Aesthetic potential of human-computer interaction in performing arts

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to my family

Preface

This is my master thesis on performing arts and computer science. I think about it as something that I have wanted to do for a while. When I decided to study bioinformatics, I thought that my art related interests would have their place in my spare time. Unfortunately studying bioinformatics ended up being a full-time job with very little free time that I filled up with my family and friends.

When I graduated, I immediately started working, waiting for the right moment to get back to the artistic part of me that I had put on stand-by. This moment came when I started my master studies. I already knew that leaving my art-related interests for my free time would be impossible. I understood that time is limited, so I did the best thing I could have done: I connected my computer science studies with art.

This thesis gave me an excellent opportunity to explore two fascinating fields: *human-computer interaction* and *performing arts*, as well as to participate in the creation of interactive dance pieces that combine movement and digital media in one harmonic system. I worked with talented dancers and choreographers and experimented with the magic world of projected images.

I hope that this study will be just the first step of a long journey on the intersection of computer science and art that will continue in my further research.

Abstract

Human-computer interaction (HCI) is a multidisciplinary area that studies the communication between users and computers. In this thesis, we want to examine if and how HCI when incorporated into staged performances can generate new possibilities for artistic expression on stage.

We define and study four areas of technology-enhanced performance that were strongly influenced by HCI techniques: multimedia expression, body representation, body augmentation and interactive environments. We trace relevant artistic practices that contributed to the exploration of these topics and then present new forms of creative expression that emerged after the incorporation of HCI techniques. We present and discuss novel practices like: performer and the media as one responsive entity, real-time control of virtual characters, on-body projections, body augmentation through human-machine systems and interactive stage design.

The thesis concludes by showing some concrete examples of these novel practices implemented in performance pieces. We present and discuss technology-augmented dance pieces developed during this master's degree. We also present a software tool for aesthetic visualisation of movement data and discuss its application in video creation, staged performances and interactive installations.

Acknowledgments

I would first like to thank my supervisors: Drs Tomás Laurenzo and Javier Baliosian, for their trust, help, support, and guidance. Without their persistent help, this dissertation would not have been possible. They allowed this thesis to be my own work, but steered me in the right direction whenever they thought I needed it.

In the same way, I would like to thank my reviewer Dr Alvaro Cassinelli for his time and effort.

I would also like to thank Lía Spatakis, Analía Fontán, Ximena Castillo and Jessica Lateulade for their ideas, time and energy put in our common work on technology-augmented dance pieces.

Also to be thanked are Dr Phillip Pasquier and other participants of the *Moving Stories* project who gave me the opportunity to exchange ideas and experiences and to work together exploring human movement and digital creation.

Also very important to this work was the support for interdisciplinary projects and research given by the Department of Computer Science and Ministry of Education and Culture. They demonstrated that work on art and technology should be promoted and encouraged.

I would also like to thank all of my friends who supported me in writing, and motivated me to strive towards my goal.

Finally, it is to be said that nothing would have been the same without Alvaro Santos's help, support, patience, and love.

Contents

List of Figures

Chapter 1

Introduction

"Technology will move in and speak through you, like it or not. Best not to ignore."

Tim Etchells [9]

This master thesis aims to identify novel practices that emerged with the incorporation of HCI techniques into performing arts, focusing on practices where the interaction takes place on stage, between digital media and performers. We[1] believe that the incorporation of real-time interactive responses mediated by computational systems has expanded the language of performing arts.

First, to better understand how HCI and performing arts, two at first sight very distant disciplines, come together and what the aesthetic implications are, we want to provide the historical context that illustrates constant influences between technology and performing arts. In this chapter, we outline examples of the cross-fertilization between these two fields and then present the thesis contents.

1.1 Technology and the performing arts

Performing arts consist of multiple disciplines like performance, dance, music, opera, theatre, musical theatre, magic, puppetry and circus arts, among others [10]. The term performing arts includes many very diverse practices, but all of them are carried out in front of a live audience and use the performer's body and presence as a medium of artistic expression [11]. Because of their staged character, elements such as lights, scenography, costumes, props, are often applied as a contribution to the overall atmosphere of the piece [12].

We consider performing arts a fascinating field of research because the ephemeral art forms that constitute this area leave no tangible traces. Contrary to visual arts, they are dynamic, real-time events, "dematerializing" the art

[1]During this thesis, we will be using the first plural person, as we find it more conventional and impersonal.

object [13]. Their nature is temporal and is experienced by the audience at the same moment when it is created by the performers. Chris Salter, an active researcher in the field of performance, in his book "Entangled: Technology and the Transformation of Performance" describes performing arts as "an unstable mixture amalgamating light, space, sound image, bodies, architecture, materials, machines, code, and a perceiving public into unique spatiotemporal events" [14]. The uniqueness of the artistic event and the extensive variety of expressive components (such as performers' actions, light, space, materials) that contribute to its aesthetic, motivated us to make the performing arts a field of scientific research and artistic practices in this master thesis.

1.1.1 The influence of technology on performing arts

"Technology, is integral to the history of performance."

Barbara Kirschenblatt-Gimblett [15]

Many artists look for new ways to augment and intensify their performances with technological artefacts. Technology incorporated into performance practices is hoped to contribute to the creation of unparalleled aesthetic and new perceptual experiences [14].

We can trace the inclusion of technology on the performance stage thousands of years back in history. Performing arts since their early beginnings were open to the incorporation of technological artefacts. Already in an ancient Greek theatre, we can find examples of technology applied on stage. In some ancient theatre pieces, apparently insoluble situations were solved by the interventions of gods or heroes that were brought to the stage by elaborate stage machines [16]. Those machines were used to extend the possibilities of human actors. They made it possible to lift the actors to create the illusion that they were flying [17]. These practices originated the term *Deus* *ex machina* (literally, "God from the machine") that we nowadays use to describe an unexpected solution of a seemingly unsolvable problem by the sudden intervention of some new event, character, ability or object.

Further on in time, other (at the time) modern technology: electric light, appeared on stage. The incorporation of electricity allowed performers like Loie Fuller[1] to experiment with electric light projections. She projected colourful light onto her undulating spacious dresses to alter and extend the medium of her body [18].

After electricity, cinema and later television and video, exerted a significant influence on the development of performance [19]. Film technology was not just simply integrated as a part of stage design, but also contributed to the creation of new art forms like cinedance (nowadays called videodance) [20]. Cinedance was created by Maya Deren in the 1940s. It contemplates the human body in movement, but at the same time uses the camera, editing, and montage to create cinematic choreography that can be performed only on film [21]. In this field, the two domains of dance and cinema come together to create a new art form that "transcends the biological possibilities of the living, gravitational body and which introduces alternative forms of embodiment" [18]. It is a clear case of a powerful cross-fertilization of technology and performing arts that resulted in a new art form that is an object of research and experimentation until present times [22].

Subsequent video technology was widely explored in dance [23], theatre [24] and performance art [25]. Video technology was used in diverse ways, for example: as a part of scenography, to create narrative sequences difficult to achieve in a different way or for illusionary purposes [26].

In the past decades, we have experienced advances in hardware (such as personal computers, mobile phones, recording/playback/control equipment),

[1] An American modern dance pioneer, known in performance studies for her innovative use of new electric technologies.

software applications (search software, graphic manipulation software) and networks (the Internet and mobile telephones) [27] that have also had an evident influence on performing arts. Computer applications like DanceForms (historically also referred to as LifeForms or Compose) [28] or Web3D Dance Composer [29] started to be used to compose, visualise and edit the dance choreographies [30], and so, reduced the time needed for live rehearsal [31].

The rapidly evolving networking systems provided more connectivity and possibilities of remote collaborations [32]. Video conferencing systems allowed connections between different geographic locations and the creation of telematic performances where images of remote actors coexist and collaborate with the live actors on stage [17]. The popularisation of digital technologies resulted in the creation of a new field in performing arts: digital performance.

1.1.2 Digital performance definition

Digital performance is an art field that brings together performing arts and digital technologies [33]. The popularisation of computer technologies facilitated their integration in traditional performing arts like theatre, dance or performance. Musicians, dancers and choreographers, more and more frequently, applied digital technology on stage. Also, new art genres appeared: we started to talk about virtual theatre [34], augmented dance [35] or telematic opera [36]. Digital performance is a term that includes all these art practices.

We consider that the most straightforward and concise definition of digital performance is the one given by Steve Dixon[1]. By his definition, it includes

[1]Steve Dixon is a British actor, academic and interdisciplinary artist. He is an internationally renowned researcher in the use of digital media and computer technologies in the performing arts. He was co-director of the Digital Performance Archive, which established

"all performance works where computer technologies play a *key* role rather than a subsidiary one in content, techniques, aesthetics, or delivery forms" [19]. This simple definition stresses the importance of technology as an essential part of the art piece, a very important point to highlight. In this context technology is not just an additional tool, but a significant part of artistic creation.

We want to stress that digital is not equal to interactive. Digital performance is a wide term that includes performances with real-time interaction between the performer and digital media (for example digital sound and images) included in the stage design, as well as a wide range of non-interactive practices that make creative use of computer technologies and digital material. Adjectives like digital, new media, cyber, augmented or multimedia are frequently used to describe the new aspect of the performance that emerged with the incorporation of computer technologies. There is no significant difference between these terms, all of them are used to describe art practices that use digital technologies to create new means of expression that expand the language of classical performance. In this thesis, we will mostly use the term digital performance to refer to this field of artistic exploration, but one should keep in mind that also other names can be found in the literature.

Digital performance constitutes a reference field for our study, because (in its wide spectrum of artistic activities) it includes staged performances that involve live human-computer interaction: artistic practices that we want to analyse and discuss in this thesis.

the largest online database in the field, and he co-founded the International Journal of Performance Arts and Digital Media.

1.1.3 HCI in digital performance

HCI is a multidisciplinary area that studies the communication between people and computers [37]. It focuses on the design, evaluation and implementation of interactive computing systems, including the investigation of the phenomena surrounding these actions [38]. The appearance of HCI technologies related to body capture, as well as the possibility of digital manipulation of sound and image and robotic systems, introduced new types of real-time interactivity into live performances: interactivity between the performer and digital media presented on stage. We believe that this fact contributed to the extension of artistic practices in performing arts that we aim to demonstrate and discuss in this work.

We define the following research questions:

- What sensing technologies used for data exchange between the user and the computer are present in performing arts?
- What are the goals of the incorporation of these technologies into performance?
- How has this incorporation influenced existing art practices?

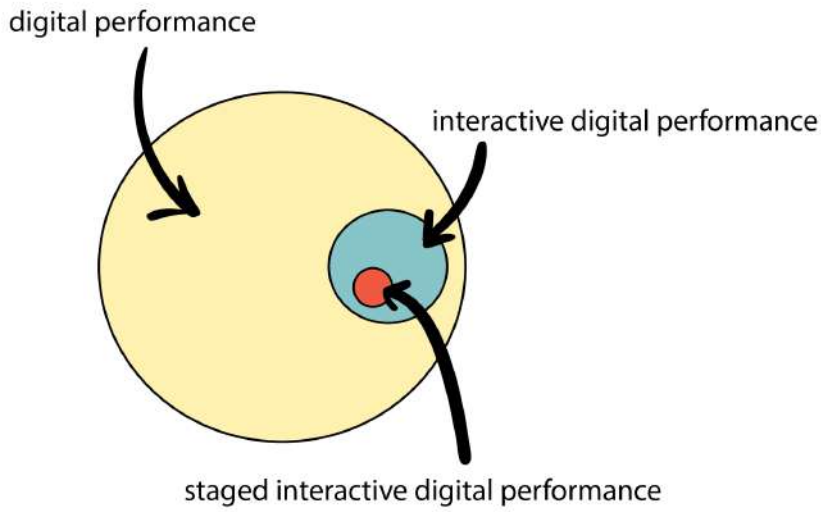

Figure 1.1: Staged interactive digital performance.

Literature dedicated to the analysis of the influence of digital media on performing arts encloses a vast panorama of digital forms of expression like video, robotics or virtual reality [19, 14, 33], but the practices presented in it are often non-interactive. There are also works that explore interactive art, but they generally focus on interactive installations where the spectator becomes the performer himself and analyses the aesthetic consequences of that fact [39, 40]. We have selected and studied different examples of interactive staged performances (Figure 1.1) and identified four relevant topics that were explored using interactive technologies: multimedia expression, body representation, body augmentation and interactive environments. Before the appearance of HCI techniques all these topics were explored in a non-interactive (or perhaps better said: in non-technology-mediated-interactive) way, but showed new creative possibilities with the incorporation of HCI.

1.2 Thesis contents

The document begins with the presentation of the reference area in our study: human-computer interaction (chapter 2). We outline its history, some key terms and give examples of HCI techniques relevant for our study. We also introduce the concept of mediated interactivity and its particular form in the field of performing arts.

In chapter 3, we introduce four relevant lines of artistic exploration in digital performance: multimedia expression, body representation, body augmentation and interactive environments. We give the historical context of their emergence and development, and present unique impacts of HCI on these artistic practices.

Chapter 4 presents four technology-augmented dance pieces and a software tool MAVi developed during this master's degree.

In the last chapter, the conclusions are laid down, along with an enumeration of possible future work.

Chapter 2

Human-computer interaction

HCI is an important field for this work since it provides the theoretical and practical context of our research. In this chapter we present the historical context of this field and current practices. Later on, we introduce different techniques that are used to mediate HCI, and so draw a landscape of possibilities that can be, and frequently are, employed in performing arts.

In the final part of this chapter we present a general definition of technology-mediated interactivity and then narrow it down to the context of staged performances. We used this definition to select works relevant for our study.

2.1 Historical context and current practices

HCI studies the communication between users and computers [37]. It analyses phenomena surrounding this communication and investigates the design, evaluation and implementation of interactive computing systems [38]. It combines areas like software engineering, computer science, human factors, ergonomics, industrial engineering, cognitive psychology and sociology [41]. HCI aims at improving already existing human-computers systems by looking for more efficient, pleasant and natural ways for information exchange and searching for new ways to communicate the user with the machine and vice versa [42].

The interaction modalities that we use to exchange information with computers have come a long way since the introduction of computers, and since the beginning have always begged the question of interfacing [43]. A user interface: a representation of the system designed for users with which they interact [44], changed multiple times to support new interaction modalities. In this section, we present how human-computer interfaces have evolved over time and show the most recent practices.

We present the evolution of HCI, starting from the direct manipulation of mechanical parts, to command line interfaces (CLIs), graphical user interfaces (GUIs) and direct manipulation, to finally introduce natural user interfaces (NUIs) that are most relevant for our study.

