INSTITUTO STOCOS – The Neural Narratives Project
Multimodal virtual body extensions for Metabody.

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Introduction

The Neural Narratives project was initiated with the purpose of developing artistic concepts and creative technologies that contribute to the topics and goals of the Metabody project. The main focus of these developments lies on the identification of abstractions of body movements and their integration into simulation-based algorithms and software tools. These tools are meant to inform and encourage generative approaches within the different practices of the Metabody project. So far, the algorithms have been used as interactive elements for dance that control synthetic music and imagery and as movement prediction mechanism in the tracking and analysis software Eyesweb. As a future goal, the simulations can be adapted and integrated as control mechanisms for robotic architectural structures.

In the context of our trans-disciplinary research, the simulation has been adapted to represent the physical bodies of real dancers and to allow the creation of artificial and imaginary body parts. The simulation integrates a mass-spring system to model body morphologies and an artificial neural network to control the bodies' behaviors. By merging the models for dancers and imaginary both parts, a hybrid form of embodiment is established that modifies and extends the dancer's original morphological and behavioural characteristics and capabilities.

This research has reached three milestones, each of which led to the realization of a dance piece that serves as an artistic dissemination of the research. The names of the dance pieces are: Neural Narratives 1: Phantom Limb, Neural Narratives 2: Polytopya, and Neural Narratives 3: Clinament. The first and third pieces were presented at the Metabody forums in 2014 and 2015, respectively. For the first milestone, the basic simulation and video tracking software was established. For the second milestone, the simulation software was further improved and in collaboration with the Infomus team a more reliable video tracking system was established. For the last milestone, video tracking was abandoned in favour of a more qualitative analysis based on body worn acceleration sensors.

Context

The Neural Narratives series follow several historical lines in the fields of performance arts and music.

With respect to performance art, Neural Narratives relates to approaches that employ artificial body modifications and extensions as a central choreographic and artistic element (see Figure 1). Examples of historical precedents include Oskar Schlemmer and Alwin Nikolais. Oscar Schlemmer treats the human bodies of the performers as an artistic medium that can be transformed via physical attachments into abstract and geometrical objects [1]. Alwin Nikolas has explored through various works how constume-based distortions of the human body alter the dancer's movement capabilities [2]. More recent precedents include works that employ actuated robotic mechanisms to extend a human body. In the *Third Hand* project by Stelarc, a mechanical hand is attached to the artist's right arm and controlled via EMG signals from various muscles in his body [3].

Figure 1: Historical Precedents in Performance Art. From top left to bottom right: Triadic Ballet by Oscar Schlemmer, Imago by Alwin Nikolais, Third Hand by Stelarc, Connected by Gideon Obarzanek and Reuben Margolin
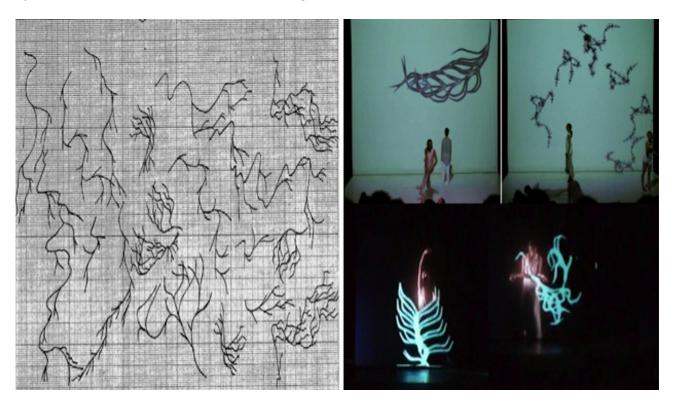

Figure 2: Branching Structures. Left: Arborescences drawn by hand by Iannis Xenakis for the piece Erikhton. Right: interactive interactive branching structures in Phantom Limb.

In the piece *Connected* by Gideon Obarzanek and Reuben Margolin, a dancer is connected via strings to a grid-like sculpture that transforms the dancer's activities into undulating movements and contortions [4]. Neural Narratives 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   For example, we find an intuitive connection and inspiration in the Arborescences theory of Iannis Xenakis [5]. 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 (see Figure 2).

In Neural Narratives, we developed a model to produce music and imagery from structures that are based on artificial neural networks and mass spring simulations. 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.

