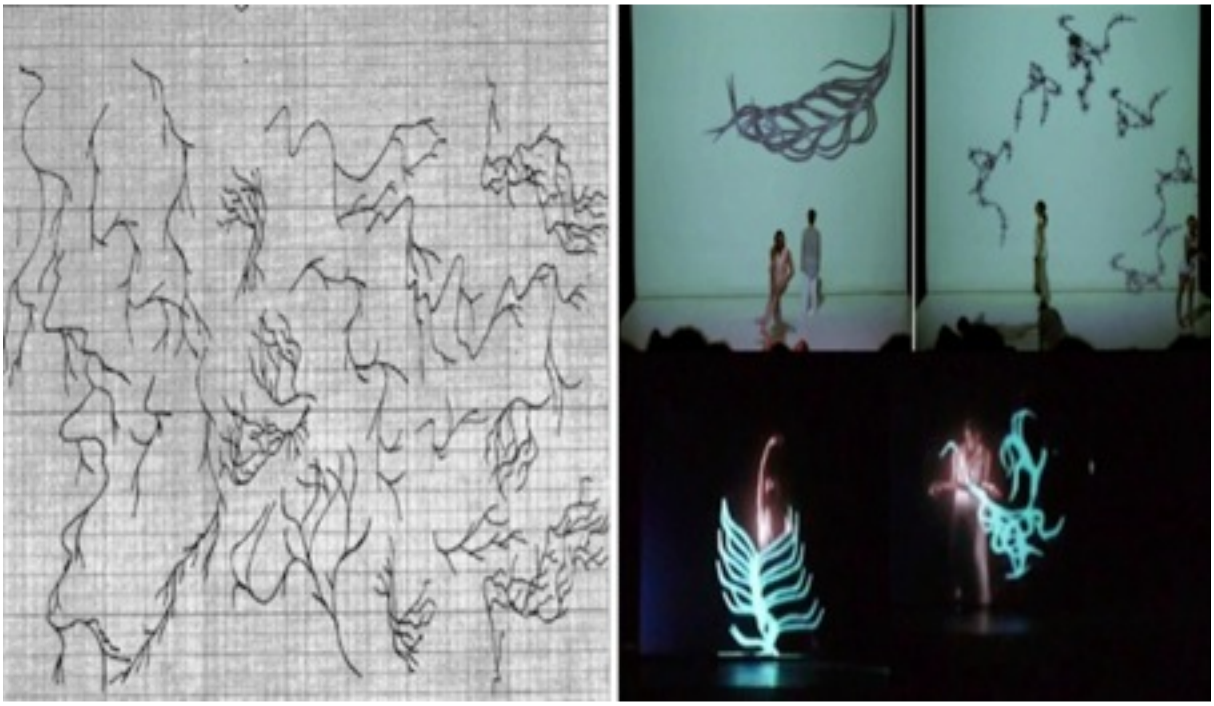

Image 2. Branching Structures. Left image: arborescences drawn by hand by Iannis Xenakis for the piece Erikhton. Right image: interactive interactive branching structures in Phantom Limb.

Along another line, Phantom Limb relates to the preoccupation with forms that emerge from the activity of forces that operate on an object. This approach is based on a mathematical analysis of the dynamical morphology of living forms. As major source of inspiration, we would like to quote the work of D'Arcy Thomson who identified a fundamental connection between morphology, biology, physics, genetics and paleonthology [6]. This work has inspired many musicians who envision music as general form of morphology. In Phantom Limb, we have tried to establish a similarly deep connectedness between simulations of neural, morphological and evolutionary processes for the configuration and articulation of artificial body structures (see Image 3).

Along a third line, the idea and concept of a neural narrative is inspired by cognitive neuroscientist Francisco Varela[7]. Varela speaks of consciousness and how we experience our

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6) THOMSON, D'arcy. *On Growth and Form*. Press Syndicate of the University of Cambridge, Cambridge , United Kingdom, 2000

7) VARELA, Francisco. La habilidad ética. Random House Mondadori, S.A, 2002, Travesera de Gracia 47-49.08021 Barcelona

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self as a flux of micro-worlds and micro-identities that are sequentially activated in our everyday life but that lack a central guiding principle. In an artistic reflection of this notion of consciousness, Phantom Limb employs organizes the choreographical material as a mosaic of ephemeral micro-worlds and micro-identities that emerge from the local interactions between artificial and natural body structures. These interactions create ephemeral configurations or patterns in flux which are in constant transition.