With the construction of the first computers the design of the interaction between humans and computers started to be a point of interest [45]. Those computers occupied a large room and needed multiple operators to load the programs via the setting of switches, dials and cable connections [46]. Hardware was a central part of user interfaces and engineers and trained programmers were the only users [47]. The main objective of HCI at that point in time was to improve the design of buttons, switches and displays [48].

Next, punch cards were used to transfer information into computers. Users punched the input information as holes in paper cards that could be read by the computer [49]. After punch cards, a device called the Teletype (TTY) with a keyboard similar to that of a typewriter was used [49]. The operator typed in commands and received on scrolling paper one-line output (such as feedback or status messages) from the computer. It was the first conceptual model of user interface involving exchange of real-time messages between the user and the computer [50] and the first incarnation of the command-line interface (CLI) [45].

CLI allows the user to express instructions to the computer directly, by typing them in with a keyboard in the form of whole-word commands, functional keys, characters or abbreviations [37]. It uses a visual display and the interactive capability of the terminal to enable the interaction [47]. The disadvantage of this type of interface is that the users must learn and memorise the predefined keywords to interact with the system. The CLI interface started to be replaced in the 1970s by the graphical user interface (GUI) [50].

GUI provides a simple visual environment that allows the user to communicate with the operating system of a computer. It uses images and graphical icons that represent the information and actions available to the user. The actions are usually performed using a pointing device [45]. GUI uses the idea of direct manipulation [51]. Direct manipulation is an interaction style where the user can manipulate digital objects through physical actions and where the operations and their impact on the object of interest are immediately visible [52]. It allows the user to interact with graphical objects on the screen, relying on recognition rather than recall, making the interface appealing to novice users, easy to remember for occasional users and fast and efficient for frequent users [53].

Figure 2.1: Different user interface paradigms.

Further studies in the field of interfaces resulted in the development of Natural User Interfaces (NUIs) [54]: interfaces that allow users to interact with computers in a more natural and intuitive way, understanding users' natural capabilities to communicate and imitating human-human interaction [55] (Figure 2.1). The NUIs allow use as input data gestures, body language, proximity and location, eye gaze position and even data like blood pressure or heart beat rate [56]. As we can see, they accept a much wider range of input modalities than the previously prevailing key-pressing and point-and-click interaction. It is important to stress that these new interfaces allowed moving the interaction from desktop based environments to more spatially independent settings, public spaces, and even performance stage [57]. That is why they are particularly relevant for the usage in performing arts, and the interaction modalities that they allow will be discussed in the following section.

2.2 Body as input

NUIs enable interaction modalities where the properties of the human are sensed by the computational system without any need of manipulating a physical device (like a mouse or joystick). They are especially suitable for performing arts since they have no arbitrary constraints on performer's actions. In this section, we present a brief overview of HCI modalities that do not interfere with performers' acting, to draw a landscape of possible interaction techniques that can be applied in performing arts. We divided the interaction modalities into three categories:

- Based on computer vision
- Based on audio analysis
- Based on wearable sensors

The next subsections describe each category and provide examples of concrete interaction techniques that they use.

2.2.1 Based on computer vision

The human-computer interaction based on computer vision is probably the most widespread area of interaction techniques research [43]. It covers a broad range of methods and applications used in human-computer communication, as well as in entertainment [58]. Some of the main research areas are presented in the following part.

Whole-body tracking. Motion tracking and motion analysis are two of the most active application domains in computer vision [59]. Motion tracking allows defining and following the position of a person from a single viewpoint [60, 61] or multiple camera perspectives [62]. It can involve procedures for body structure analysis, pose estimation and movement recognition [63].

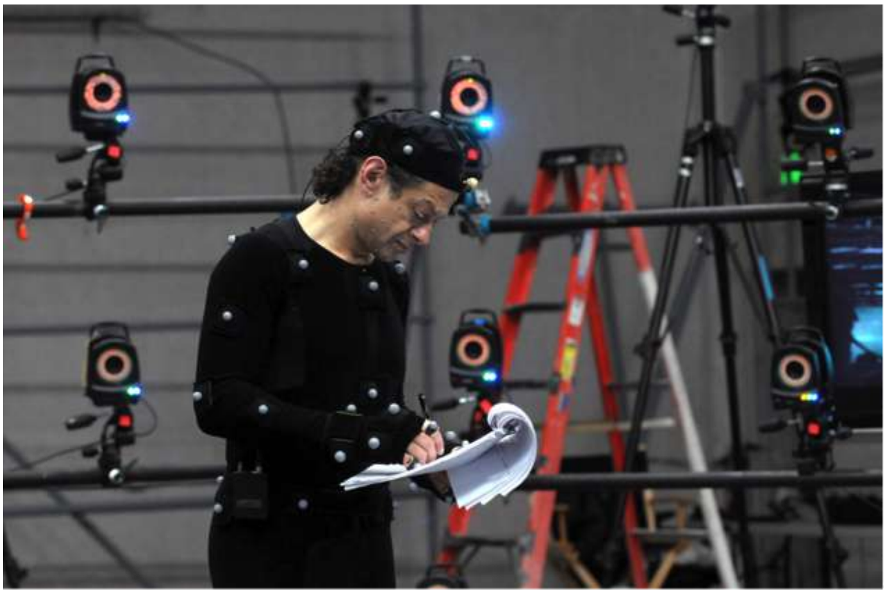

Figure 2.2: Human subject with reflective markers in an optical tracking system [1].

In this group, we also include methods that perform motion tracking based on optical markers. Markers are typically placed on body joints and tracked by multiple fixed cameras that triangulate the position of each marker. The markers can be colour markers [64], infrared passive (reflective, Figure 2.2) or active (light emitting) markers [65]. Whole-body tracking is used in games, virtual environments or animation [66].

Gesture recognition. Gestures are meaningful physical movements of the fingers, hands, arms, head or body that are used to convey information or to interact with the environment [67]. Hand gestures are a common means of non-verbal communication [68] and are more frequently used for human-computer interaction than other body parts [69]. Vision-based techniques allow recognising both dynamic and static gestures [70]. These techniques are applied in, for example, games [71] and music creation [72].

Face and facial expression recognition. These techniques are based on face detection, recognition and face features extraction [73]. Face detection and recognition allow recognising human faces on pictures or live video [74], and facial expression recognition allows distinguishing emotions like, for example, happiness, sadness, surprise, anger [75].

Gaze tracking. Eye tracking studies the motion of the human eye during the assimilation of visual information and allows determining the target of the user's visual attention [76]. Eye gaze interaction can provide a convenient and reasonable addition to user-computer dialogues and is especially suitable in situations where the user's hands are occupied [77].

2.2.2 Based on audio analysis

Interaction via audio signals can be based on simple properties of sound waves or focus on the transmitted content (words, voice commands). We can distinguish between interactions based on audio spectrum characteristics (like tone or pitch) or speech recognition [78].

Speech recognition. Natural language processing (NLP) employs computational techniques for the purpose of learning, understanding, and producing human language content [79]. It offers mechanisms for incorporating natural language knowledge into user interfaces to create speech-based interfaces capable of controlling interactive systems with words or natural language sentences [80].

Human-made noise. This interaction technique allows detecting human presence and creating responses to audio features (energy, pitch, and speaking rate, among others) [81]. Also, efforts towards automatic recognition of human auditory signs like laughter [82] or crying [83] have been reported.

Auditory emotion analysis. There are several approaches to inferring emotions from speech. Auditory emotion analysis based on speech acoustic parameters like pitch, intensity, duration/pausing and sound spectrum [84, 85] identifies emotions like confidence and hesitation [86] or stress [87]. Acoustic features combined with linguistic features improve recognition performance [88, 89].

2.2.3 Based on wearable sensors

In this section, we present techniques that fix instruments to the user in order to collect the data necessary for the interaction. We want to stress that we introduce examples where the sensors do not have to be manipulated but are fixed to the human body while collecting the data. They allow registering the performer's actions without limiting them.

Motion tracking. Sensor-based motion tracking systems include inertial [90], magnetic [91], acoustic [92], and mechanical trackers [93]. They allow measuring the position and orientation of objects, typically body joints [94]. They can also be used for gesture recognition [95, 96, 97]. Hybrid trackers attempt to combine various sensing technologies to increase accuracy, and reduce latency and measurement errors [98].

Bio-sensing. Biofeedback sensors are analytical devices for measuring physiological signals like electrical activity of the heart, blood pressure, pulse rate, neural activity, body temperature, skin conductance or respiration changes [99]. Changes in these physiological parameters are frequently associated with emotions [100] and present an interesting field for the development of interfaces that respond to users' emotional states [101].

Techniques presented in previous sections are often combined in multimodal interfaces able to interpret information from different communication channels [102]. The use of multiple channels in human-computer communication has many advantages like more bandwidth in the communication, various alternatives of communication depending on the situation and environment or the prevention of errors [78].

Without doubt, new sensing technologies make it possible to capture human body properties that we can not register with traditional interaction devices like mouse and keyboard. These new possibilities have been explored in artistic projects that involve, to name just a few examples, movements [103, 104], gestures [105], face tracking [106] or tone of voice [35].

2.3 Technology-mediated interactivity

Technology-mediated interactivity is an essential component of art practices examined in this study. In this section, we present both a general definition of mediated interactivity and the definition of interactivity in the particular context of digital performance.

2.3.1 General definition

Mediated interactivity involves the use of a technological medium for transmission of data across time and space [107]. A wide range of media technologies can be applied to mediate communication, ranging from radio, television, through telephone, e-mail, chat to WWW and virtual reality [108]. Scholars have analysed mediated interactivity from different angles, putting the focus on communication context [2], user perception [109] or media technology [108]. We present these three approaches below.

Communication context

The first type of interactivity definition focuses on the communication context. These definitions put the emphasis on the interconnected relationships between exchanged messages and the degree of control that every interaction participant has over this exchange.

From this perspective, the communication is interactive if subsequent messages sent between two parts are related to each other [2] (Figure 2.3).

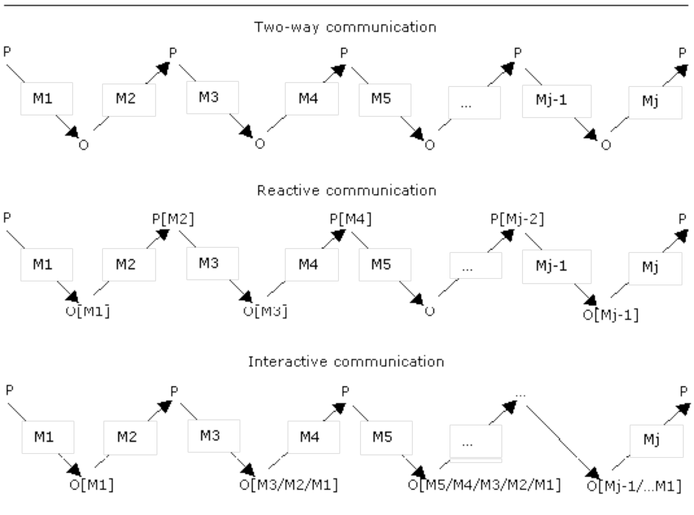

Figure 2.3: Rafaeli's concept of interactivity in three levels [2]. Only interactive communication is based on all previous messages (Mj) between the person (P) and the other (O).

In this approach, another important aspect is the degree of control that the participants have over the exchanged messages. Their capability to choose the timing, content, and form of the communication define the level of interactivity of the system [110].

User perception

This approach to interactivity concentrates on the user's perception of the communication process. According to it "interactivity resides in the perceptions of those who participate in the communication" [109]. According to this definition, the same medium can be perceived as more or less interactive dependent only upon people's perceptions. For example, email messages addressing large audiences indicate smaller levels of perceived interactivity than those targeting small audiences [111]. Interactivity, in this case, is a psychological variable. The level of interactivity of the medium is defined by our perception, not the medium properties or communication aspects.

Media technology

The third definition of interactivity focuses on technology applied in the communication. It claims that interactivity is associated with the media technology used in the messages exchange. Interactivity is a range of influences that the media allow the user to exert in real-time [108]. The media's potential of enabling the user to choose from information stream (teletext), to make requests to the system (WWW, video-on-demand), to generate input (e-mail) or the potential of the media to register information from the user and adapt to this input (interactive fiction) defines the degree of the interactivity of the system. From the three approaches presented, this one is particularly relevant to interactive digital performance. In the following subsection, we present the definition of interactivity narrowed to this particular area.

2.3.2 Interactivity in digital performance

In digital performance, interactive systems are real-time environments that allow the generation, synthesis and processing of digital information in response to a performer's actions [5, 112, 113]. The data exchange and technical mediation are used as an aesthetic means [114]. Interactive environments allow the generation of real-time aesthetic relationships between the performer and the digital media that are part of the performance. That is why the definitions of interactivity present in the digital performance literature are mostly based on media technology. Above all, they focus on the potential of the media to sense information from the user and adapt to it. The interactivity is seen as "a collaborative performance with a control system" in which a performers' movements or actions are used as input to activate, generate or control other media (such as text, graphics, digital images, video, audio, midi) [115]. We used this definition to analyse the art pieces and define their relevance for our study.

This chapter aimed at providing the definition of interactivity and a landscape of interaction techniques that translates the performer's body characteristics into real-time interactive environments. In the following chapter, we analyse how these techniques have influenced the performing arts.

Chapter 3

The influence of human-computer interaction on the performing arts

"Digital performance is an extension of a continuing history of adoption and adaptation of technologies to increase performance and visual art's aesthetic effect and sense of spectacle, its play of meanings and symbolic associations, and its intellectual power."

Steve Dixon [19]

In the previous chapter we presented HCI techniques that can be incorporated into staged performances. This incorporation led to the creation of new types of artistic practices, contents, psychological effects [19] that enhanced traditional forms of performance [57].

In this chapter, we present the historical development of four lines of creative exploration that are part of digital performance. We present practices focused on: multimedia expression, body representation, body augmentation, and interactive environments, and discuss how the incorporation of the interactive technologies influences these fields. First we present non-interactive practices that established certain lines of artistic research which were retaken and extended with the appearance of computer-mediated interactive systems. Then, we present examples of new artistic practices that emerged with the incorporation of interactive technologies and give examples of particular performance pieces.

3.1 Multimedia expression

In this section, we focus on artistic experiments in which diverse media come together to create an aesthetic experience. We identify diverse approaches to create poetic relationships between media and their artistic purposes. We present examples of artistic practices related to the performing arts that use diverse media in a creative way and as an integral component of the overall work, significantly contributing to the content of the production.

