Neural Narratives - Dance with Virtual Body Extensions

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ABSTRACT
From the context of two dance productions, the Neural Narratives project has started to emerge as a comprehensive exploration of simulation-based approaches that enable the creation of artificial body extensions for dancers. The simulation, visualisation and sonification of these body extensions allow a dancer to alter and enlarge his or her bodily presence and movement possibilities. The main focus of this publication lies in the contextualisation and discussion of a number of questions that have arisen during the realisation of the dance productions. These questions relate to concepts of embodiment, agency, and creativity and their possible implications for the realisation of interactive systems for dance. We try to address these questions by drawing from ideas that originate from a wide range of fields including dance and technology, cognitive science, systems science, and medical engineering. By connecting our own practical activities to a broad disciplinary context, we hope to contribute to a discourse concerning future directions for research and creation that deepen the integration of technology and dance.

Author Keywords
Dance Technology; Interaction; Embodiment; Agency; Creativity; Body Extension; Mass-Spring Simulation; Artificial Neural Network; Artificial Evolution; Visualization; Sonification;

ACM Classification Keywords
H.5.1. Multimedia Information Systems: Artificial, augmented, and virtual realities

INTRODUCTION
The project "Neural Narratives" experiments with interactive simulation-based approaches that allow a dancer to alter and extend his or her bodily presence and movement possibilities. The project has emerged from the practical and creation focused context of two dance productions entitled "Neural Narratives 1: Phantom Limb" and "Neural Narratives 2: Polytopya". These productions were realised as collaboration between the two authors and the choreographer Muriel Romero. For both productions, the chosen approach is based on the simulation of artificial body structures whose morphological and behavioural properties are tightly interrelated with the dancer's body and movements. These structures take on the role of virtual extensions of the dancer's body that respond to his or her activities via a combination of reactive and pro-active behaviours. The reactive behaviours are based on a physical coupling between the dancer's body and a simulated mass-spring system [MSS] that mechanically perpetuates the dancer's gestures. The pro-active behaviours spontaneously emerge from the internal dynamics of a simulated artificial neural network [ANN].

The following aspects play a central role for establishing strong connections between a dancer and the virtual body extensions.

> The dancer and the body extensions are represented via identical computational abstractions and thereby can be interrelated via common simulation-based processes.

> The morphology, perception and behaviour of the virtual extensions are mutually constituted via a common grounding in an underlying physical simulation.

> The behaviour of the virtual bodies is conditioned to respond to the idiosyncratic movements of a dancer via a process of evolutionary adaptation.

> The virtual extensions are made perceivable via visualisation and sonification approaches that expose the simulation-based processes.

Throughout the following sections, the article focus predominantly on a contextualisation of Neural Narratives and rises a series of questions and issues that have emerged as part of our reflection concerning the future directions that this project could take. This focus comes at the expense of a detailed technical description of the simulation, visualisation and sonification tools that have been developed as part of the project. And it also comes at the expense of an elaboration of the choreographic, visual and musical ideas that informed the creation of the two dance pieces. Concerning these topics, the reader is referred to the following publications [8], [7], [24].

BACKGROUND
The following section presents a small and by no means comprehensive selection of works in the field of new media and dance that are related to Neural Narratives. The selection focuses on two particular types of approaches. One approach emphasizes a strong connection between a performer's appearance and activity and generative processes that underly

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the creation of new media elements. The other approach employs technical systems as artificial dance partners that exhibit some degree of variability and autonomy in their behaviour. Other backgrounds that are also of relevance are omitted here for the sake of brevity. Excluded is a contextualisation of Neural Narratives with respect to activities in performance art that deal with modifications of the human body by physical means such as costumes or robotics. Also excluded is a discussion concerning notions of morphology in music and art and early attempts in computer music that try to connect them. Some information concerning these contexts have been previously published in [7] and [24].

Since the 1960', the intersection of new media and dance has become a very active field of artistic experimentation. Bench argues, that dance has been more thoroughly influenced by new media than any other field due to the fact that new media has the potential to fundamentally challenge the natural perception of bodies and the environment [4]. Gunduz takes an optimistic stance and highlights the unique opportunity that technology provides for creating either a dialogue or a confrontation between aspects of corporality and incorporeality and thereby enables a re-negotiation and re-interpretation of the human body [15].