Simulation

The simulation software models the morphology and behavior of virtual body structures (see Figure 3). The morphology 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 relative rest direction. 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. Sensing elements read the property of a spring and modify the activity of a neural node. Actuation elements change the property of a spring based on the activity of a neural node.
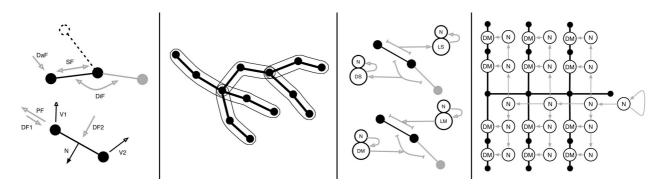

Figure 3: Simulation Principles. From left to right: mass-spring simulation (black circles: mass-points, lines: springs, DaF: damping force, SF: spring force, DiF: directional force), propulsion forces (PF: propulsion force, DF1: damping force vector 1, DF2: damping force vector 2), mass-spring morphology, sensors and actuators (N: neuron, DS: directional sensor, LS: length sensor, DM: directional motor, DL: length motor), morphology with associated neural network (gray arrows: neural connections).

The simulation also models forces that permit the virtual body structure to propagate to space. These forces are derived from the mass points' relative velocity with respect to the direction of their corresponding springs. Via a collision detection and resolution

mechanism, the body structures can be confined to the inside or outside of bounding volumes. These volumes can either operate as hard limits that cannot be crossed or as soft limits that exert opposing forces. The shape of the bounding volumes can either be specified in advance or they can be derived on the fly from the input of a video tracking system.

Tracking

In Neural Narratives, a number of different tracking systems are employed to allow the virtual body structures to respond in real time to the postures and movements of dancers.

In Neural Narratives I and II, tracking was based solely on computer vision and combined a variety of different cameras and tracking applications (see Figure 4). A custom developed software was used to derive the dancer's body contours from the image of a distance sensing camera. These body contours are used to create dynamic bounding volumes within the simulation. An additional distance image from a second camera was analyzed by an Eyesweb [6] patch to derive a skeletal representation of a dancer. This representation was translated into corresponding morphological structures within the mass-spring simulation. A dancer's gestures, activity level and body extension were analyzed and categorized by the Motion Composer System [7] and used to either trigger discrete events within the simulation such as the creation of additional artificial structures or to create continuous control values that modify the physical properties of existing artificial structures.
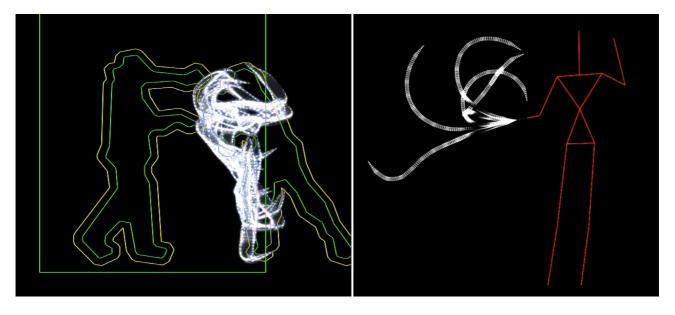

Figure 4: Video Tracking. Left: The tracked contours of dancers serve as bounding volumes that confine a virtual body structure. Right: A virtual body structure is attached to the hand joint in the tracked skeleton of a dancer.

For the last milestone of the project and in connection with the needs of the Metabody project to develop street performances and interaction situations inside the planned interactive pavilion, the interaction between natural bodies, artificial body parts and synthetic sounds was based on wearable acceleration sensors. Two types of these devices were used, the MiniBees designed by Marije Baalman and standard Android Smartphones. This sensing technologies provides a more detailed data related to the turning and acceleration of a dancer's limbs. In addition, it allows to experiment with higher level expressive movement qualities like fluidity, weight or impulsiveness and their

relationship with the behavior of the artificial body structures. This work is conducted in collaboration with the Infomus research group.

Hybrid Embodiment

Behavioral couplings between dancers and virtual body structures are established by combining their respective representations into a shared neural network and mass-spring system (see Figure 5). By embedding mass-spring elements that are part of the skeletal representation of a dancer into the morphology of a virtual body structure, the virtual body element becomes a physically coupled extension that responds to the dancer's movements via a direct mechanical reaction. Alternatively or in addition, a neural coupling can be established via sensing elements that translate angular positions of skeletal joints into neural activities. As a result, these activities affect the dynamics of the neural network which in turn controls the body structure's active behaviors. The combination of mechanical and neural coupling gives rise to a shared form of embodiment that tightly integrates natural and simulated morphological and behavioral properties.
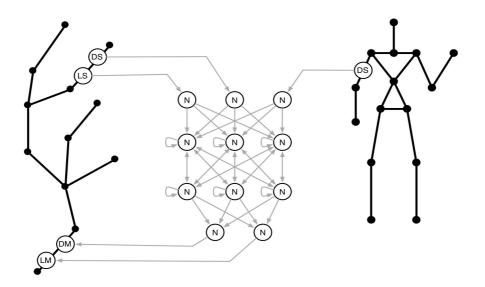

Figure 5: Behavioral Coupling: Schematic representation of a neural coupling between a virtual body structure (on the left) and a skeleton representation of a dancer (on the right). For the sake a clarity, only a small subset of a full neural network is shown.