3.1.1 *Gesamtkunstwerk*

The importance of the synthesis of art forms was stressed by a revolutionary of stage design: Richard Wagner. He promoted the hybridization of traditional disciplines into a unified piece with the aim of intensifying the audience's experiences of art [116, 117].

Wagner, German opera composer and theorist, was concerned about the disintegration of the drama into constituent parts [118] and boosted the idea of the *Gesamtkunstwerk*: a unification of creative and expressive disciplines to achieve full immersion of the public [116]. "Artistic Man can only fully content himself by uniting every branch of Art into the *common* Artwork" claims Wagner in his essay "The Artwork of the Future". For Wagner, the *Gesamtkunstwerk* was the union of Hegel's three humanist arts: dance (movement), tone (music), poetry and the three plastic arts: architecture, sculpture and painting [119].

Wagner's reflection on *Gesamtkunstwerk* is avowed as "one of the first attempts in modern art to establish a practical and theoretical system for comprehensive integration of the arts" [120]. His idea of the integration of different arts into a hybrid form of expression is a clear precedent of current multimedia expression in which multiple artistic forms and technologies create a single art work. It makes Wagner's theories and works important roots for multimedia practices in digital performance.

Wagner's idea of aesthetic integration was developed and extended in the next field of artistic exploration that we discuss: multimedia theatre.

3.1.2 Multimedia theatre

New media like electric light, radio broadcasting and video projections extended the language of theatre, giving a start to a new theatrical form: multimedia theatre [17]. This theatrical practice purposefully uses multiple media (television, slide and data projections, projected backdrops) on stage as an integral visual and conceptual component of the piece [121].

At the beginning of the twentieth century, theatre director, producer and designer Erwin Piscator was actively investigating the possibilities of the integration of cinematic media on stage. He is considered by some as the first major director that significantly integrated live actors and film material [122, 123]. The film allowed theatre to be liberated from the temporal and spatial limitations of the stage and made it possible to shift viewpoints [124]. To bring reality into theater space he used films of real events and dramatic reconstructions as a part of the scenography [26].

Theatre companies like Laterna Magika[1] continued the experiments with film material on the theatre stage. The company creates illusions and fantasy spectacles using live broadcast, CCTV (closed-circuit television) and multiple, mobile screens on stage [125] (Figure 3.1). It frequently presents live performers on stage along with pre-recorded versions of themselves [126]. The same actors appear on screen and stage and interact with each other raising questions of identity and mediation [127]. Laterna Magika is one of the first groups to introduce projections of the performers from remote locations, creating interaction between live video performers and the actual performers physically present [128].

Erwin Piscator and Laterna Magika made the stage image more dynamic, multi-levelled and suggestive by introducing video material into theatrical performance [126]. Through their artistic practices they also contributed to the discussion on live and mediated performance. Their explorations resulted in interesting examples of how one particular medium (video) can replace another expressive stage element (scenography) and how it can be used to reflect upon, or even replace, the live performer. Their experiments inaugurated new artistic experiments where video becomes not just a complement, but also a substitute for stage elements and/or live performers.

The Futurists presented another interesting approach to the integration of

[1] Laterna Magika is a cross-disciplinary group founded in 1958 in Prague. It was a pioneer in the merge between theatre, film, video, dance and media exhibition [14]

Figure 3.1: *Legends of Magic Prague* [3]. Laterna Magika, 2014.

diverse media on stage.

3.1.3 Futurist performance

Futurism is an early twentieth-century avant-garde movement presented in almost all of the art forms: painting, sculpture, ceramics, graphic design, industrial design, interior design, urban design, theatre, film, fashion, textiles, literature, music and architecture. Its primary focus was on speed, technology and progress [129].

In the field of performance, the Futurists worked toward a new synthesis of technology and performance by "multimedia convergence of artforms and the marriage of art with technology" [130]. They believed that classical art forms were inadequate for capturing the speed, energy and contradictions of contemporary life. For many futurists, the modern experience could only be evoked through art that contained within itself the complete range of perception and required the active cooperation of all the senses [120].

They continued the effort to intensify the spectators' experience of art by integrating traditionally separate disciplines into single works [120] and also presented a new way of interrelating diverse media. They experimented with performance as a live concatenation of different, sometimes conflicting media [115] and nonlinear, simultaneous, parallel actions on stage [131]. Günter Berghaus in his book "Italian Futurist Theatre, 1909–1944" [132] describes the Futurist performance as "dynamic, fragmentary symphonies of gestures, words, noises, and lights". They even elaborated a formula that illustrates the new theatrical form that they promoted: synthetic theatre [133]:

Painting + sculpture + plastic dynamism + words-in-freedom + composed noise [intonarumori] + architecture = synthetic theatre

They not only presented a new face of multimedia performance, but also advocated the extension and exchange of the elements used on stage. They focused on media and materials related to urban civilisation and its sensorial experience like "words-in-freedom, music of noises, kinetic sculptures, mobile, sonorous and abstract plastic compositions, glass, iron and concrete architecture" [131]. The futurist performance introduced into the performance field new types of media and a new order of presenting them on stage.

The artistic movement called Fluxus made the next historically significant step in the area of multimedia expression.

3.1.4 Fluxus

Fluxus emerged around the 1960s and is often described as an *intermedia movement*. The term intermedia describes a hybrid, conceptual fusion of diverse media where one "can't really separate out the different media in an integral way" [134]. This relationship between diverse media in the piece of art is distinct from the previously presented examples because it looks for aesthetic experience not in the multiplicity of media, but in the art activities that lie formally and conceptually between established media [135].

Examples of intermedia are concrete poetry[1] that is a fusion of visual art and poetry; Happenings as a fusion of visual art, music and theatre; or sound poetry as a fusion of music and literature [136].

Fluxus artworks are interesting examples of art practices that aim to dissolve the borders between the arts [120] and an important example of a new approach to the integration of multiple media.

As we saw, the usage of diverse media on stage has a long tradition in the performing arts. Different approaches to the media exposure (linear, nonlinear) and media interrelation (parallel, intermedia) allow to achieving diverse creative aims: enhancing the spectator's experience of art, discussing live and mediated, present and past, creating new dynamic stage scenography or breaking the linearity of the stage narrative. The exploration of multimedia expression was continued and extended with the appearance of HCI techniques that enabled a new type of media-performer relationship.

[1]Poetry in which meaning is conveyed through the poem's graphic shape or pattern on the printed page.

3.1.5 Multimedia expression and HCI

"For the first time in history, the image is a dynamic system."

Peter Weibel [137]

In the multimedia expression practices mentioned above, new types of media were integrated into staged performances, but they could not be easily altered. They were presented on stage in their linear order or were manipulated by an external operator [5]. We can say that they were part of the performance and coexisted with the performers acting, but it was impossible to control the timing and form of their presentation in response to performers actions.

Nowadays many of the media applied on stage have their digital form. We can manage digital sound, text, computer graphics and video. Because of their digital character, these media can be easily manipulated using a computer [138]. This fact together with the broad range of inputs accepted by user interfaces brought multimedia practices to a new level. Currently, human-computer interfaces allow us to capture a variety of human body properties and feed them into a computational system to affect the digital media exposure. In this context new relationships between the performer and media can be created: the performer's actions (such as movement, speech, gesture) can directly influence audio, video, computer graphics and other digital media. It allows the coupling together of media presentation form and dynamic with body properties. In this context, the performer and media are not independent expressive units, but are one interconnected entity. This relationship between media and performer is a novelty introduced due to new interfaces that sense and transmit in real-time the performer's actions to computational systems. It is an important advance that introduced new expressive possibilities into performing arts.

As an example of a concrete piece that takes advantage of this new media-performer relationship, we present the work of Polish composer Jarosław

Kapuściński[1] *Yours* (2000) [139]. Together with German choreographer Nik Haffner and American ballet dancer Antony Rizzi he created a piece that explores this unique relationship between the media and the performer.

In the piece, the pianist's musical gestures activate the projection of a nude male dancer. The music created by the performer manipulates the order and the speed of the dancer's pre-recorded movements. The musical score shapes the video reproduction and so "dances the dancer". It can be seen as a new implementation of the traditional interplay between the dancer and the music. This time, the dancer dancing to the music is mediated through video material. The music constructs and transforms the dancer's movements. Interactive control of digital media is a central part of the piece and allows the development of music and pictorial material simultaneously and in an interrelated way [140]. The new media control, or rather, media interrelation paradigm created interesting audio-visual opportunities for live performance.

Mapping. The question of mapping between activities from one expressive domain onto another is an interesting aspect of interactive multimedia expression. In *Yours*, musical gestures of the piano player were used to manipulate video media, but the range of possibilities is immensely wider. In current computer-mediated systems, we have available a variety of input (subsection 2.2 "Body as input") and output modalities (such as visual, auditory, tactile feedback) [141]. It makes the mapping between the possible inputs and outputs an interesting and challenging task and an important field for artistic exploration. The particular relation between input data (linked to the performer's actions) and output events (that influence the stage design), is often an important aspect of composition and artistic statement, and many authors have reflected on this relationship in the field of music

[1] Composer, performer and media artist specializing in intermedia. His particular interest lies in composing free and abstract narratives that emerge between aural and visual layers.

[142, 143, 144], dance [145, 105] and theatre [146, 147].

Multimedia expression is a wide field with diverse approaches for media presentation and role. Non-interactive practices that we presented searched for forms of creative expression in a multiplicity of media, new roles for media, new types of media presented on stage, new orders of media reproduction and new relationships between media. With the incorporation of HCI techniques, new relationships appeared between media and artists performing on stage. HCI inaugurated a possibility of a new arrangement of the exhibited media and performer: not as parallel independent layers, but as an interrelated aesthetic ensemble.

3.2 Body representation

"By developing the artistic body, choreographers have attempted to enhance, extend, decentralise, defigure, dissipate, schematise, objectivise the human body. Not only its form but also its meanings and references have been altered in these representations."

Inma Alvarez [148]

We use the term "body representation" to denote practices where the attributes of a person are transposed into a new pictorial interpretation of him/her. We present non-interactive practices based on video, film and computer graphics and then discuss interactive practices that involve real-time representation of the body and body movements. We concentrate our analysis on the different media applied to visualise the body and present novel aspects of each of them.

We will not discuss painting and photography because it is not common to use them as a part of staged performance. We assume that due to their invariable nature, they can hardly dialogue with real-time moving bodies.

3.2.1 Video and film

Video and film made possible the recording and reproduction of reality not just in the form of a single frame, but as a continuous register. Moreover, live video streaming enabled the introduction of virtual moving bodies into diverse art practices like theatre [149], dance [32], performance [150], video art [151] and installation art [152].

In Paul Sermon's *Telematic Dreaming* [153] art installation, beds in separate rooms were connected with a telepresence system. The performer's body lying on one bed in the first room was filmed and projected over the other bed in the second room that was open to the public. Two bodies (the real body of an audience member and the virtual body of the performer) could meet in the same mixed-reality scene.

With the introduction of video technology, body images gained a new temporal dimension. They reproduced the changes of the body in time and contributed to the discussion on the liveness of screen-based body images [154, 155, 156]. Human subjects represented on film were not just frozen frames like in the case of photography or painting, but, spanned over time.

3.2.2 Computer graphics

Another way to work on human body representation was investigated by dancer and choreographer Merce Cunningham[1] in his dance piece *BIPED* [4], a piece considered a landmark in contemporary technology augmented dance [157]. This piece explores the possibilities of animation technology and motion capture in the creation of virtual dancers.

In this work 70 dance phrases of real dancers were registered with motion capture technology. Next, dancers' bodies were transposed into digital characters and projected onto a huge transparent scrim at the front of the stage, behind which the live dancers performed (Figure 3.2). The abstract hand-drawn dancers created using motion-captured phrases were a novelty on the performance stage [158]. These digitally-mediated bodies posed questions about our perception and appreciation of the resulting human movements in the absence of the real body [148].

Computer graphics together with motion capture allows not only "copying"

[1]A leader of the American avant-garde considered one of the most influential choreographers of our time. His collaborations with artistic innovators from every creative discipline yielded an unparalleled body of work in American dance, music and visual art.

Figure 3.2: *BIPED* [4]. Merce Cunningham, 1999. Live performers share the stage with abstract dancers.

reality, as in the case of video, but also extracting and transpositioning of the human body and motion into new abstract representations. It makes possible to represent the body and its three-dimensional dynamic in a way that film can not achieve.

In this subsection, we presented a variety of techniques and materials to create expressive characters based on the human figure. In digital performance we can find a multiplicity of possible roles that artistic body representations can assume. They can represent alter-egos, spiritual emanations, incarnations of the body related to notions of ghosts, astral bodies, out-of-body experiences and soul projections [23] and are used, among others, to reflect upon the changing nature of the body and self, technology and performance [19]. Although these artistic representations are interesting resources to support and extend the narrative of the performance pieces, they lack the possibility to adapt to the variations in the performance. For example, a videotaped actor can not respond to the changes in the dynamics of a live actor's delivery. The appearance of interactive technologies allowed working with real-time data that describe the body and its dynamics, overcoming these limitations.

3.2.3 Body representation and HCI

Currently, we can access diverse body parameters like joint positions, body contour, face expressions, voice parameters and use them for real-time animation of virtual characters on stage. Thanks to this, digital performers can be as spontaneous as real actors, without losing their ability to dynamically incarnate in various distinct identities.

In the theatre piece *The Tempest* [5] directed by David Saltz three-dimensional real-time motion capture was used to introduce the character of Ariel that was a played simultaneously by both a live and a virtual performer. The pose of the live actor was transposed onto the virtual character displayed on stage. Ariel was a spirit that could appear and disappear in a flash and transform himself into any form he desired. The character's magical and non-human nature was achieved with computer graphics that allowed seamlessly changes between various appearances of this virtual actor. Ariel in his humanoid puppet-like form was animated in real-time, taking as reference the real actor's movements. Thanks to whole-body capture the character did not lose spontaneity and the possibility of improvising.

Figure 3.3: Marshall Marden (Prospero) with the animated Ariel in rehearsal for *The Tempest* [5].

This example shows how the integration of full-body interaction on the performance stage helped to make the presence of digital characters more flexible against the possible variations in the performance. It is a clear example of a significant contribution of HCI in the field of body representation.

In the following section, we analyse another, quite different subject of artistic practices related to the human body: body augmentation.