Of particular interest in the context of Neural Narratives are works that try to establish a processual rather than representational connection between the bodily characteristics and movements of a dancer and media elements on stage. A good example is the work "Apparition" by Klaus Obermaier[23]. In this work, the generation of imagery is directly controlled by a dancer and carries in its appearance traces of the dancer's movements. Accordingly, the characteristics of the imagery is not externally defined and imposed but rather operates as an extension of the dancer's bodily dynamics. Another example is the work "Stocos" that has been realised by the authors of this article. In this work, the synthetic video and music is composed of simple abstract graphical and sonic constituents. It is primarily the dynamics of movement of these elements that unfolds in close relationship with the dancer's bodily appearance and activities and which shapes the sonic and visual presence of the work [6]. This relationship is established via a tight coupling between a simulation of flocking behaviour, a computational representation of the dancer's bodily shape and and movement forces, and methods for sound synthesis and visual rendering. By integrating a simulation of a complex and self-organised process, the technical system is endowed with the capability to perceive and respond to the dancer's activities with a certain level of independence and spontaneity. This shifts the perceived role of the technical system towards that of an artificial dance partner which can be attributed a level of autonomy and agency of its own.

The desire to design responsive media that are able to assume the role of synthetic partners in a dance performance constitutes an important trend in new media. Two distinct approaches seem to currently dominate the field. One approach focuses on the application of machine learning techniques to create artificial systems that can recognise and mimick the gestural repertory of a human dancer. The artificial system then typically assumes the appearance a humanoid avatar that is able to recreate movement sequences from previously categorised dance postures. For example, McCormik has created an avatar that is trained based on motion capture data from a particular dancer [22]. The unsupervised machine learning algorithm consists of two ANN with operate as self-organised maps (SOM). The first ANN learns to categorize dance postures whereas the second ANN learns to categorize transitions between dance postures. Once trained, the avatar is able to recognize the dancer's gestures in a performance situation and responds to them by replaying those gestures with small variations. Berman and James present a somewhat different avatar-based approach that focuses on endowing the technical system with a higher level of improvisational capabilities [5]. Here, a map of dance poses is derived via non-linear principal component analysis (PCA) from previous recordings of a dancer. When interacting with a dancer during performance, the avatar constructs its movements by following trajectories throughout the pose map. The degree of "improvisational freedom" depends on the distance by which these trajectories are allowed to deviate from the initially selected starting pose.

An alternative approach abstains from mimicking a human body and movement in favour of using more abstract systems whose behaviours are generated via an underlying physical simulation. A famous example is the piece entitled "How long does the subject linger on the edge of the volume" that has been collaboratively created by the Open Ended Group and the Trisha Brown Dance Company [11]. For this production, an artificial creature has been created that consists of a physically simulated body. The movement of the creature results from its attempts to attach to positions of motion on stage and to maintain its balance in a simulated environment that has gravity and a ground. An other interesting and more recent example is the performance "Chiselling Bodies" by Alaoui and Cavaille [2]. In this work, a dancer interacts with an abstract artificial creature whose body consists of two simulated MSS. A small MSS is directly actuated by the dancer's tracked movements. A much larger MSS is connected to the small MSS and exhibits choreographed movements such as blossoming. These movements are triggered by the dancer via a predefined mapping between dance gestures and MSS behaviours.

The approach for designing an interactive system that has been chosen for Neural Narratives situates itself somewhere in between the imitational approaches of avatar-based systems and the simulation-based approaches of abstract physical systems. While the morphology of the artificial body extensions is based on an abstract MSS, its topology is reminiscent of animal or human body parts. Also, while the mechanical movements of the body extensions emerge from the dynamics of the MSS, the initiation and control of these movements is subject to an ANN whose sensorial capabilities and activity has been tuned to the behaviour of a particular dancer via a process of simulated evolutionary adaptation.

The artificial body extensions share a further similarity with the previously described avatar and physics-based systems.