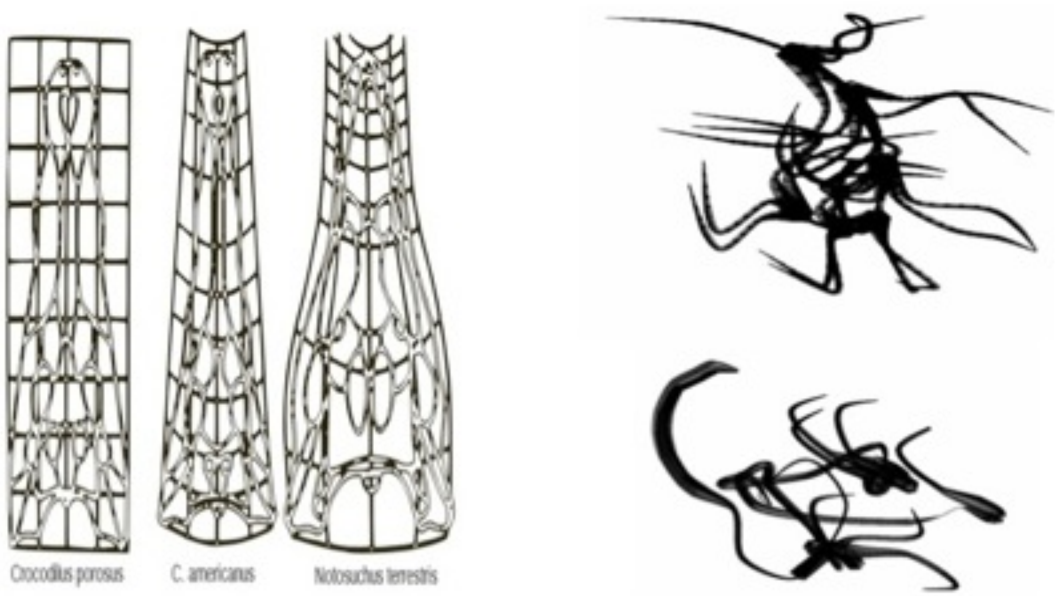

Image 3. Dynamic Morphologies. Left image: mathematical analysis and cartesian transformations of natural forms by D'Arcy Thomson. Right image: moments of transformations for two virtual body structures that have been designed for Phantom Limb.

Finally, the realization of Phantom Limb is inspired by a long standing tradition within performance art that employs artificial body modifications as medium for artistic expression. Historical precedents include the artists Loïe Fuller, Oskar Schlemmer and Alwin Nikolais. Among the more recent examples that are relevant in the context of this publication are works by Stelarc, Gideon Obarzanek, and Christiaan Zwanikken to name just a few which employ robotic structures as actuated mechanisms that extend a human body. A more detailed description of these historical precedents is available in a previous publication about Phantom Limbs[8].

3. Simulation

The simulation software is responsible for modeling the virtual body structures. The morphology of the virtual body structures consists of a mass-spring system that is organized into a branching tree like structure. An individual branch in this structure is termed a body segment. The mass-spring simulation models spring tensions forces according to Hooke's law. In addition, it also simulates a directional restitution force that pushes springs towards a preferred rest direction which is relative to the direction of the preceding spring.

The simulation also implements an artificial neural network. This neural network can exhibit recurrent connections and signals propagate with time delays. The activity of the neural network can affect the properties of the mass-spring system and vice versa. This functionality is realized via the implementation of sensing and actuating elements that respond to or alter the length or orientation properties of the springs.

The interaction between dancers and simulated body structures is based on video tracking. The tracking system that employs a combination of conventional cameras and depth sensing Kinect cameras analyzes the dancers' postures and movements. Based on this analysis, a geometrical representation of a dancer's body contours is derived that serves as a collision boundary for the simulated body structures. An additional analysis permits the identification and localization of body centroids which allow to establish a skeleton representation of a dancer's body. This skeleton is translated into corresponding morphological structure within the mass-spring simulation.

4. Sound Synthesis and Virtual Instruments.

In Phantom Limb, we employ a compound sound synthesis approach. Four types of sound synthesis models are used: an extended form of dynamic stochastic synthesis, subtractive

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8) BISIG, Daniel, and PALACIO, Pablo. "Phantom Limb – Hybrid Embodiments for Dance". In Proceedings of the *Generative Art Conference*. Rome, Italy, 2015.