3.3 Body augmentation

We define as body augmentation practices as performance works that use physical and virtual appliances like costumes, light projections, fabric and metal constructions, robotic extensions, wooden appendages or wire to augment body presence, dimensions and range of movement, as well as to extend the perceptive capabilities of the body.

First, we present three artists and performers that reflect on body augmentation without usage of any interactive technology. Each of them worked on body extension with particular artistic purposes and technical means, so we have decided to present their works as interesting examples of different approaches to body augmentation in performance. Then we present and discuss new artistic experiences introduced with the incorporation of HCI techniques into body augmentation practices.

3.3.1 Loie Fuller

American dancer Loie Fuller is known for innovative experiments with technology with the aim of transforming and enhancing her body [159]. In her performances, she worked with coloured lamps, reflector technologies and cane-shaped wooden appendages below her ample costumes (Figure 3.4). She used them to augment the natural range of movement of her body and so, to add volume, dynamic flexibility and an airy quality to her dance [160].

By projecting coloured lights onto her spacious dresses, she extended the bodily art form of dance with elements of visual language like colour and form, introducing three-dimensional rotating and morphing screens formed from her loose costume's cloth [161]. She used the combination of light, mechanics, bodily gesture and fabric to transfigure her body into metaphors of animals or flowers [18]. In her body augmentation experiments she converted

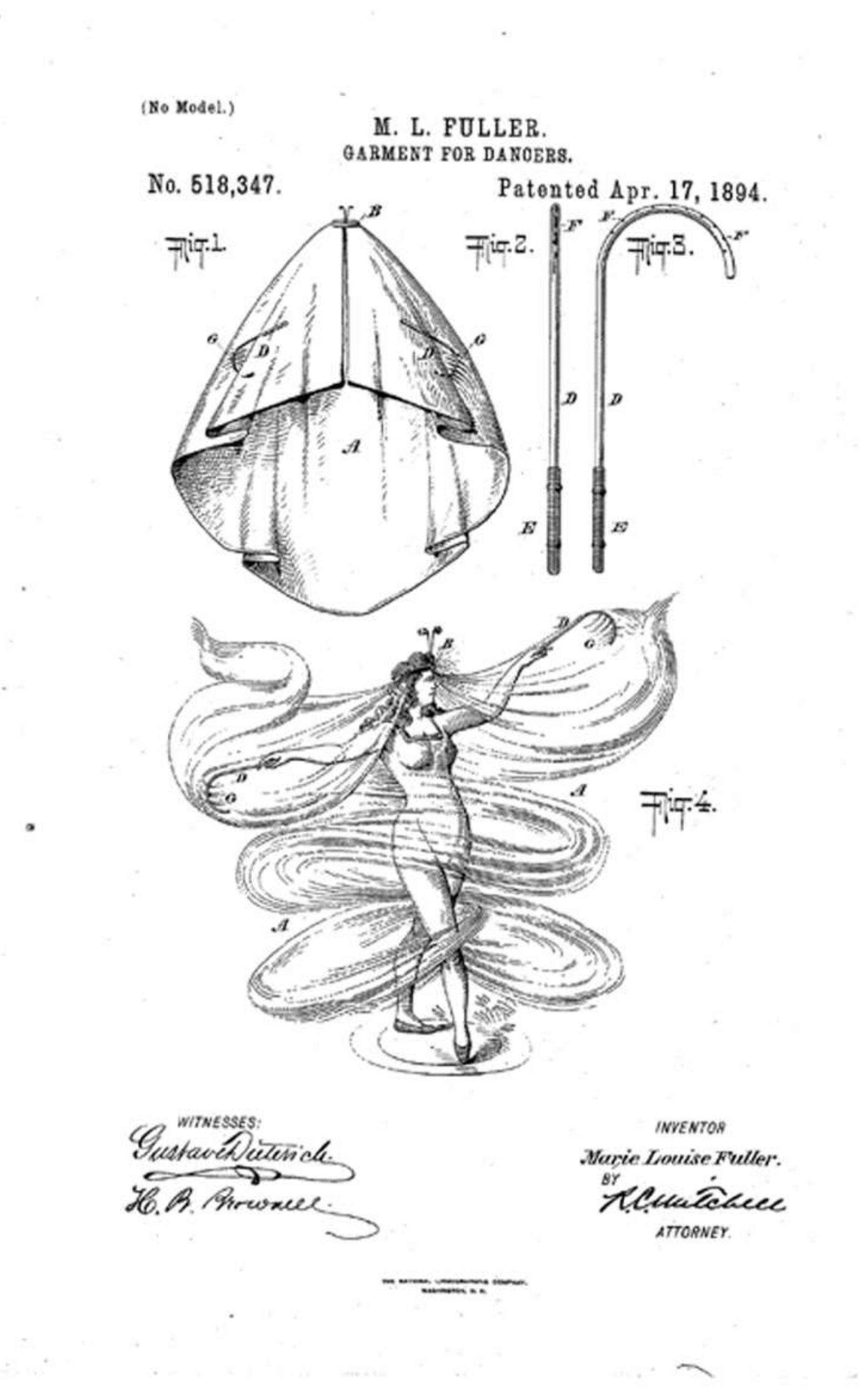

Figure 3.4: Loie Fuller's patent for her stage costume [6].

her costumed body into a rhythmically moving shape of changing forms.

3.3.2 Oskar Schlemmer

Another artist that aimed to “enlarge it [the body] beyond its dimensional and temporal limitations” [162] was German painter, sculptor, designer and choreographer Oskar Schlemmer.

In his dance performances, he used wooden sticks, wire and abstract costumes as technical augmentations of the body to amplify and alter the human form and extend it into space. With this means, he aimed to explore the relationship between the organic geometry of the human body and the abstract geometry of the surrounding space [163].

He explored the potential of physical transformations inherent in costumes and masks to transform the body and convert dance movements into spatial sculptures [161]. In his performance pieces the body became a costumed instrument in motion which acquired a non-realist, abstract and metaphysical dimension [164]. He used these resources to “free man from his physical bondage and to heighten his freedom of movement beyond his native potential” [162].

3.3.3 Rebecca Horn

Rebecca Horn’s body augmentation practices focus on the renewal of her perceptual possibilities through wearable physical appliances [165]. In her performance *White Body Fan* [166] she used wing-like fabric and a metal construction that allowed her to extend her body capacities and feel the movements of the surrounding air [167]. Besides the *White Body Fan*, she worked on body augmentation in the performances *Unicorn*, *Head Extension*, *Pencil Mask*, *Cockfeather Mask*, *Arm extensions*, *Finger Gloves* and *Cockatoo Mask*, where she explored the perceptual relationship between the body and the mind [165].

The artists presented above made use of body extensions with different artistic goals: to enhance body and movement and to extend the performer's perceptions. They extended the physical dimensions and the range of movement of their bodies through illumination techniques and concrete physical materials. HCI techniques enable different new types of body augmentation that we discuss in the following subsection.

3.3.4 Body augmentation and HCI

The incorporation of interactive technologies on stage creates new ways to extend the limits of the human body and human perception. Here we discuss two new means of artistic expression: interactive on-body projections and interactive human-machine systems. They show how we can extend the body by both invasive[1] (human-machine systems) and non-invasive (on-body projections) solutions.

[1] In this context, invasive solutions means solutions that require body instrumentation.

Figure 3.5: *Apparition* [7]. Klaus Obermaier, 2004.

Body as screen

Live on-body projections have been on the performance stage since the early experiments of Loie Fuller at the beginning of the twentieth century [19]. Her wide, illuminated dresses became changing dynamic costumes. However, there was no exact coincidence between the projection and the dancer's body or costume. Part of the projection illuminated the performer and the rest, the stage. To synchronise both parts (the body and projection) a system capable of analysing in real-time the position of the performer and generating the corresponding graphics was needed. This became possible with the appearance of whole-body tracking techniques based on computer vision, depth sensors or wearable sensors. These technologies enable the usage of interactive costumes perfectly fitting the performer's body. Performers become moving projection surfaces [168].

Due to the possibility of an instantaneous adaptation of the projection's position and dimensions, live on-body projections leave room for improvisation and the personal voice of the performer [169]. They enhance the expressive potential of the performer whose body becomes extended and reconfigured through digital images [170]. The projections make the performer visually transcend the limitations of his/her physical body, while at the same time the living, breathing body of the performer is used as a screen that "humanizes the digital image" [169]. This combination transforms the performer into "something other than purely human or purely digital" [127] and is an example of a powerful tool for artistic expression and an extension of already existing body augmentation practices.

Interesting examples of on-body projections are the works of Klaus Obermaier[1]. For example, in his interactive dance performance *Apparition* [7], he combined frontal on-body projection and almost ten meters wide background projections, leading the aesthetics of the piece towards immersion [171]. His idea of the piece was to reflect about how we interact with digital systems [170]. Obermaier did not just simply project a pre-rendered video onto the body, he created the projected content in response to the performer's body dynamics. The body features were transferred in the architecture of the real-time generated space projected onto the dancers. The visual effects were rendered more fluidly or rigidly depending on the performer's movement. Obermaier states that in this configuration "the overall interactive system is much more than simply an extension of the performer, but is a potential performing partner" [7].

This piece is an outstanding example of on-body projections, where the interactive relationship between the performer and the projected image merge both parts in a "visually and dramatically coherent whole" [171].

The human body augmentation techniques that we have presented so far serve to enhance the expressive potential of the human body through physical appliances or interactive projections. They are used as an artistic resource to intensify performers interpretation in dance, performance or theatre pieces. However, body enhancement through technology itself became an important

[1]Media-artist, director, choreographer and composer. Creator of innovative works in the area of performing arts, music, theatre and new media.

field of artistic exploration in digital performance, as it encouraged artistic reflections on the nature of the body, robotic body extensions and cyborg bodies.

Human-machine systems

With the appearance of interactive technologies artists started to experiment with body augmentation using robotic prosthesis and hybrid human-machine systems and presented them on stage [172]. These practices were frequently motivated by the desire to explore the possible fusion of the human body with technology [121] and to reflect on body condition, evolution and adaptation in a technological environment [173]. The integration of artificial components or technology and the human body is a complex subject involving the hope of enhancing human abilities, but also has negative connotations, as it displaces the biological, live or real [127]. It has been discussed from the philosophical, ethical and artistic points of view by many writers, artists and performers [174, 175, 176, 177].

Robotic extensions. Different artists experimented with the conjunction of the natural and the technological using robotic body extensions [178, 179, 180, 181]. As an example of a robotic extension used for artistic purposes we present one of the best-known performance objects of the Cyprian performer Stelarc[1]: *The Third Hand* [183]. It is a mechanical human-like hand, controlled by electrical signals from his abdominal and leg muscles. This robotic device is capable of grasping and rotating and has a tactile feedback system intended to provide a rudimentary "sense of touch" [182]. He developed it to explore the conjunction of technology and media

[1]Stelarc works focus heavily on body amplification and extension. He considers that "the body is obsolete" [182] and studies the possibilities of body extension through medical instruments, prosthetics, robotics, Virtual Reality systems, the Internet and biotechnology.

with the body [184] and to expand his power and reach [173]. Stelarc used it in one of his first robotic performances in 1981 at Tamura Gallery in Tokyo where he investigated the possibility of writing "THE THIRD HAND" with his right and artificial hand at the same time [173]. This work incites reflection on the human body by focusing on its limitations and then visualising its potential extension through technology. Although Stelarc's performances are frequently viewed as controversial, without doubts they helped open the debate on body limits and our changing nature as humans [127]. They are relevant examples of the usage of interactive systems on stage where the human-computer interface is a subject of artistic reflection.

The exploration in the field of human-machine systems took another interesting track when the human body was used as an output interface.

Body as an output device. We use the term *body as an output device*, to denote practices that use the body as an output interface of an interactive computer-mediated system. In these practices, the performer's body becomes an object of manipulation using, for example, computer-interfaced muscle stimulation systems. The body is presented as an operational structure connected to a computational system and controlled by external factors [185].

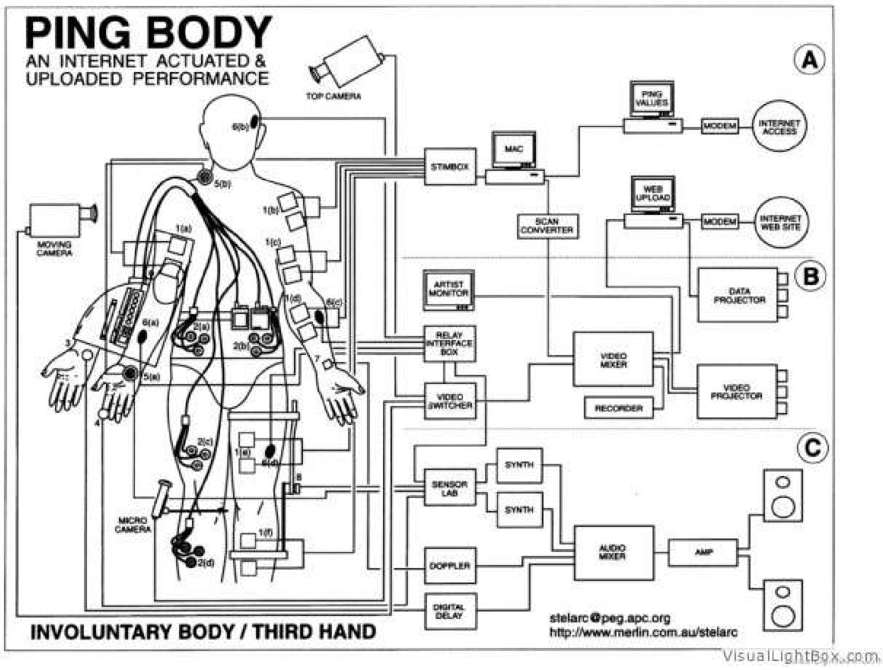

Figure 3.6: *Ping Body.* Stelarc, 1996. Connections schema [8].

The use of the body as an output device presents an intriguing example of a new configuration of computational systems and the human body, completely opposite to the classical human-computer configuration where the human body is the source of input data and the computer generates digital output as a response. It is a significant new mean of artistic expression grounded in a novel interpretation of human-computer interaction systems. Artistic explorations using the human body as an output device contribute provocative reflections on the manipulation of the human subject [127], on the consequences of reducing the body to a display device and on the relation between the human and the computational system including the Internet [186].