Their participative role in a dance performance is not that of a fully autonomous synthetic dancer but rather that of a semi-autonomous entity that partially depends for its performative usefulness on the creativity and competence of a human dancer. McCormik argues that due to this limitation, the dancer and the artificial system have to share and combine their respective competences [22]. For this reason, both of them exhibit in their decision making a form of distributed cognition. In the case of Neural Narratives, a similar claim can be made, but rather than to focus solely on the cognitive aspects of the engagement between dancer and artificial system, the distributed characteristics involves a combination of morphological, perceptual and cognitive aspects. For this reason, it seems more appropriate to talk about a distributed form of embodiment through which dancer and artificial body extensions coordinate their respective activities.

SOFTWARE

The following section gives a very brief overview over the functionality of the software that has been specifically developed for the Neural Narratives project. A more thorough and detailed description of the software can be found in [7].

Simulation

The simulation software models the morphology and behaviour of the body extensions (see Figure 1). The morphology consists of a MSS that is organized into a branching tree like structure. An individual branch in this structure is termed a body segment. The simulation models spring tension forces according to Hooke's law. It also simulates directional restitution forces that pushes springs towards relative rest directions. In addition, the simulation implements an ANN. This network can possess recurrent connections and signals propagate with time delays. The activity of the ANN affects the properties of the MSS and vice versa. This functionality is realized via the implementation of sensing and actuation 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. The simulation also models forces that permit the virtual body structure to propagate through 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 extensions 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.

Simulation-based Behavioural Coupling

Behavioural coupling between dancers and virtual body extensions is based on their common abstraction and operationalizion as MSS and ANN (see Figure 2). The MSS representing the dancer's body is acquired from the distance image of a Kinect camera either via the skeleton tracking functionality of the OpenNI software library or the centroid extraction mechanism in the Eyesweb software. This skeletal MSS is extended with a simple ANN that serves as a proprioceptive sensing mechanism which translates the dancer's body postures into neural activity patterns. By connecting some MSS elements of the skeletal representation with those of a virtual body extension, the latter becomes a physically coupled mechanical system that propagates a dancer‘s movements. Alternatively or in addition, a neural coupling can be established by axonal connections between the ANN of a body extension and proprioceptive sensing elements located on the dancer's skeletal joints. As a result, the dancer's movements affect the dynamics of the neural activity in the ANN which in turn can initiate and modulate the active behaviours of the body extension.

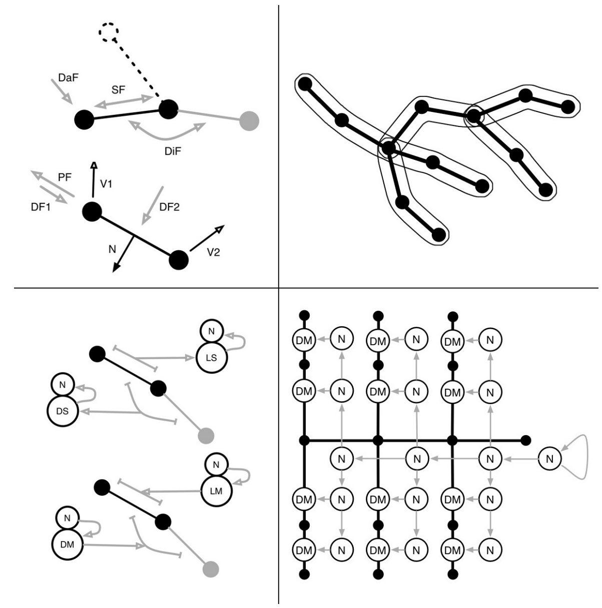

Figure 1. Simulations. Top half: mass-spring simulation (left side) and morphology (right side). Bottom half: sensing / actuator neurons (left side) and recurrent neural network (right side). Graphical elements: filled black circles: mass-points, black lines: springs, dashed lines and circles: target rest positions for mass points and springs, outlined gray arrows: physical forces, filled gray arrows: neural connections, outlined black circles: neurons. Abreviations: DaF: damping force, SF: spring force, DiF: directional force, PF: propulsion force, DF1: propulsion damping force 1, DF2: propulsion damping force 2, N: neuron, DS: directional sensor, LS: length sensor, DM: directional motor, DL: length motor