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synthesis, additive synthesis, and physical modeling. The algorithms for sound synthesis and and generative musical structures are implemented in the Supercollider programming environment. The piece combines pre-composed sections with interactive sections. During the interactive sections, the music is connected to the movement of the dancers and the artificial body structures. The dynamics between the virtual body extensions and the dancers are also controlled from Supercollider using stochastic patterns that introduce alterations in the configurations of the body extensions and their attachment to the skeletal representation of the dancers. Vice versa, the synthesis algorithms are controlled by the simulated body structures. Accordingly, the sonification of the simulated structures and the structures' behavioral characteristics and transformations are mutually interdependent.

A straightforward approach to sonification consists in the mapping of the vertical and horizontal position of each mass point of a virtual body structure to the frequency and spatial position of the resulting sound. A synthesizer is connected to each segment within the virtual body structure (see Image 4).

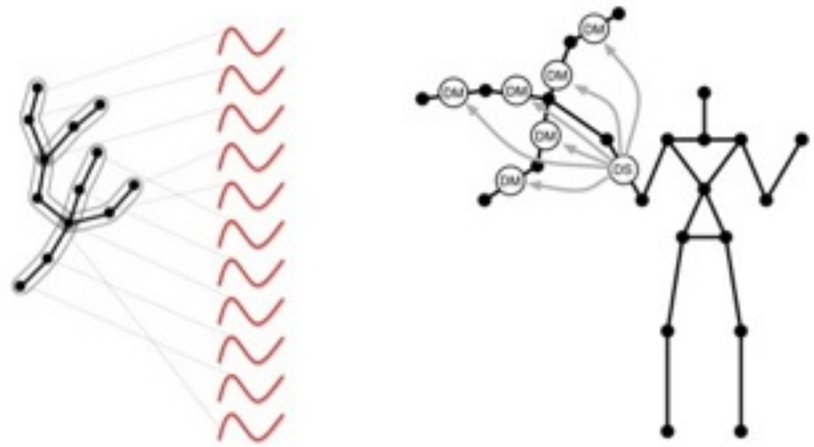

Image 4. Artificial Body Structures. Left image: a schematics of the body structure of an artificial body extension with a synthesizer (in red) connected to each segment. Right image: the body structure connected to the skeleton representation of a dancer.

The mapping of the movement of the mass points results in interesting musical phenomena that range from unisons to highly complex clusters. As mentioned in chapter 2 of this

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publication, this approach of translating branching graphical elements into musical structures has a famous historical predecessor in Iannis Xenakis *arborescences*. Of particular musical interest are the harmonic structures that emerge from those springs which are connected to joint positions of the dancers' skeletal representations. For these springs, the dancers' body proportions give rise to waving chords that move in coordinated glissandi which are transformed according to the choreography of both the natural and virtual bodies.

A more sophisticated mapping approach is used in the case of dynamic stochastic concatenation synthesis[9]. In this model, several waveforms generated by stochastic functions (the so-called *gendys*) are juxtaposed. This results in sounds that are of a more granular quality which offer a range of timbral possibilities. The structure of each gendy is connected to the structure of each spring within a body segment, thereby mirroring the spring's shrinking and expanding.