Stelarc's *Ping Body* [187] performance premiered in 1996 in Sydney is an interesting example of this kind of practice. In this piece, a computer program sends messages over the Internet to more than 30 domains around the world and measures the time of response of each domain [185]. The measured delays (from 0 to 2 seconds) were then transformed into electrical discharges between 0–60 volts and applied to the multiple muscle stimulators attached to the performer's naked body [187] (Figure 3.6). The involuntary gestures caused by the electrical shocks turned the performance into an odd dance choreographed by data streams. This performance presented an interesting inversion of the usual relation between the body and Internet: "instead of collective bodies determining the operation of the Internet, collective Internet activity moves the body" [127]. It is also an important example of body augmentation where the body "is no longer the body as a closed unit but a data-body and an every-place body" open to external information and interaction [127].

The appearance of HCI systems initiated a new type of human relationship: a relationship with computers and information technology. This fact raised questions about the place of the human in this new relation. Artists and performers explored body augmentation by using the body as both an input and an output device. These art practices could not have emerged without human-machine interfaces that are both: the subject of artistic contemplation and a technological tool used on stage.

In the following section, we analyse how HCI systems have influenced artistic practices in interactive environments.

3.4 Interactive environments

An interactive environment is nowadays understood to be an interactive system that "correlates in a meaningful way, data gathered about its environment (usually a user's behaviour) with output" [188]. In this section we present non-interactive artistic experiments that have contributed to the creation of this field of artistic exploration, as well as interactive environments created using HCI techniques.

We hypothesize that the emergence of interactive stage environments is a consequence of two changes in the field of performance: a change in emphasis of an art piece from object to performative process and the development of a more participatory audience.

3.4.1 Artwork as process

In the case of the visual arts, an artwork is understood as an object or product and in the case of performing arts, as a finished piece based on narrative principles [117]. Artistic movements like Dada, Fluxus and Conceptual Art advocated the shift of the essence of an artpiece from object to process. These art movements placed the emphasis on concept, event and participation of the audience, and so they appear as opposed to the idea of an art piece as a unified, finished and invariable object [189].

Interesting examples of this shift can be found in the works of John Cage[1]. In 1952 he initiated the *Untitled Event*, a multimedia performance that took place at Black Mountain College. Besides Cage, artists like Merce Cunningham, the composer Jay Watts, the painter Robert Rauschenberg, the pianist David Tudor and poets Mary Caroline Richards and Charles Olsen participated in this event. Their participation was not scripted, only the timing of the moments of action, inaction and silence was indicated for each performer [190]. The rest was left to the artists. In this event multiple actions took place at the same time: texts were recited, music was played, abstract colourful slides were projected over paintings, dancers performed. All of these actions were integrated into one performance piece that dissolved the

[1] An American avant-garde composer, music theorist, writer and artist. A pioneer of indeterminacy in music, electroacoustic music and non-standard use of musical instruments.

structured based convention of performing arts and "dissolved the artefact into performance" [117].

The process initiated through this type of experiment contributed to the creation of a new vision of art based on *concept* or *process*, rather than on a finished static product. That is why we identify them as direct ancestors of environments where the real-time interaction between the parts creates the artistic content.

3.4.2 Audience participation

The *Untitled Event* was an important example of art as process, but also an example of a piece where the audience could actively participate in the performance. In this event the public was able to influence the technical setup by, for example, tuning the radios used by Cage, and altering the sound of the piece [40]. Active public engagement and the performative character of the *Untitled Event* led to its being considered "possibly the first direct predecessor to interactive media art" [191].

Allan Kaprow[1] went a step further in his artistic exploration; in his performances (called Happenings) the active engagement of the public became a central idea. He made the spectators themselves participants, executors and performers of the artistic process [192]. Kaprow declared active audience participation to be a crucial element of an artistic event: "Whether it is art depends on how deeply involved we become with elements of the whole and how fresh these elements are" [193]. He created interactive environments based on the participation of both performers and the audience.

The active engagement of the public, together with the shift from object to

[1] An American painter, theoretician and a pioneer in establishing the concepts of performance art.

performing process, contributed to the conceptual change in the definition of a performing art piece. It wasn't anymore a static, predetermined, finished piece, but a continuous process where performers' actions (frequently unplanned and spontaneous) and the interaction with the audience became the artwork itself.

We consider that the idea of an environment where real-time interaction takes place led to the current search for technology-enhanced stage settings. In these new stage settings the performers are embedded in a responsive interaction system and the interaction is an essential part of the artwork [194]. The notion of an art piece as an interactive process, pioneered by the artists described earlier, was an important factor motivating the exploration of interactive technologies in the performing arts.

3.4.3 Interactive environments and HCI

Until the appearance of interactive technologies, the stage was sculptured by illumination, scenography and sound. These resources accompanied and enhanced performers' movements on stage, but they lacked an instant response to their actions. Artists like Mark Coniglio[1] have recognised that non-interactive media are "antithetical to the fluid and ever changing nature of live performance" [195]. The appearance of human-computer interfaces and the possibility of manipulation of digital media made it possible to reflect the changing nature of real-time performance.

In section 3.1 "Multimedia expression," we concentrated on the new relationship between media and performer introduced by interactive systems: performer and media as a responsive entity. Here, we want to demonstrate how this new relationship was applied to create interactive scene environments in the performing arts. In these environments performer-related features (such as voice, shape and quality of gesture, full-body movement, group dynamics) are interpreted by the computer and used for real-time manipulation of performance elements like virtual scenography, interactive graphics, light, video, sound, or even robotics [158, 104, 196, 197]. They provide an opportunity to link common performance elements like dance or vocal parts to other visual and sonic elements of the piece to dialogue with the performer's actions. The creation of this kind of environment is used to enrich the narrative structure and composition of the performance [198].

[1]Mark Coniglio is a media artist, programmer and composer. He is one of the pioneers in the integration of live performance and interactive digital technology and a co-founder of the performance group Troika Ranch that explores the union of dance, theatre and new media. He is also the creator of interactive media presentation software Isadora.

Responsive scene design

Early attempts at the creation of stage environments using technology mediated interaction were made in 1966 by Merce Cunningham and John Cage in their *Variations V* [199] performance where the sonic stage design responded to dancers' movement captured by antenna-like poles and light sensors. Whenever the dancers came within a four-foot radius of the antennas or interrupted the light to the photocells, they altered the sound mixer that was shaping the sound. This sensing system was revolutionary in staged dance performance and allowed the creation of a unique musical landscape in response to dancers' movements [200].

Interesting examples of interactive stage environments can be found in the research group "Opera of the Future" of the MIT Media Lab[1] [201]. This group, dedicated to the implementation of technical solutions in the field of musical composition, performance, learning and expression, created many innovative instruments and performance pieces. *Death and the Powers* [202] is one of the technology-augmented operas of this group and an excellent example of interactive environments.

In this piece, the main character Simon Powers, a wealthy inventor and entrepreneur, in order to perpetuate his existence beyond his physical being, uploads his consciousness and memories into The System, an elaborate environment he has developed. After his physical death, The System become a living version of Powers that controls every object in the surroundings: books, furniture, walls.

In the main part of the piece, the stage and the environment itself comes alive as the main character. The behaviour of the scenic elements, including lighting, visuals and robotics, are influenced in real-time by the singer's

[1]The MIT Media Lab is an interdisciplinary research laboratory at the Massachusetts Institute of Technology that explores the convergence of technology, multimedia, sciences, art and design.

performance. The singer is not visible to the public, but his presence is translated into an animated stage, a musical chandelier and a chorus of robots. The singer's gestures, breath and voice are used to shape the output media on the stage in an expressive way [197].

We find this piece a fascinating example of a complex interactive environment where the performer's actions are used to create suggestive responses in the form of lighting, movement and sound. Human-computer interfaces allowed the capture of the performer's voice and gestures and their transposition into expressive elements of the stage design. Adding interactive stage design to classical opera performance extended its language and enabled the creation of aesthetic relationships impossible to achieve before.

Bio-sensing

An important point is not just how the environment responds to the human performer but also, the variety of the body parameters that the environment can respond to. Using biofeedback-based human-computer interfaces, response is even possible to human physiological parameters. Use of such data in interactive environments is worth mentioning, because it gives artists the possibility of capturing and interpreting characteristics of the body that are invisible to the human eye. As a result, the process of shaping of the stage can be controlled by data like heart rate, blood pressure or body temperature. The visualisation or sonification of these imperceptible characteristics can be used for artistic purposes to reflect on our embodied nature. In this approach, the data, normally used to measure key body functions, become evident and perceptible through, for example, the visual or auditory channel.

In the pieces *Heartbeat Duett* [203] of the performance group Palindrome [204], the heartbeat of the dancer was represented in the form of sound and contributed to the scene design of the piece [205]. Electrodes were used to sense the heart activity of two dancers, and each heartbeat was converted into a separate musical note. The resulting music was mixed with the composed musical score and used to sonify the performance [158]. Making a heartbeat a part of the performance sonification was a novel aspect in the creation of interactive environments.

We recognise that the growth of the human-computer interfaces variety contributed to the extension of possibilities in the creation of interactive environments. The phrase of Myron Krueger[1] “the environment cannot respond to what it cannot perceive” [206] shows the importance of HCI in the creation of an aesthetic, meaningful interaction. Because of the technological advances in HCI software and hardware, current interaction systems are more sensitive and extensive, and allow the generation of new responses, and the extension of the expressive palette of artists who incorporate interactive technology on the performance stage.

[1]An American computer artist, a pioneer in the research on full-body interactivity and virtual environments.

Chapter 4

Personal exploration

"Dance enacts both being completely in the body and transcending the body."
Susan Sontag [207]

4.1 Motivation

After the exploration of the history and current practices of digital performance, our interest was placed on interactive dance performance. Dance was especially intriguing for us because of its diverse nature. On the one hand ephemeral, and on the other hand strongly attached to the physicality of the performer, the bodily character of dance made it an interesting object of study.

Our goal was to experience, through practice, novel forms of expression that HCI introduced into staged performances. We collaborated in four technology-augmented dance performances framed in the previously defined fields of multimedia expression, body representation and interactive environments. We participated in the development of the artistic statement and programmed the interactive environments.

In the process of creation of interactive elements for the four dance pieces, we were confronted with the following questions:

- How we can describe and record the human body and its actions (gestures, position, speech)?
- Is there any *natural mapping*[1] between human body properties and other media output parameters (for example music volume, computer graphics colour, robotic movements direction)?
- How can real space be connected with data space on stage?

These inquiries are already present in the works of contemporary artists and researchers [103, 209, 210]. Our works do not fully respond to these

[1] The term "natural mapping" was presented by Don Norman in his book "The Design of Everyday Things" and refers to relationships between the controls and the object to be controlled that are intuitive and natural for the user [208]. In the context of digital performance the controls are the actions of the performer and the objects to be controlled are the parameters of the mediated representation.

questions; their aim is to explore a few possible answers by means of concrete implementations. They are reflections on these subjects, more than answers.

We devoted another part of our practice-based research to software solutions. We developed a tool for movement visualisation that can be applied in diverse fields: for creating still images, staged dance performances, video dance or interactive installations. In the following section we present both dance pieces and the software tool developed during the master studies research.

4.2 Technology-augmented dance pieces

In this section, we present artworks created between 2014 and 2015. We were involved in the design and programming of interactive sound and visuals of four pieces. All the pieces were developed in Processing [211], an open source programming language built on the Java language. We decided to use Processing taking into account its wide application in rapid prototyping and the variety of third-party libraries.

We wanted to show the dance pieces in different locations, so we decided to work with technology easy to transport and deploy. We used mainly interactive projections and interactive sound design.

In most cases, interactive effects were based on full-body tracking using a Kinect sensor [212]. We used SimpleOpenNI library [213] in the pieces where user tracking was needed. SimpleOpenNI is a Processing wrapper for OpenNI [214], a framework that exposes all Kinect sensor's functionalities. It allows working with RGB camera images, infrared images, depth measurements, and provides additional information about the position and pose of detected users. In the following part we discuss the artistic statement, formal decisions and technology of four dance pieces: *Violenta ternura*, *Señal de ajuste*, *1/f* and *GEA*.

4.2.1 Violenta ternura

Violenta ternura is a dance piece that was presented in Teatro Solis (Sala Zavala Muniz) in March 2014. This piece was developed in collaboration with the dancer and choreographer Lía Spatakis. An exhaustive documentation of the piece can be found on https://vimeo.com/100032402.

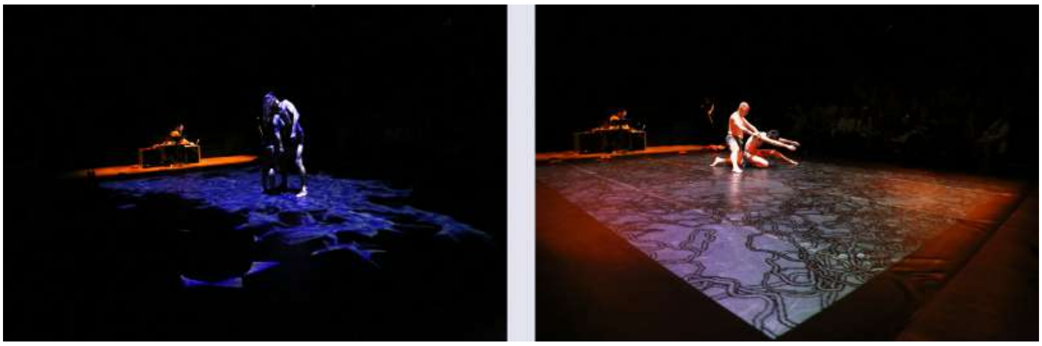

Figure 4.1: *Violenta ternura*. Montevideo, 2014.

Artistic statement

This choreographic composition explores the social hypocrisy of double standards, the difficulties of loving another (sometimes renouncing oneself) and investigates the limits of love, tolerance and risk. It is composed of separated parts, assembled together in a dialogue of broken fragments and parallel stories of love, madness and betrayal.

It explores how real-time generated digital images can help to build and reinforce the atmosphere of a dance performance.

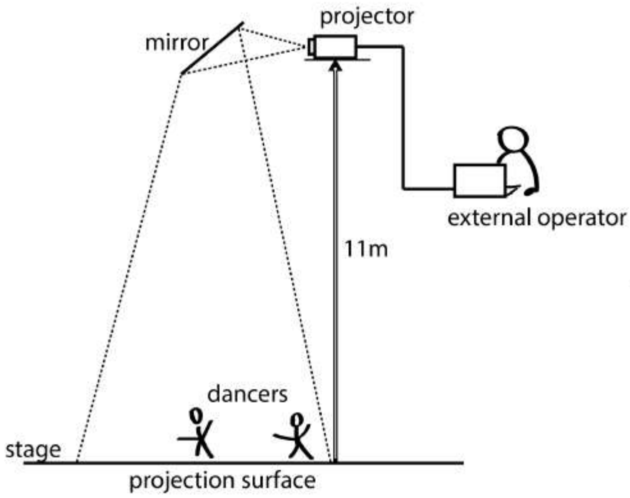

Figure 4.2: *Violenta ternura.* Schematic representation of the stage setting.