Evolutionary Adaptation

For most virtual body extensions, the MSS has been designed by hand whereas the ANN has been generated automatically by a process of artificial evolutionary adaptation (see Figure 3). This adaptation process was conducted ahead of a performance and served to create for each type of MSS a repertory of behaviours that are related to the specific movements of a particular dancer. Adaptation is based on a genetic algorithm 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 the movement of the skeleton was derived from pre-recorded dance sequences. The fitness function combines an analysis of the overall quantity of motion

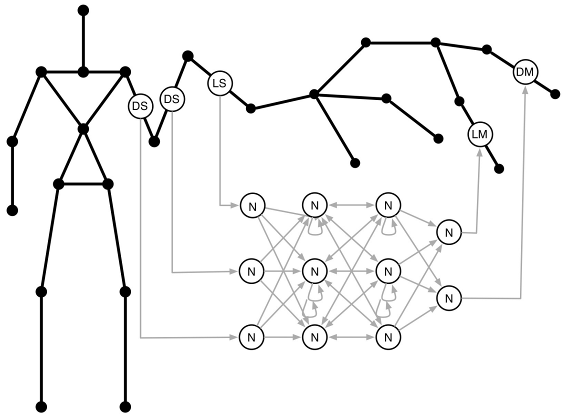

Figure 2. Simulation-based Behavioural Coupling. Schematic representation of a morphological and neural coupling between a skeleton representation of a dancer (left side) and a virtual body extension (right side). For the sake a clarity, only a single morphological attachment and only a small subset of a full neural network are shown. The graphical elements and abbreviations are the same as in Figure 1.

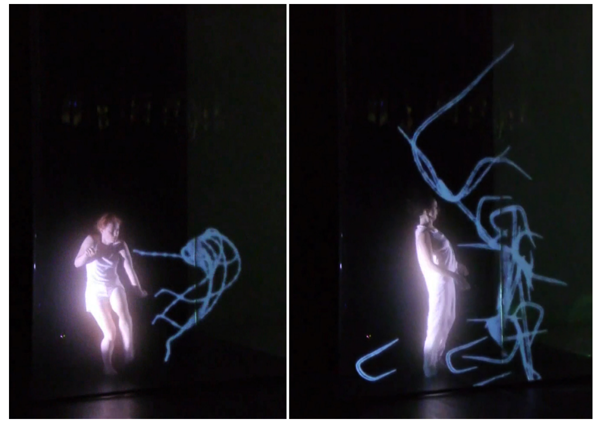

Figure 4. Visual Presence of Body Extensions on Stage. The two photographs show a stage situation in which a visual rendering of the virtual body extensions is projected on a transparent screen that hangs in front of a dancer. The photograph on the left shows a body structure that is attached to multiple joints of a dancer. The photograph on the right shows a body structure whose morphology has fractured and become partially dissociated from the dancer‘s body.

and a subjective evaluation of the aesthetic appeal of the behaviours.

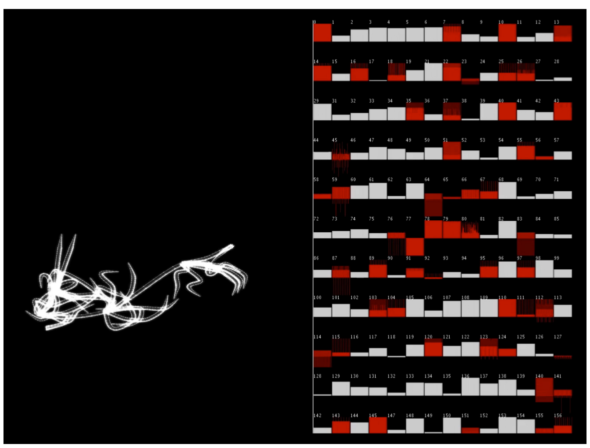

Figure 3. Evolutionary Adaption. A visual rendering of a virtual body structure (left side) is shown together with the activity levels of neurons (right side) that belong to a neural network which has been automatically created via evolutionary adaptation. Changing activity levels are shown in red, static activity levels are shown in grey.