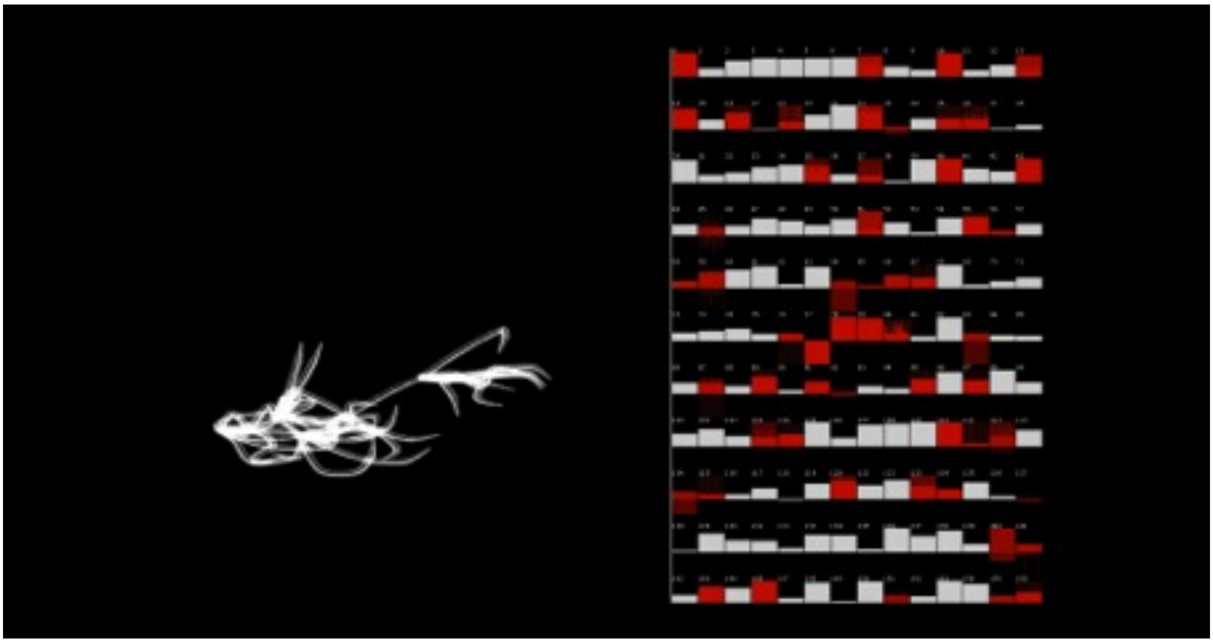

Image 5. Neural Activity. A representation of the activity of each neuron in the artificial neural network of a body structure.

Finally, the spikes of the time delayed recurrent artificial neural network that propagate the activity through the artificial body structures is used as a direct source for musical poly-

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9) LUQUE, Sergio. “The Stochastic Music of Iannis Xenakis”. Leonardo Music Journal, Vol. 19, MIT Press, Cambridge, USA, 2010.

rhythmic composition (see Image 5). In addition, these neural bursts are used to trigger abrupt but synchronized parameter changes in the dynamic stochastic concatenation synthesis.

5. Sound Spatialization

One one hand, the music is diffused using a six channel loudspeaker array surrounding both the stage and the audience (see Image 6). One the other hand, a parametric speaker is used to produce a very localized sonic beam that travels along the theater space. This type of speaker consists of a grid-like arrangement of multiple ultrasound emitting capsules which together form a highly directional audio beam. This inaudible ultrasonic beam acts as carrier wave for a sound signal which becomes audible only when the beam hits an obstacle such as for example a wall, a ceiling, or a human body. In this situation, the obstacle becomes perceivable as source from which the sound signal originates.