Technology and design

This piece required a special technical setting because we worked with interactive visuals projected on the floor embracing the whole stage. To project on the theatre's floor, the projector was placed 11 meters above the ground (Figure 4.2). Rehearsal in similar conditions exceeded our financial possibilities, so we decided not to work with real-time motion capture as it required rehearsals and calibration in conditions similar to the final ones. We worked with Processing native variables *mouseX* and *mouseY* to create the visuals at a specific place on the stage, normally where the performer was located, simulating dancer tracking.

We used keyboard events to manipulate the visual effects. They controlled diverse parameters of projected graphics such as line thickness, shape fill colour or size. The generation of the graphics was real-time, but the parameters of the drawing were controlled by an external operator.

To manage different visual effects corresponding to the specific part of the dance piece, we implemented a SceneManager class and a Scene interface. Implementation details can be found in Appendix A.

Description of the piece

Violenta ternura was our first approach to digital performance. Through real-time projections we wanted to stress the emotions of dancing characters, as well as to create a stage design that partnered the atmosphere of each part of the show.

In the first part, the responsive environment stresses the emotional state of a male character. Abstract distorted figures in constant motion surround and follow the dancer to illustrate his growing inner tension.

In another part of the piece, to reinforce the image of a toxic relationship, animated worms are constantly crossing the scene, leaving more and more pronounced black traces (Figure 4.1). In this part, the projected graphics did not correspond to the performers' positions; we controlled the presence/absence of the digital worms and their colour in real-time through keyboard.

In the last part, we generated a ludic, playful moment where the dancers were interacting with projected words that express positive feelings like hope, joy, peace and happiness (Figure 4.3).

Figure 4.3: *Violenta ternura.* Montevideo, 2014. Dancers playing with projected words.

4.2.2 Señal de ajuste

Señal de ajuste was presented in November 2014 as the closing show in the Ingeniería deMuestra event[1]. This piece was developed in collaboration with the dancers and choreographers Analía Fontán, Ximena Castillo and Jessica Lateulade. The video documentation of the piece can be found on `https://vimeo.com/133552867`.

Artistic statement

This piece explores the approximation process of adjusting the body and the device in the new environment extended through technology.

The piece outlines three stages of human-media relationship:

[1] Ingeniería deMuestra is an event open to the public organised yearly by the Faculty of Engineering of the University of the Republic of Uruguay were researchers and students show their works.

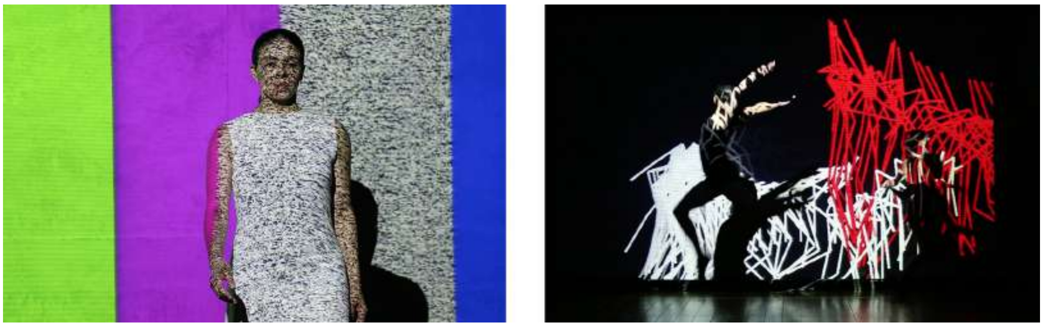

Figure 4.4: *Señal de ajuste.* Montevideo, 2014. Images from adjustment and interaction phase.

- Phase 1: Adjustment. Adjustment of signals, systems, sensations and perceptions. Adaptation to the new medium.
- Phase 2: Interaction. The performer becomes a user of the system and is in contact with the medium.
- Phase 3: Critical judgment. The performer has enough knowledge about himself and his environment to conduct a conscious process of selection and processing of the information that he is exposed to.

In this piece technology-mediated interaction is a medium that we first get to know in the phase of the adjustment, and then we use it consciously in the stage of interaction and, eventually, apply it with critical judgment. We developed interactive visual and sonic effects to illustrate these phases, going from simple system responses to fluid interplay between the dancers, sound and projected images.

Description of the piece

This piece was our first approach to HCI on stage coupling body directly with image, and body with sound. This made the research richer, but also more challenging.

Phase 1: Adjustment. In the first part of the piece the interaction with the system is controlled by the performer's position on stage and its distance from the sensor. This part is based on a simple and direct system response. The visual and sonic effects were designed to introduce the adjustment phase, where the interaction modalities are discovered and the human body adapts to the technology.

Two dancers interact with coloured stripes from a television test pattern signal; their presence alters the colour bars and the sonic effects. We use a test pattern image and a 1000 Hz sine wave (most common reference tone in audio engineering) as a base for the stage setup. White noise and pink noise are used as a sign of the dancers' presence.

Phase 2: Interaction. In the following phase, the dancers become a conscious part of an interactive system. They dance with their abstract digital representations. Their bodies are represented as colour skeletons that change their roles over time from simple abstract dancers to expressive brushes (Figure 4.4). They leave colour traces on the screen that reflect the dancers' movements. The dancers become aware of the system responses engaged in the play. New body traces mix with old, creating a background for the dancers' performance.

We experimented with body representations to illustrate how we can be perceived in a technologically mediated world. Thanks to whole body tracking we created abstract body representations in the form of stick-figures that copied dancers' movements. By contrasting real, moving bodies with their virtual representations on the screen, we alluded to our abstract and nonmaterial presence in the digital world.

The next part works upon the same idea of the user as a conscious part of the interaction. We use two texts that reflect on communication in the form of language: one by Martin Heidegger and the other by Walter Benjamin. The director selected them because of their focus on communication, a concept

Figure 4.5: *Señal de ajuste.* Montevideo, 2014. Words appearing and growing close to the dancer's position.

that we wanted to illustrate in this part of the piece. Performers' bodies are used to uncover the parts of the texts projected behind them and to stress certain words denominated as meaningful by making them grow if they are close to the performers' positions (Figure 4.5). This interaction creates a lyric environment of music, text and dance where communication is the subject and interaction is the medium.

Phase 3: Critical judgment. The third phase shows critical judgment of the human-media relationship. A love story between a dancer and an unmanned aerial vehicle (UAV), commonly known as a drone, is used to illustrate this concept (Figure 4.6). A hidden drone operator is controlling a drone, trying to win the heart of the dancer. They play together, dance, but the *real* encounter is impossible because the interaction is mediated through technology.

By proposing this interactive interplay between the human body and the mediated reality we wanted to raise the questions of human place and possible roles in technology-mediated systems. The technological mediation enabled by HCI techniques was the subject and an artistic means of expression on stage.

Figure 4.6: *Señal de ajuste*. Montevideo, 2014. Images from interaction and critical judgement phase.

Technology and design

To illustrate the technology-mediated interaction, we designed a responsive environment using a Kinect 1 sensor, three frontal projectors and audio speakers.

In this project, we worked with three kinds of data: skeleton joint positions, user silhouette and depth measurements. More details about body capture in this piece can be found in Appendix B.

Visual effects. To manage the visual layer of the piece we used Scene interface and SceneManager class presented in Appendix A. We implemented three different Scenes: the first to recreate test pattern stripes and generate white noise visual patterns that become visible with the performers' presence (Figure 4.4); the second to draw the connections between body joints and to manipulate the persistence of the drawn patterns; and the third to render the text and to manipulate parameters such as text size, the size of the region affected by the dancer's presence or delay in the text presentation.

Sound control. In the first part of the show (i.e., the adjustment phase) we used the Minim audio library [215] to respond with diverse sounds to three scenarios: absence of performers on stage, only one performer on stage, more than one performer on stage.

In the initial part of the performance (no dancers on stage) we reproduced the 1000 Hz sine wave test signal. White noise was used to mark the presence of one performer, and pink noise was used when two performers were present on stage.

4.2.3 1/f

This piece was presented at the event Ingeniería deMuestra in October 2015. Interactive projections were part of an audio-visual show prepared in collaboration with musicians Christian Clark, Guillermo Berta, Marco Colasso, VJ Juan Pablo Colasso and dancer Ximena Castillo. The video documentation of the piece can be found on YouTube `https://www.youtube.com/watch?v=w-FEgGAZaLY`.

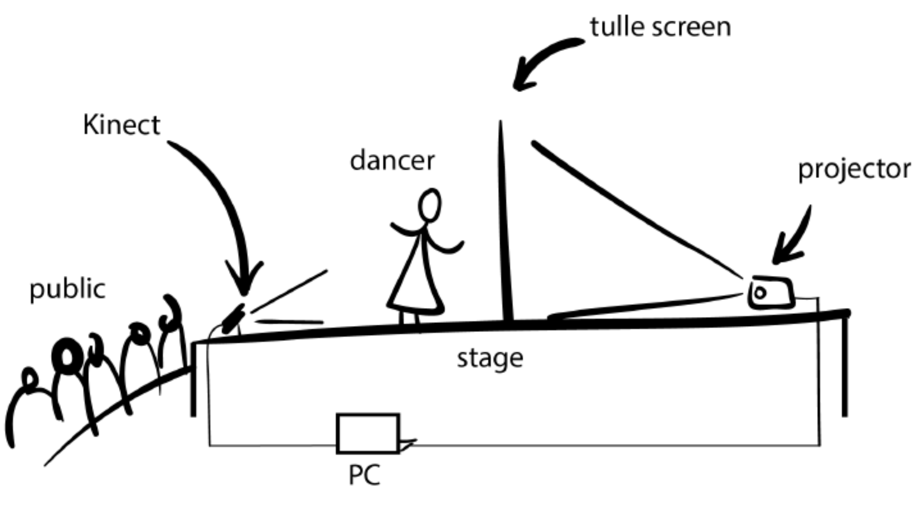

Figure 4.7: *1/f.* Schematic representation of the stage setting.

Artistic statement

With this piece, we strove to recreate the unique and fleeting atmosphere of a thunderstorm. The piece is divided into two parts. The first is abstract, based on black and white computer graphics. The second part includes videos of nature, VJ performance and live music.

Technology and design

For this piece, we used a tulle screen of 3x4 meters for retro-projection (Figure 4.7). We placed a wide-angle projector behind the tulle screen to cover the surface with the projections. The dancer performed in front of the audience having behind the tulle screen used to project an interactive background. The Kinect sensor was placed in front of the performer.

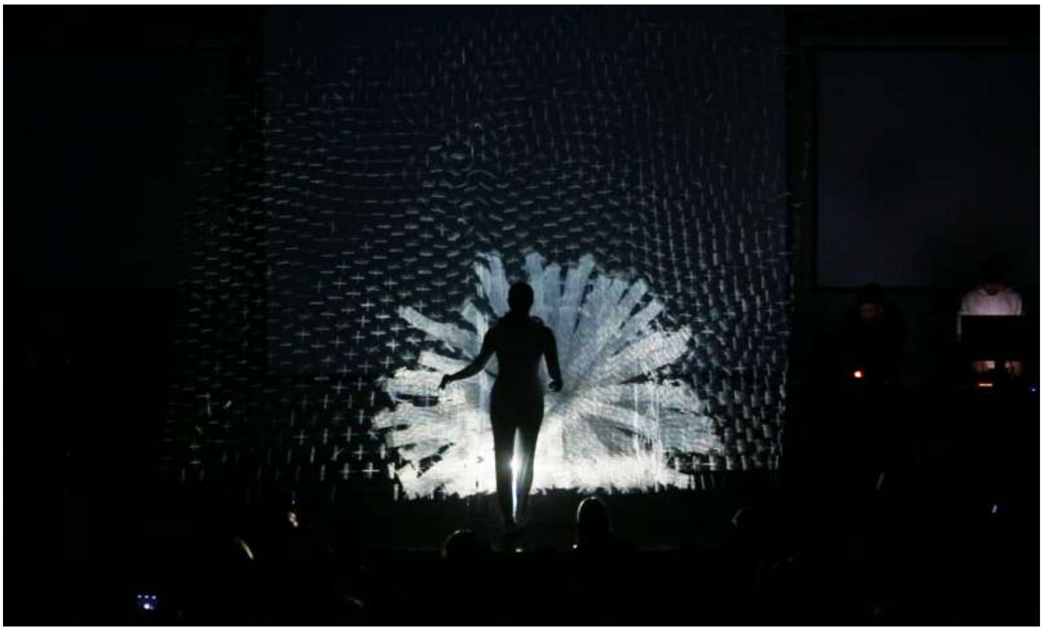

Figure 4.8: *1/f.* Montevideo, 2015. Interactive projections illustrate the creation of rain.

Body capture. Because the Kinect sensor in this configuration often had problems with depth measurements (many out of range values) we decided to implement three separate methods for tracking. The first method was based just on detecting the silhouette of the user using the *userMap* function of SimpleOpenNI library, the second just on depth differences obtained with *depthMap* and the third combined both silhouette tracking and depth differences (for more technical details see Appendix B). We also added the possibility of the replacement of the performer's position data by the mouse cursor to quickly design, develop and test the interactive graphics without the need to use the Kinect sensor.

Graphical user interface. We designed a minimal user interface to select between tracking methods and to control the parameters used for tracking adjustment. We used the library ControlP5 [216] to create an external window for the controllers and to create sliders, radio and toggle buttons. We also used the GUI to display a timer that helped to synchronise the visual part with the music.

Interactive audio-based effects. In this performance, we explored the possibility of interaction between music and visual aspects. In the first Scene, the arrangement of the displayed shapes responded to the dancer's position, but the size of the shapes was controlled by the music volume. For this part, we used the class AudioInput of the Minim audio library [215].

MIDI events. We used an extra MIDI keyboard Akai MPK mini [217] to change between developed scenes and manipulate a set of predesigned effects in real-time. We used the Processing MIDI library The MidiBus [218] to receive the events from the MIDI controller.

NoteOn-events received changed the order between the developed Scenes, using the pitch value to define which Scene should be activated. NoteOn-events also activated or deactivated the audio interactivity, changed the interaction mode of one scene and reset the clock.