Evolutionary Adaptation

For most virtual body structures, the morphology has been designed by hand whereas the neural network has been generated via evolutionary adaptation (see Figure 6). This adaptation process was conducted ahead of a performance and generate for each type of morphology a repertoire of behaviors that are related to the movements of a particular dancer within a specific scene. For this, a genetic algorithm was implemented that controls the number, topology and parameterization of neurons, sensors and actuators. During each evolutionary run, sensory units that respond to joints in a dancer's skeleton were present and their activities were derived from recorded dance sequences. The fitness function combines a quantitative analysis of the level behavioral activity and a subjective evaluation of the qualitative appeal of a behavior.
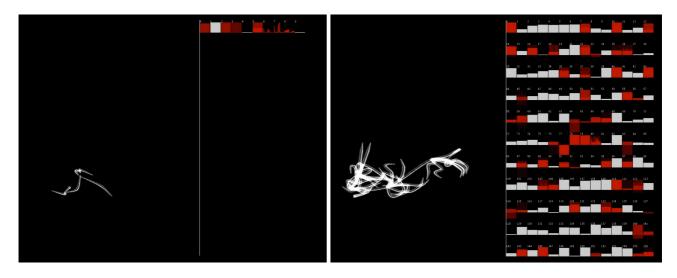
Figure 6: Evolutionary Adaption: A visual rendering of a virtual body structure is shown together with the activity levels of the neurons in its associated neural network. Changing activity levels are shown in red, static activity levels are shown in grey. Left: a simple virtual body structure with a small associated neural network. Right: a complex virtual body structure with a large associated neural network.

Blended Appearance

The interaction between the dancers' bodies and the artificial body structures forms the basis for the generative creation of synthetic music and imagery. This creation process is based on the combination of two artistic strategies: the establishment of a blended appearance between dancers and virtual body structures and the usage of the artificial body structures as multimodal virtual instruments.

The image generation follows mainly the first strategy. The visual rendering highlights the morphology of the body structures by rendering them as three dimensional tube-like structures that conform via spline-based interpolation to the branching topology of the underlaying mass-spring systems. The visual presence of the dancers and virtual body structures gives rise to a blended appearance that highlights the intimate integration of their respective embodiments. The graphical rendering of the artificial morphologies is projected on a transparent screen in front of dancer in such a way that the visual characteristics of the physical and virtual bodies are layered on top each other via an optical superposition (see Figures 7 and 8).

As interesting extension of the concept of blended appearance, we have recently started to experiment with mechanical feedback mechanisms that translate the activity of the virtual body structures into a proprioceptive sensation for the dancers. Several small pager motors are attached to the body of a dancer. The level of activity of these motors is proportional to the depth of the intersection between a virtual body structure and the dancer's body contour. As a result, this form of self-touching of the hybrid embodiment is made perceivable to the dancer as a buzzing sensation on his or her skin.

Multimodal Virtual Instruments.

The sonification of the simulated body structures and their behavioral characteristics and morphological transformations form a mutually interdependent feedback loop. The sonification is based on a compound sound synthesis approach that combines an extended form of dynamic stochastic synthesis [8], subtractive synthesis, additive

synthesis, and physical modeling.

According to the notion of virtual instruments, the virtual body structures can be employed as complex mechanisms that translate the physical activities of the dancer's into sonic material. Due to the fact, that the activity of the artificial body structures is based on both passive excitation and self-generated movements, the virtual instruments combine the properties of musical instruments and autonomous organisms. The following section describes some of the virtual instruments.

One of these instruments is a hand-like structure that consists of six segments that are initially connected to the right hand of the dancer. In addition, a simple neural network allows the dancer to control the structure's behaviors. Throughout the scene, the number and position of the skeleton attachments changes (see Figure 7). The segments are composed of several springs, each of which is coupled to a synthesizer. The synthesizers are 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%. This leads to a spectral fusion of the tone complex into a single pitched sound.