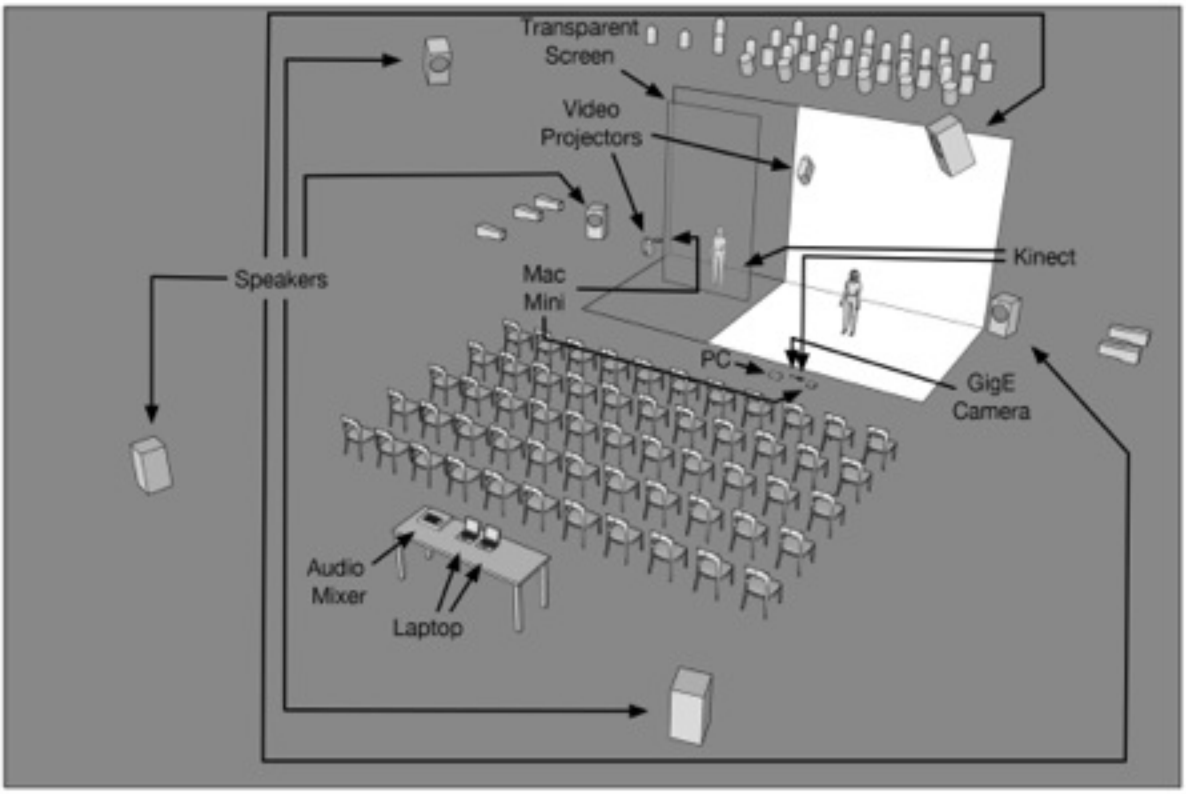

Image 6. Schematic depiction of the stage setup. Indicated are among others the positions of the regular loudspeakers.

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In Phantom Limb, the parametric speaker is manipulated by one of the dancers in total darkness. The dancer points guides the sonic beam across the walls and ceiling of the venue and the audience. According to our experience, the most striking results are achieved by using very complex spectral changing sounds (which can be achieved for instance by extreme configurations of dynamic stochastic synthesis) and projecting these sounds on highly reflective surfaces.

6. Multimodal interaction design, sonified body extensions, and virtual instrument design.

The combination and integration of the aforementioned elements form the basis for a multimodal representation of the artificial body structures. These structures act as virtual instruments that are linked with the physical body of the dancers, permitting them to create synchronized sonic and visual material via their physical activities. These instruments, due to the underlying algorithmic simulations of biological phenomena, resemble living creatures and operate with a certain degree of autonomy. As a been previously mentioned, the representation of the dancers' bodies as mass-spring structures within the simulation environment plays a central role for the integration of simulated and natural bodies into a hybrid form of embodiment. On a purely mechanical level, the springs constituting the virtual body elements can be interconnected with the springs representing a dancer's skeletal structure. Based on this purely physical connection, the dancer's movements propagate mechanically through the mass-spring system and thereby cause a movement of the simulated body structure. An additional and more elaborate level of behavioral relationship between dancers and their virtual body extensions can be realized by creating shared neural networks. For each of the springs that correspond to a skeletal representation of a dancer's body, a sensory neuron can be added that responds to the direction of the associated spring. The resulting activity of these neurons subsequently propagates through a body structure's artificial neural network which can lead to a change in its behaviors[10].

The following section describes some of the virtual instruments. One of the instruments is a hand-like structure that consists of six segments that are initially connected to the right hand

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10) BISIG, Daniel, and PALACIO, Pablo. "Phantom Limb – Hybrid Embodiments for Dance". In Proceedings of the *Generative Art Conference*. Rome, Italy, 2015.

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of the dancer (see Image 6). In addition, a simple neural network allows the dancer to control some of the structure's shape properties. Throughout the scene, the number and position of the skeleton attachments changes (see Image 7) Each of these segments is composed of several springs, each of which is coupled to a synthesizer. The synthesizer is based on a synthetic model of a resonating string system. Each synthesizer is composed of a variable number of integer multiples of a fundamental. These partials are perturbed by a brownian movement generator which adds a natural and organic quality to the sound. However, the perturbation of each partial does not deviate from its center frequency by more than 2%, which leads to a spectral fusion of the tone complex into a single pitched sound. This phenomena is described by Diana Deutsch in her article concerning grouping mechanisms in music[11].

Image 6. Artificial hand extension composed of six segments that are connected to the right hand of the dancer.

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11 … go, Califor…

Image 7. Dynamics, transformations and multiple attachments of the virtual hand extension. In the two rightmost images, the hand attaches to multiple skeleton joints of the dancer.

Another of virtual instruments is a jellyfish-like body structure. This structure is sonified using a model of dynamic stochastic concatenation synthesis. The bursts of the body structure's artificial neural network trigger abrupt changes in both the structure and the parameters of stochastic synthetic model such as number of breakpoints, amplitude, frequency, and values of the random walk elastic barriers. The structural couplings between the dancer and the virtual body structure alternatives between different several stages: the body structure acts as an autonomous and complex entity, the structure fractures and dissociates into multiple individually moving fragments, the structure coalesces and attaches to the dancers body (see Image 8).