ControllerChange-events controlled visualisation parameters like transparency, colour or size.

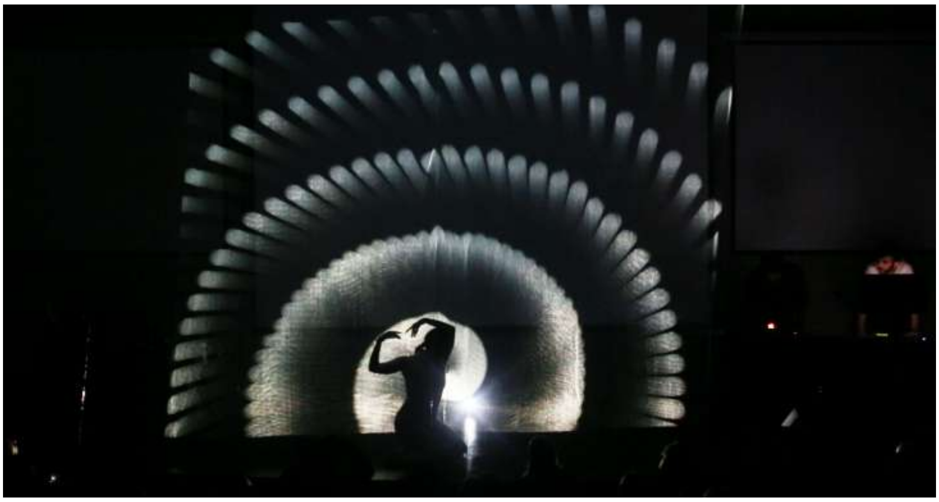

Figure 4.9: *1/f.* Montevideo, 2015. Interactive projections accompany the waking up of the storm creator.

Description of the piece

The first part illustrates the creation of a thunderstorm. The main character wakes up to prepare the storm. Her actions rebound in the entire scene. She creates the rain, the clouds and distributes them in the air and falls asleep again.

In this part, an interactive scenario stresses the role of the performer in the act of storm creation. We use the information about her position to arrange the virtual elements to surround her body. This arrangement shows the performer as the indubitable source of air movements, rain particles and clouds (Figure 4.8).

In the second part, the storm manifests itself in nature. Live music and digitally manipulated videos illustrate changes happening in the world with the arrival of the storm. The calm and clear videos of the sky and melodic music introduce the atmosphere before the storm. Their gradual distortion reflects the coming thunderstorm. In the climax, the effects in the visual and sonic layer become noisy and screaming. After the high point, everything goes back to the initial state.

In this piece we created an interactive environment that aimed to partner the performer and highlight her role in our interpretation of storm creation. We manipulated the media presentation to reinforce the dancer's presence and underline her actions.

4.2.4 GEA

GEA was part of a dance and technology workshop supported by the Ministry of Education and Culture and presented in Maldonado, San José de Mayo, Rocha and Montevideo between August and October 2015. As an independent piece it was presented in Montevideo in Laboratorio de Lenguajes Transversales [219] and in the festival of art and technology Festival Equinoccio 2015 [220]. This piece was developed in collaboration with dancer and choreographer Ximena Castillo. The video documentation of the piece can be found on Vimeo `https://vimeo.com/133552865`.

Artistic statement

This piece explores possible connections that can be made between geometrical figures and the human body. We look for different ways of mapping

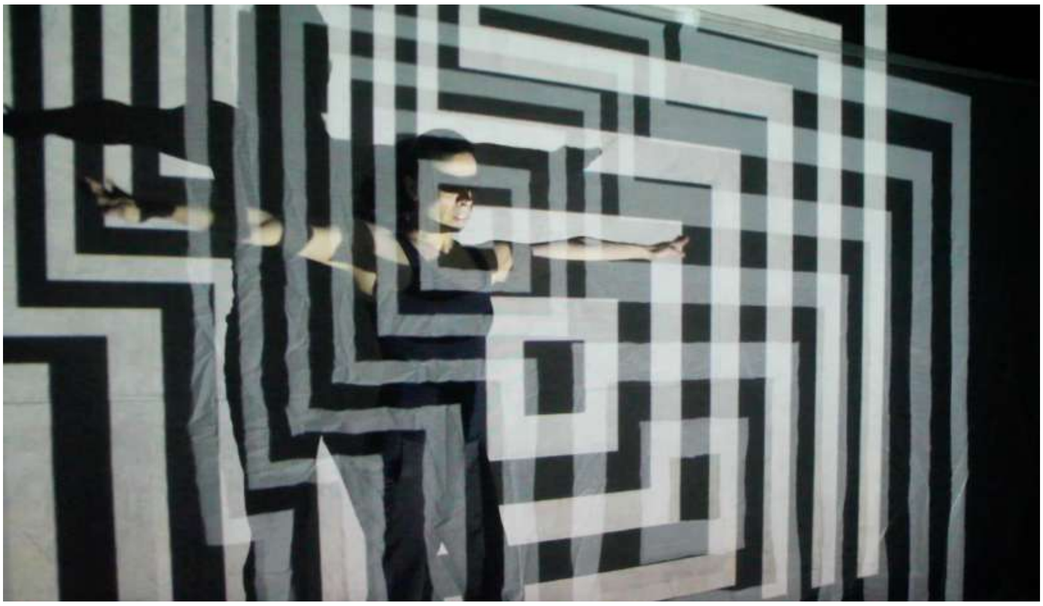

Figure 4.10: *GEA*. Montevideo, 2015. The dancer between the main projection screen and the tulle screen.

body parameters into dynamic values used for the rendering of geometrical forms. Body position, distance to the sensor or joint positions are captured and mapped into angles, quantities and directions of regular forms. We look for different roles for interactive projections: as a subject for manipulation, as interaction partners and as a performer's live representation.

Description of the piece

To reveal different body-geometry relationships, we developed fourteen different scene settings. In the first part of the performance, a three-dimensional rotating sphere accompanies the dancer and envelopes her body. It grows or reduces in size depending on the dancer's pose.

In the following parts, we introduce repetitive patterns of geometric figures and fractals and connect them with the movement parameters. Changes in

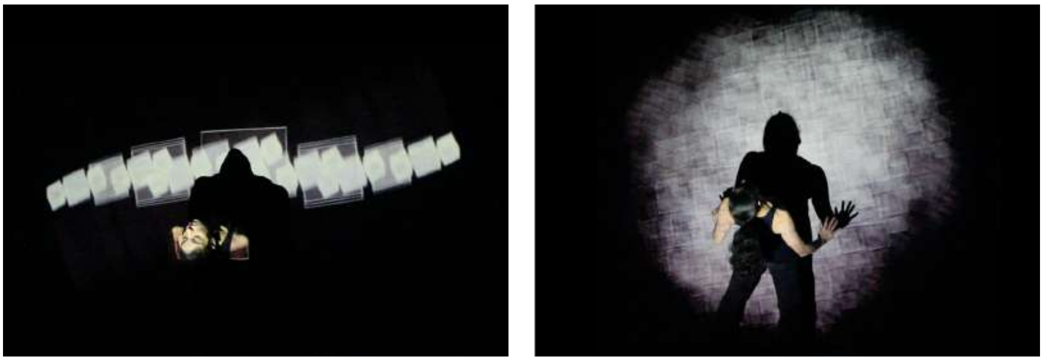

Figure 4.11: *GEA*. Montevideo, 2015. Changes in the distribution of visual elements caused by dancer's movements.

the dancer's position modify the number of elements, the angle between them or their size (Figure 4.11). It creates an interplay between the dancer and the projected pattern where both of them, the dancer and the geometry, are dancing.

Next, the dancer is immersed in the graphical environment where she interacts with the virtual objects that are attracted, repelled, or bounced by her body. In this configuration, the performer is more an interaction partner than a simple event trigger.

In the final scene, the dancer's body alters a series of parallel horizontal lines. The performer's silhouette is represented through the change of height in the arrangement of lines. We mirrored the image so that the dancer was able to dance with her geometrical representation (Figure 4.12). Body image and actions distort a carefully arranged world of parallel lines, showing the human as a distortion and disturbance in an organized system.

As we discussed in section 3.1 "Multimedia expression", HCI enabled the creation of a new connection between the performer and digital media on stage. In this piece, we sought to connect a human body with visual geometrical patterns to create one harmonic entity. We mapped body properties into parameters of the projected graphical to develop a visual instrument played

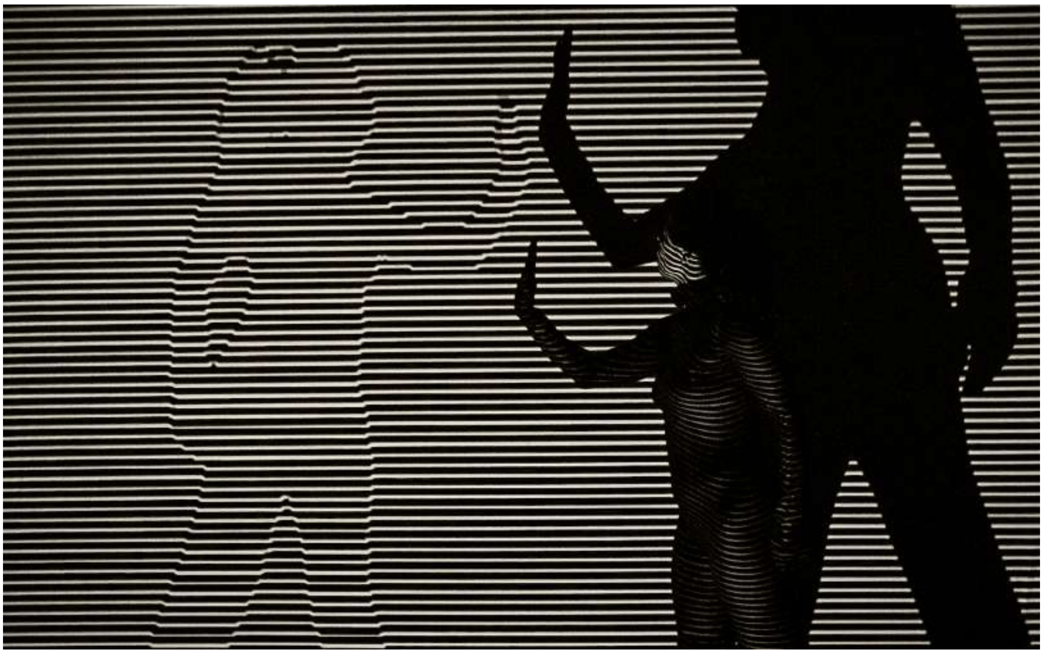

Figure 4.12: *GEA*. Montevideo, 2015. Dancer and its geometrical representation.

by the dancer's body.

Technology and design

To display the graphics we used a wide-angle projector. In the initial part of the piece, we applied a tulle screen. It was set one meter in front of the main projection screen so that the dancer could move between the main and tulle screens and also in front of both (Figure 4.10).

This piece used the Scenes model developed in the previous projects (see Appendix A). The independent visual effects were implemented as separate Scenes.

The tracking of the body was performed using skeleton tracking and user silhouette combined with depth differences. In some scenes we also used the distance between the performer's body and the Kinect sensor to modify the projected graphics.

Laws of physics. To implement the gravity force in one of the scenes, we used the Processing library fisica [221]. It provides methods to set the mass, velocity and position of the objects, as well as basic functions to set the gravity strength and direction and the behaviours of colliding objects.

Stroke rendering problems. Some of the Scenes raised problems with the stroke visualisation. The problems occurred because we were using a three-dimensional renderer that is known for rendering the overlapping strokes without considering the order of the shapes [222]. To solve the issue, we rendered the problematic Scenes creating a new two-dimensional rendering context [223].

4.3 Movement Aesthetic Visualisation Tool

The Movement Aesthetic Visualisation Tool (MAVi) is a tool designed and developed to explore the possibilities of using movement data for video making and live performance. We developed it during an internship at the School of Interactive Arts and Technology of Simon Fraser University Surrey in Canada between May and June 2015. MAVi is an open-source tool and its source code can be found on `https://github.com/ewelinka/MAVi`. The tool was presented as a work-in-progress in the International Symposium on Electronic Art (ISEA) in Hong Kong in May 2016 [224]. Also, a video piece *Internal* [225] developed using this tool was presented at the same conference as an artist talk. The videos of some MAVi functionalities can be consulted on:

- Colour Texture: https://vimeo.com/138398001
- Noise: https://vimeo.com/198052611
- Background Visualization: https://vimeo.com/199002090 https://vimeo.com/138398000
- Video Texture: https://vimeo.com/138397999
- Kinect User Map: https://vimeo.com/140516422

Motivation

Movement and its dynamics have been subjects of intensive scientific and artistic research since the end of the nineteenth century. Researchers like Etienne-Jules Marey and Eadweard Muybridge made the first attempts to record human and animal movements [226], [227]. Current motion capture techniques allow us to record and reproduce the movement data in three dimensions. This possibility provoked an interest in looking for new ways to interpret this kind of data. From the convergence of data art and motion capture techniques, started to appear projects focused on the movement aesthetic visualization like MotionBank [228], software and interactive systems designed for this purposes like Live Forms [229], Eyesweb [230], EMVIZ Visualization System [231] or Double Skin/Double Mind [232], and audio-visual art pieces like Forms [233] or as·phyx·i·a [234].

MAVi is a software tool that allows three-dimensional movement data visualisation, animation and creative interpretation. We developed it to explore the artistic potential of movement data. Inspired by the works of the visual artist Quayola [235], we selected triangulations as the visualisation modality.