Figure 7: Hand-like Virtual Body Structure. Dynamics, transformations and multiple attachments of a hand-like virtual body structure. In the two rightmost images, the hand attaches to multiple skeleton joints of the dancer.
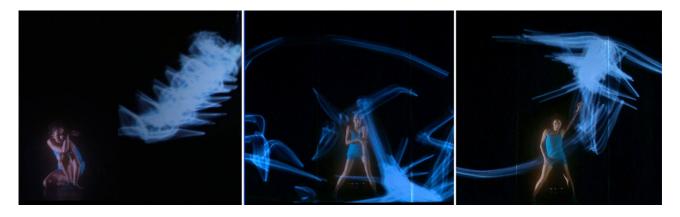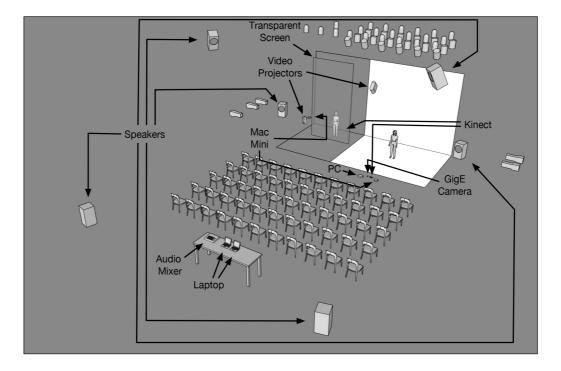

Figure 8: Jellyfish-like Virtual Body Structure. Dynamics, fracture, and attachments of a jelly fish-like virtual body structure. Left: entire jelly fish structure. Middle: fragmented segments that attach to different joints of the dancer. Right: all segments are connected the dancer's left hand

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.

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 the stochastic synthetic model such as the number of breakpoints, amplitude, frequency, and values of the 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 Figure 8). In this case, the activity spikes of the neural network are used as a direct source for poly-rhythmic musical composition. In addition, these neural bursts are used to trigger abrupt but synchronized parameter changes in the dynamic stochastic concatenation synthesis.

Performance setups.

The performatic space has been designed in such a way that it permits both the dancers, the virtual body structures and the synthetic music and imagery to co-exist within the same physical space. The setup consists of the following elements: several conventional and depth sensing cameras that are placed on the ground and that observe different subregions of the stage, several screens that are either fully transparent, semi-transparent or opaque and on which visual renderings of the virtual body structures are projected, a spatially distributed group of stationary loud-speakers, and a hand-held ultrasonic loud-speaker (see Figure 9).

Figure 9: Performance Setup. The schematic image depicts a 3D representation of the performance setup for the dance piece Neural Narratives I: Phantom Limb.

The transparent screen [9] as well as the ultrasonic loudspeaker [10] are of special interest. The transparent screens which are hanged from the ceiling permit the rear projection of a video image that appears to be floating in front of dancers that stand behind the screens. The dancer's tracked body and the graphical rendering of the virtual body extensions are aligned in such a way that they match in position and size from the point of view of the audience. By controlling the intensity of the projected image and the illumination of the dancer, the combined visibility of the dancer and the virtual body extensions can be adjusted to give raise to a mixed appearance.

Another approach for using transparent materials for projection was employed using the so called Metakinespheres that have been developed by Reverso. These objects engulf the dancer and allow the projection of the artificial body parts both from within and from the outside.

The ultrasonic loudspeaker emits a highly focused and inaudible ultrasonic beam that becomes audible at the position of its intersection with a surface. This method permits dancer who holds the speaker during a full blackout to accurately place a sonic output at specific locations in the venue. It is via the combination of these principles with more conventional audio spatialization and video projection techniques, that a clear relationship between the location and appearance of natural and synthetic acoustic and visual elements can be established.

Conclusion

The main goal of the Neural Narratives project is to experiment with hybrid forms of embodiment in dance and extend the software tolls and abstractions that underly this approach to other Metabody objectives such as the interactive pavilion . Our approach consists of establishing a simulation-based augmented reality situation on stage. This situation allows virtual body extensions and the dancers' physical bodies to merge into composite corporeal structures whose morphological and behavioral properties deviate significantly from a normal human body. As part of this project, a set of technical tools has been developed that comprises custom developed simulation software, several video tracking systems, audio and video synthesis and spatialization tools, and video screen setups. These tools have allowed us to develop and present some initial ideas in the form of several performances that have served as a valuable testbed for our ideas and technologies and helped us to outline future improvements and research directions.

To summarize, we believe that our research that combines ideas and methods from artificial life, new music, 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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