VISUALIZATION

The visual rendering highlights the morphology of the body extensions by rendering them as three dimensional tube-like structures that conform via spline-based interpolation to the branching topology of the underlaying MSS (see Figure 4). This rendering is projected on a transparent screen that hangs in front of the dancer. This places the resulting image at a position and scale that aligns with the dancer's own body position and size. This settings fulfils two purposes: the correspondence between the dancer's own body and movement and the virtual body extension is clearly visible for the dancer, and the audience perceives the appearance of the dancer and that of the virtual body extensions as a visual superposition.

SONIFICATION

The sonification of the body extensions complements their visualization and foregrounds the sensorimotor coupling between the dancer and the artificial body structures. It does so by rendering audible the internal structural relations and dynamic processes that underlie the simulated behaviour. The sonification employs a combination of different sound synthesis and mapping techniques, each of them specially designed to sonically highlight the idiosyncrasies of a particular artificial body structure. One of these approaches employs an additive synthesis model. Here, the MSS of a virtual body extension is rendered audible by mapping the y-component of each mass point to the fundamental frequency of a corresponding synthesiser, whereas the x-component is mapped to a position in the audio spatialisation. As a result, the movement-based perturbation of the MSS becomes perceivable as musical phenomena that range from unisons to complex clusters of coordinated glissandi. Another approach employs an extended model of dynamic stochastic concatenation synthesis [20]. Here, the structure of a segment within an artificial body extension is directly used to define the shape and number of breakpoints of a polygonized waveform. In addition, bursts of activity within the ANN are used to trigger abrupt but synchronized parameter changes in the same sound synthesis algorithm. Finally, periodic activity bursts in the ANN are used to control a synthetic percussion model. This gives rise to a polyrhythmic musical structure. The music is diffused using a ring of loudspeakers surrounding both the stage and the audience. In addition, a handheld parametric loudspeaker is occasionally operated by a dancer which allows her to pinpoint the musical output to an exact location either on stage or within the audience.

DISCUSSION

The Neural Narratives project has led to the development of simulation, visualisation and sonification tools that allow the creation of virtual body structures whose morphology, behaviour and appearance are closely connected to a dancer's bodily presence and activities. Now that these intense production phases are over, it seems to be a good moment to take a step back and reflect about the implications of this approach. In particular, we feel it would be useful to initiate a discussion concerning the following two questions:

1. how can an artificial system form a useful component in embodied awareness and creation practices in dance?

2. what forms and levels of agency in an artificial system are interesting for dance performance?

Reasoning about these questions will be helpful for situating the Neural Narratives project in a wider context and for outlining directions of research and creation along which the project could be further developed. We try to address these questions by touching a larger number of fields than we did in the background section, starting from a performance centric discussion and then expanding into wider a disciplinary territory.

Embodied Awareness and Creativity

In dance, the notion of embodied flow describes a state in which a dancer is deeply immersed and engaged with the sensational and qualitative aspects of his or her bodily movements. The term combines the psychological meaning of "flow" which describes a highly self motivated and full involvement into an activity [10] and the notion of "somatics" from the field of movement techniques that places a strong emphasis on a performers personal and internal bodily perception [12]. Akerly discusses the importance of embodied flow when engaging with a responsive audio system [1]. She concludes that the characteristics of the communication channel between the dancer's activities and the responsive audio system plays a crucial role in that they should facilitate iterative cycles of experimentation, listening and responding while at the same time prevent a distraction of the dancer from his or her own bodily awareness. This argument can be extended for interactive systems that operate with different or additional sensory modalities. A promising approach for designing interactive systems that foster embodied flow is to link the system's behaviour via a physical simulation to kinaesthetic sensing and feedback mechanisms. The responsiveness of such a system can then be correlated with the dancer's own kinaesthetic awareness.