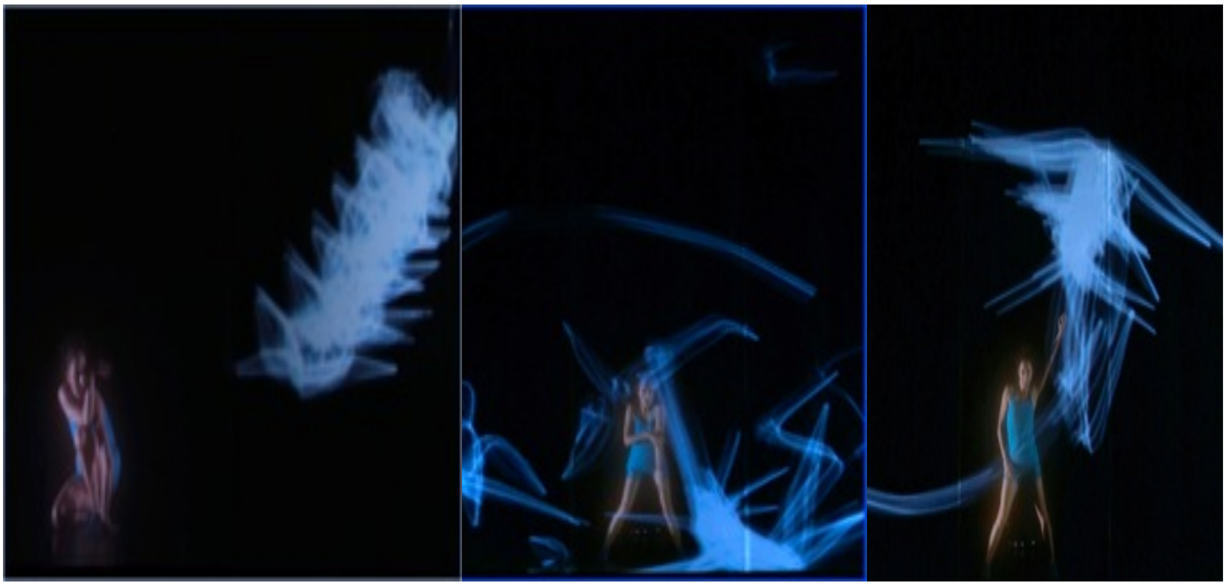

Image 8. Dynamics, fracture, and attachments of the jelly fish-like body structure. Left image: entire jelly fish structure. Middle image: fragmented segments that attach to different joints of the dancer. Right image: all segments are connected the dancer's left hand.

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7. SUMMARY AND FUTURE STEPS

Phantom Limb is the first part of this Neural Narratives series of works in which we have experimented with body extensions that offer the possibility to expand human movement into multimodal augmented gestures. In February 2015, the second part of this project Neural Narratives2: Polytopya was premiered in Barcelona at Mercat de les Flors at the IDN festival. For this second part, we experiment with a new variety of artificial body structures and different sonification approaches. Furthermore, the stage setup was modified to accommodate two video projection screens that are placed behind each other. This setup creates an immersive situation in which the merging of the dancer's bodies and simulated body structures manifests as multiple overlapping locations and different levels of depth.

The relationships between the human bodies and the virtual entities in this first and second parts of the project were based on camera-based tracking methods such as skeleton tracking and contour tracking that sense only low level aspects in the dancers' posture and movement. We are currently working on the application of more sophisticated and higher level tracking systems that allow us to measure expressive features such as fluidity, weight, impulsivity or suddenness of movements. This work is conducted in collaboration with the Infomus research group at Casa Paganini in Italy. Progress along these lines will allow us to further develop the concept and realization of hybrid embodiment.

To summarize, we believe that our research that combines ideas and methods from artificial life, generative art and dance provides ample opportunities to explore new forms of choreographing the human body. By creating and manipulating hybrid forms of embodiment, the performers bodily identity can be transformed into a plurality of morphological and behavioral differentiations and possibilities. The fluid transition between these various bodily manifestations creates a level of malleability that helps to transform a dancer's body characteristics into an expressive medium. As such, our approach continues a tradition of artistic works that experiments with the construction and alteration of the human body.

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