Another important technique in dance relates to the notion of "hyper reflexivity". This notion describes a constant shift between reflexive and pre-reflexive modes of consciousness. [18, p. 38]. 'Hyper reflexivity forms an important aspect when learning new movements. During training, the dancer operates in a reflective mental state. But once sufficient expertise has been acquired, the dancer shifts to a pre-reflective mode in which his or her body is automatically set into motion. Drawing from this, it can be argued that if an interactive system should operate as an integral component of a dancer's movements, then the system must permit a transition from a reflective mode of learning to a pre-reflective mode of engaging with the system. As an inspiration how such a system could be designed, it might be worthwhile to look into research in the field of prosthetics. An interesting example is an EMG-controlled robotic hand prosthesis that provides tactile feedback [16]. The hand employs a neural network-based adaptive learning system for recognising the EMG signals and generating an appropriate movement response for the hand. The authors argue that the patient's self-attribution of the prosthesis forms essential aspect of rehabilitation and is mediated by at least two aspects. The capability of the prosthesis to provide correlated kinaesthetic and multi-sensory feedback. And a user-centric form of control that helps to reduce the cognitive distance between movement intention and movement execution. Both findings underline the importance of kinaesthetic feedback modalities and pre-reflexive forms of interaction. In a related publication, the authors showcase that acoustic feedback can substitute the role of kinaesthetic feedback better than visual feedback when trying to guide a simulated body prosthesis [14]. This argument underlines the importance of acoustic feedback modalities in interactive systems that are used in a dance context.

Embodied forms of creativity play a crucial role for creating new dance material. Due to the fact, that dancers use their bodies as cognitive tools, it is the relationship between the physical and motor dispositions of a dancer's body and his or her kinaesthetic imagination that plays a central role for the creative generation of new dancerly movements [17]. In performance situations, the physical body fulfils the additional role of a communication channel that operates via the evocation of kinaesthetic empathy [3]. An appreciation for the importance of the body as a creative tool both for the creation and the transmission of new movement ideas should inform the design of interactive systems. By creating systems that strongly connect to and modify the dancer's awareness of their bodily capabilities, the processes of interaction can become part of bodily forms of creativity. In this situation, the feedback modalities of the interactive system fullfill a dual role. The output of the system can alter a dancer's bodily awareness and thereby evoke new kinaesthetic images via cross modal transfer [17]. And the output of the system which can be perceived by multiple performers at the same time can act as mediator for and transformer of kinaesthetic communication.

While the previous discussion has been strongly inspired by a phenomenological understanding of cognition, it might be interesting to also take into account concepts of bodily representation. The most common distinction between different forms of body representation is given by the terms "body image" and "body schema". The term body image refers to a conscious awareness of one's own body and includes perceptual,, emotional, and social aspects. The term body schema refers to sensorimotor representations of bodily properties that are relevant for subconscious action planning and action control [13]. It seems justifiable to relate these terms to the previously described notions of hyper-reflectivity and the issue of cognitive distance. In these contexts, the terms might be useful as part of a design heuristics for interactive systems in that they help to clarify the intended purpose of the system; for example whether a system is meant to challenge a dancer's bodily awareness or whether it should facilitate embodied flow. From the point of view of embodied creativity, it might be interesting to design the interactive system in such a way that it allows a dancer to alternate between modes of disruption and flow.

Agency and Autonomy

The concepts of agency and autonomy play a very important role for planning and implementing interactive systems that are supposed to exhibit some degree of originality and independence in their behavioural response to a performer's activities. But for informing a design heuristics, these concepts are delicate for a number of reasons. They represent fairly elusive concepts that still need clarification [26]. More often than not, designers, even if they have a background in artificial intelligence, specify their design criteria based on a loose understanding what these concepts imply. As a result, these systems are usually designed to full-fill their desired purpose for a particular application via an ad-hoc combination of bottom-up internal mechanisms and externally imposed top-down criteria. While this approach may constitute an acceptable compromise within the tight limits of a production workflow, it doesn't contribute much for a more general understanding and appreciation of the potential role that proactive and autonomous systems could play in performance. Another issue that troubles the concepts of agency and autonomy is the fact that their attribution suffers from an observer / frame problem [25]. By focusing only on the internal mechanisms of a system, one runs into the danger of neglecting the inter-subjective nature of this capability. And by focusing on externally perceivable criteria for agency, one might favour a superficial imitation of this capability rather than its genuine instantiation. Interactive systems for dance might provide a fertile ground for working with this duality of viewpoints. On one hand, the combination of software engineering and somatic techniques can provide complementary approaches for specifying and assessing the inner mechanisms underlying agency. On the other hand, during rehearsal and performance phases, the observer point of view of dancers and audience provide complementary access to the experiential aspects of agency. The former enables an interaction-based and focused form of probing an the interactive system, the latter enables a more encompassing point of view that assesses the interrelations between multiple agencies present on stage.

A definition of agency and autonomy that is informed by a system's science point of view could serve as an interesting background for the discussion about interactive systems. According to system's science, agency arises from dynamic processes within complex adaptive systems [9]. On their most basic level, these processes deal with self-maintenance. But in addition, they form part of a continuity of increasingly integrative and pro-active capabilities that eventually lead to the manifestation of cognitive capacities [27]. There are a number of aspects to this notion of agency and autonomy that are of interest in our context. First of all, agency is defined as a graded and processual characteristics rather than an absolute and representational one. This notion resonates with approaches that relate dance and responsive media on a processual level. And it also connects well with attempts to evoke capabilities of agency via the simulation of complex systems. Also, according to system's science, agency influences the degree by a which a system is decoupled from immediate environmental conditions. Agency therefore affects the amount of interactive possibilities that a system is able to exhibit. This consideration can serve as a design heuristics for endowing a system with a range of responsive capabilities which elude direct control by a dancer. Furthermore, a focus on the processual notion of agency places an emphasis on the highly distributed and integrative aspects of agency. Accordingly, agency doesn't appear as an isolated property of a particular entity but rather refers to the characteristics of the interrelationships among multiple entities and their environment. This notion of agency supports approaches in dance and technology that attribute agency as a distributed property which is shared between dancers and interactive systems. This notion also links to the broader scope of choreographic methods that distribute the creative process beyond the limits of a single person's own body and mind [17]. Finally, and maybe most importantly, a notion of agency that can be linked through layers of conscious, subconscious and physiological processes to morphological and physical predispositions closes the loop to the previously discussed issues of bodily awareness. Designers of interactive systems can try to foster this emergent quality of agency by deeply integrating simulations of complex systems with the physical and bodily presence and awareness of a dancer. If the resulting system achieves to function as an artificial partner in a performance, it will do so in manner that has a much greater potential for creative engagement than a simple mimicry of a dancer's behaviours.

OUTLOOK

In this outlook section, we attempt to make a full turn back from the previous discussion towards the specification of concrete and practical objectives for the Neural Narratives project. Some of the objectives are rather incremental in nature while others are more radical and speculative. Both types of objectives can only be reached in a meaningful manner if they form part of a process that integrates dancers and developers into iterative cycles of design, experimentation and evaluation.

With respect to the topic of bodily awareness, it seems necessary to reconsider the exclusive use of camera based controls and audiovisual feedback. While this decision was motivated by the desire to establish a sensing and feedback system that can be apprehended both by the dancers and the audience, it doesn't adequately take into account the kinesthetic aspects of the dancer's attention and interaction. While the acoustic feedback can convey kinaesthetic aspects of movement, the visual feedback is more problematic in that regard. Not only is visual feedback less suitable to substitute kinaesthetic sensations but it also requires directed attention. Both aspects have been experienced by the dancers as being detrimental for reaching a pre-reflexive mode of performing. For this reason, we would like to complement the acoustic and visual modalities with tactile forms of feedback. We have already conducted a small series of tests by embedding pager motors into a wearable sleeve that can be worn on a dancer's hand. In these tests, the tactile feedback conveys cues as to whether a virtual body extension has collided with the tracked body contour of the dancer and with a bounded region on stage. We plan to continue this line of research.

A similar rationale informs our plans for revising the sensing aspects of interaction. Cameras provide allocentric spatial information that help to establish positional relationships between physical and virtual body elements. But such a spatial reference system doesn't take into account a dancer's egocentric and kinaesthetic awareness. Furthermore, the usage of Kinect cameras imposes constraints that further increase the gap between computer-based sensing and human awareness. Limitations of the posture recognition mechanism require a dancer to be aware of his or her distance and orientation with respect to the camera. In addition, skeleton tracking adds a significant latency to interaction that hampers the establishment of a continuous sensorimotor loop between physical and simulated behaviours. To alleviate these problems, we plan to complement the usage of cameras with wearable motion sensors, whose output is more closely related to egocentric and kinaesthetic aspects of movement and exhibits lower latency.

With respect to the bodily characteristics of the artificial body extension, it might be interesting to at least consider the possibility of replacing the current simulation-based approach with a robotic implementation. By connecting a physical manifestation of a synthetic body structure to a dancer's body, the impact on body awareness and movement possibilities will be much more substantial than via the mediation of a simulation-based entity. On the other hand, a robotic extensions will most likely act mainly as a constrainer of existing movements rather than an enabler of new movements. And while a robotic extension possesses much more presence on morphological, behavioural and sensorial levels than a simulation-based extension, the former is also much less flexible and malleable on these levels. As result, a robotic extension can't compete with a simulation-based extension concerning its potential to deviate from and exceed the capabilities of a human body.

With respect to the topic of agency and autonomy, the current realisation of the simulation leaves ample room for improvement. At the moment, the body extensions consists of two mutually interdependent layer of complexity: a simulated mass-spring system and an artificial neural network. While the ANN emerges from a formation process that is situated within the simulation itself, the MSS is hand-designed. Furthermore, both the MSS and the ANN remain fixed in their architecture once a body extension has been created. For this reason, there is very little room for those processes of self-constitution which are so characteristics for natural forms agency. Also, the behavioural repertory that is created via artificial evolution for a particular body extension is usually very limited and rarely comprises more than one or two movement and interaction patterns. Therefore, most of the diversity of engagement between a dancer and a body extension is initiated by the dancer or externally imposed via a manual intervention from the control desk. In order to improve the level of agency and autonomy that the extension exhibits, are number of strategies seem feasible.

On the level of sensorial input to the ANN, it might be worthwhile to explore means of permitting the network to better discriminate between different movement qualities than by simply sensing and integrating the activities of the MSS. The same argument applies for the design of the fitness function for the evolutionary selection process, which in its current version is also based on a simple physical quantification of movement. A prime candidate for sensorial input are movement qualities that are of particular relevance within dance, such as for instance the Laban movement qualities [21]. For some of these movement qualities, there exists ample literature from the field of quantitative human motion research, see [19] for a recent review. The discrimination of these qualities could be conducted by a pre-processing layer within the ANN itself, or less ideally, it could be based on a machine-learning algorithm that operates externally to the ANN.

Concerning the creation and subsequent operation of the virtual body extensions' morphology and neural network, it would be interesting to allow for a higher degree of self-organization and openness. First of all, the MSS could be created via a similar process of evolutionary adaptation as it already does in case of the ANN. But more interestingly, an already realised artificial body extension could undergo an additional process of adaptation that continues through rehearsal and/or performance. This process doesn't necessarily have to be limited to learning based modifications of a ANN, but might as well modify the the morphology of the extension itself. Such an adaptation mechanism could be implemented as a form of reinforcement learning. The value system that guides reinforcement learning can either represent some criteria that are inherent in the simulated system itself (such as structural stability, energy expenditure etc) or that reflect aesthetic, interactional and choreographic criteria. Regardless of the rather challenging details of such an implementation, a process of adaptation and change that is ongoing throughout a performance would dramatically increase the possibility for creative experimentation and open ended improvisation. At the same time, such an adaptation will likely complicate the integration of the system into a somewhat predefined choreographic structure. But the necessity to find a balance between constraints and openness when working with performers is inherent to any performative practice.

To conclude, we hope that we have managed to convey an understanding of our motivation and particular approach for designing artificial systems that operate via their simulation-based underpinning and audiovisual rendering as morphological, behavioural and audiovisual extensions of a dancer's bodily presence and activities. Despite the fact, that some of the design decisions are somewhat arbitrary and specifically tied to the needs of two particular performance productions, we believe that this approach is of interest to a wider community of researchers and practitioners in dance and technology. For this reason, we've placed a strong emphasis on a contextualisation and discussion of the most pertinent issues that have arisen during the realization of and reflection about the Neural Narratives project: the issues of embodiment, agency, and creativity. By reasoning about those topics not only from the perspective of dance technology but also from points of view that originate from more distant fields such as medical engineering and system's science, we hope to foster a discourse that inspires more substantiated approaches for integrating technology in dance. We are optimistic that such a discourse will eventually feed back on and augment the artistic practice in dance and technology, including our own.

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