The main objectives of the created tool were to:

- integrate mocap or animation data files in two standard formats: the Biovision Hierarchy (BVH) and comma-separated values (CSV)

- integrate real-time Kinect 1 data
- visualise movement data
- allow real-time manipulation of data visualisation
- record visualisation frame-by-frame

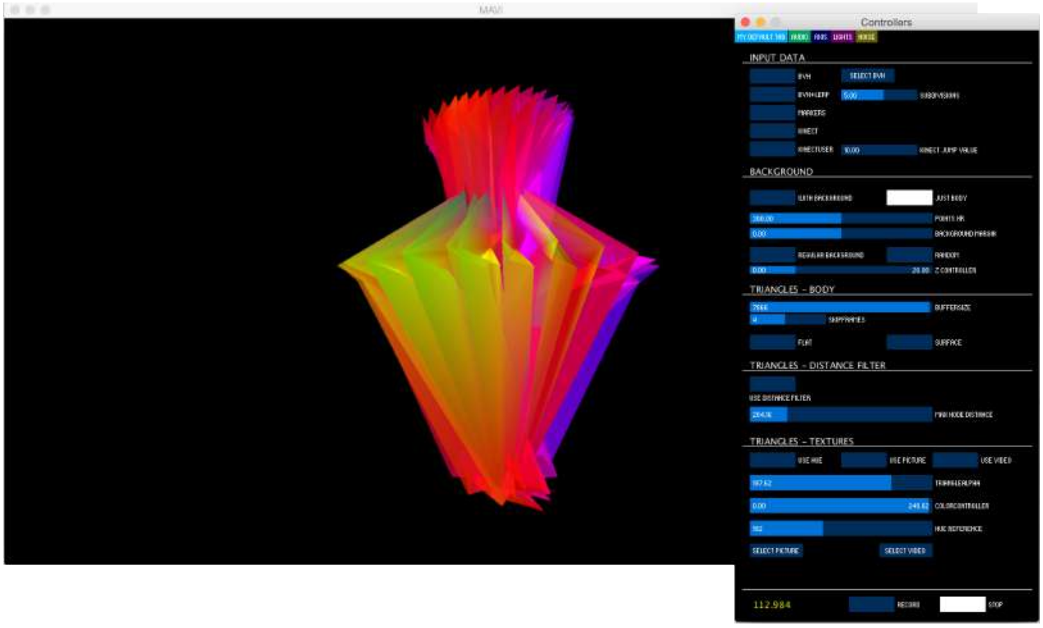

Figure 4.13: An example of turn movement visualisation using MAVi.

MAVi takes body points as input, and creates triangulations between neighbouring points. It allows the application of textures (colours, pictures and videos) to the created triangles and modification of their positions in three-dimensional space. It is also possible to add automatic camera movements, light setting manipulation and data noise. Our tool works with technologies like optical motion capture systems and Kinect. It can be used not only for movement data visualisation, but also for real-time manipulation and recording. Every frame can be saved and used to create video dance pieces.

The possibility of work with real-time Kinect data makes it suitable not only for video dance but also for live performance and artistic installations.

Implementation

We developed our tool in Processing [211]. Version 1.0 of the tool implements the following modules:

- Input data: allows defining the type of data to work with. They can be BVH formatted skeleton joints data, CSV files with markers positions provided by Vicon motion capture system [236] or Kinect "user map" or skeleton points provided by SimpleOpenNI library.
- Triangles: it is possible to manipulate properties like transparency or texture (colours, pictures or video frames) of every single triangle. It allows uploading videos or pictures for texture generation and controls the number of the visible triangles from previous frames in the scene.
- Background: manipulates the parameters related to the background.
- Auto rotation: controls automatic camera movements.
- Lights setting: manages the light setting of the scene.
- Noise: adds noise to the data points (random noise or Perlin noise).
- Recording: allows frame recording for further video creation.

We used the Triangulation library [237] to generate triangles between neighbouring points. The triangles can be generated between body points or body and background points.

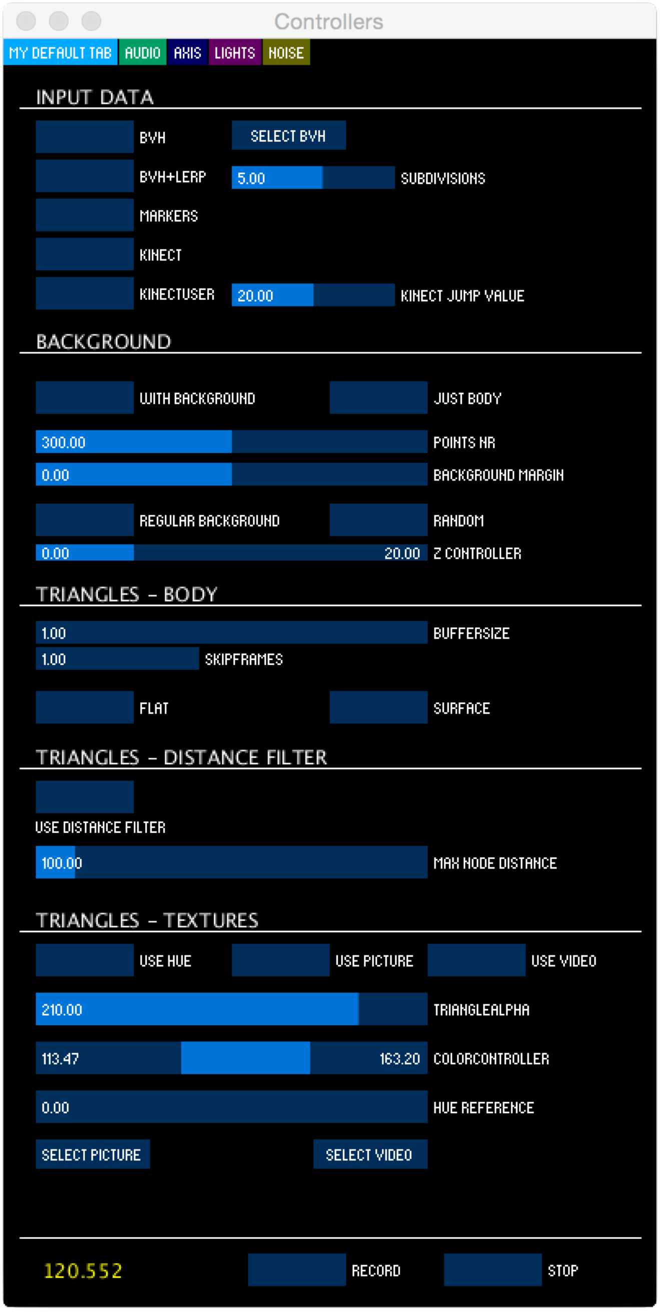

Figure 4.14: MAVi's user interface. Default tab active.

User interface

We developed the graphical user interface using the library ControlP5 [216] (Figure 4.14). This library provides a simple way to create sliders, buttons and toggles. These controllers allow the user a real-time manipulation of all visualisation parameters.

The interface includes five tabs that cluster MAVi functionalities. In the first tab, there are main controllers that manage:

- input data selection
- triangles visualisation parameters
- background creation parameters
- frame recording

The second tab controls the audio reproduction, the third the automatic rotation of the camera, the fourth the scene illumination parameters and the last one the noise parameters.

Internal

We used MAVi to prepare a video piece *Internal* [225]. This piece looks for new ways of generating meaningful, non-realistic movements through the disturbance of motion capture data and to enhance the expressive potential of simple mocap data with aesthetic visualization.

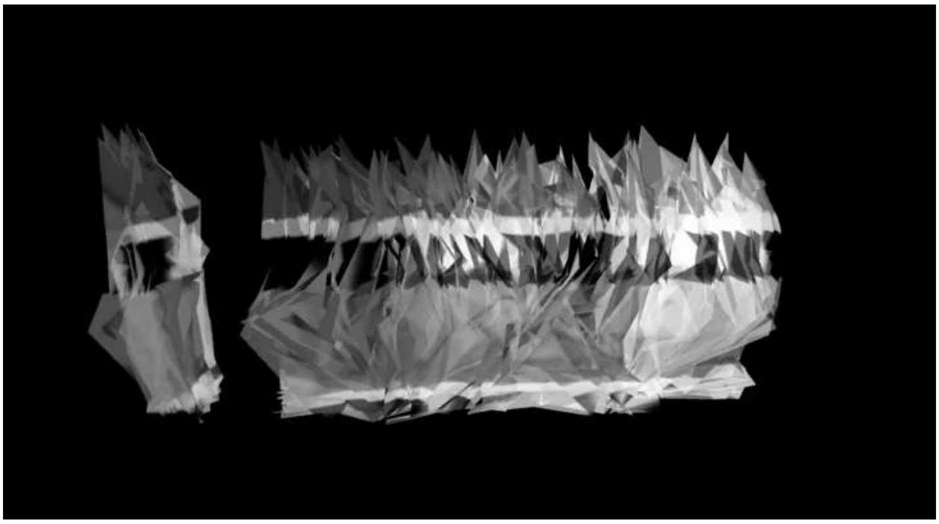

Figure 4.15: *Internal.* MAVi used to visualise movement over time.

The piece reflects upon our complexity as human beings and on our hidden emotions. The mocap data used in the piece were systematically altered using the noise module to generate the sensation of internal tension and anxiety. We applied video textures and camera rotations to reinforce the video's atmosphere.

We used data manipulation as a medium to evoke feelings, presenting some concrete and personal responses to the following questions:

- How, through visual parameters like form and color, can we code emotions?
- Where is the balance between noise and real movement information that make the original movement still recognizable?
- Are randomness and noise associated with negative feelings? Is the orderliness positive?

Figure 4.16: *Internal.* Random module applied to movement data.

Conclusions

MAVi is an example of a versatile software tool that extends the possibilities of creation in diverse artistic domains like video dance, live performance or installation art. It facilitates the exploration of movement data in three-dimensional space and the modification of parameters related to the created visualization. It allows the creation of body representations with a high degree of variability from both pre-recorded and live movement data. Moreover, the GUI developed to control the visualization parameters makes the tool suitable not only for programmers, but also for novice users.

Chapter 5

Conclusions and future works

This work aimed to analyse the influences of HCI on performing art practices. To meet this goal we:

- introduced a reference field for this analysis: staged interactive digital performance
- presented the definition of mediated interactivity and narrowed it to the context of our work
- drew an overview of HCI techniques that enable the capture of body characteristics and body movements
- introduced and discussed four relevant fields of artistic exploration that are part of digital performance: multimedia expression, body representation, body augmentation and interactive environments
- traced the historical appearance of these four fields and presented examples of art pieces from each of these fields created without interactive technologies and then presented novel practices that emerged with the incorporation of computer-mediated interactive systems
- presented personal practise-based exploration in HCI and digital performance (software tool MAVi and four dance pieces)

In the theoretical part of the thesis, we confirmed that HCI introduced novel forms of expression into performing arts. In the field of multimedia expression, real-time control of media reproduction introduced a new aesthetic relationship between the performer and the media used on stage. The performer and the media controlled by the performer's actions became one responsive entity. This was a new paradigm in media presentation since the media exposure in non-interactive systems had no relation to the performer's actions.

This fact drew our attention to the question of mapping between input data delivered by the performers and multimedia events. The creation of particular relationships between these two parts appeared to us an intriguing task that we later closely explored in the practical part of this research.

In body representation, another area of digital performance, data like real-time captured joint positions started to be used to create body representations. It allowed transposing the human body into virtual, animated characters. These characters extended the expressive limits of the human performer by enabling instant and continuous transformations of the characters' appearance without losing their personified nature.

Also, body augmentation practices were influenced by the appearance of interactive technologies. The body was extended through a new layer of interactive on-body projections. Videos and graphics projected onto the body surface created a mixture of the virtual and the in-the-flesh performer that visually transcended the limitations of the human body. Another type of interactive body augmentation - body augmentation through human-machine systems - made it possible to augment the capacities of the human body and reflect on human body condition in this new human-machine relationship.

Interactive environments, another important field of digital performance, also received an indubitable contribution from HCI research. Body-sensing techniques supported the creation of interactive settings where performers' actions have a direct influence on stage design. Application of bio-sensors in this field was identified as an innovative practice. The possibility of capturing and interpreting data like heartbeat rate, electrical impulses generated by muscle contraction or brain activity contributed to the current state of the art: it added a new way to create stage environments using invisible properties of the human body.

As we can see, the influence of HCI technologies on the performing arts can be demonstrated by various examples. They confirm the aesthetic potential of HCI in this area. Our study shows that interactive practices are both a continuation and extension of already existing practices.

Our personal practise-based research contributed to the current state of the art with a software tool for artistic creation and four pieces of technology-augmented dance.

The software tool MAVi contributes to many artistic fields. This creative instrument allows creating works of diverse types. It can be used to produce still images, video dance or can be applied in live performances or artistic installations. We see the extension of MAVi functionalities with new modules and the creation of similar tools as an exciting field to explore in the future.

During the work on the dance pieces, we took advantage of the possibilities provided by HCI systems to design and develop interactive pieces framed by the previously explored areas of body representation, multimedia expression and interactive environments. This practical approximation to digital performance allowed direct experimentation with studied categories. Interactive stage environments that we developed were essential components of the artistic statement of the developed pieces.

Violenta ternura was the first approach to digital performance. Although the interactivity in this piece was controlled by an external operator, the piece is an interesting example of an artistic use of real-time interaction. Interactive graphics not only accompanied performers' actions but also comprised an important part of the scenography. They wrapped the dancers and helped to create an evolving atmosphere of the piece.

Señal de ajuste was a piece in which HCI was not just a part of stage design, but also a subject in itself. Current technology allowed us to reflect on technology-mediated systems, by using them on stage.

In *GEA* and *1/f* we embedded the dancers in environments that extended and accompanied their movements and produced dynamic backgrounds for their performance.

The theoretical research and concrete instances of the encounter of performing arts with live human-computer interaction confirmed that it is possible to create a cohesive union of both fields and that it has great aesthetic potential. This intersection of the two apparently distant areas is an exciting field of research for both HCI researchers and artists. We consider analysis of the influence of HCI on the relationship between the audience and performer, as well as between audience and stage design, to be interesting future work.

We conclude that the analysis of the influence of performing arts practices on the HCI field will produce other interesting future work. There are already some works that indicate that movement qualities drawn from modern dance can be applied to design interfaces [238]. Detailed analysis of this kind of influences can result in new HCI practices based on performing arts.

Chapter 6

Appendix

Appendix A

Scene and SceneManager

To manage different visual effects corresponding to specific parts of the dance piece, we implemented a SceneManager class and a Scene interface.

The Scene was used to define the logic of each different interactive visual entity that formed a separate part of the performance. Every Scene had to implement five functions: *initScene*, *drawScene*, *closeScene*, *getSceneName* and *onPressedKey*.

```
interface Scene
{
    void initialScene();
    void drawScene();
    void closeScene();
    String getSceneName();
    void onPressedKey(String k);
}
```

In the *initScene*, the variables proper for each scene were set to their initial values. This function was the first function called after a change between Scenes and so ensured the same initial condition for each execution of the corresponding effects.

The function *drawScene* was the central function of each class where the appropriate visual effects were created and displayed. Method *closeScene* stopped the memory or CPU demanding processes of one Scene before the change into another one. *OnPressedKey* was used to pass the captured keyboard events to the active Scene. The keyboard was used to control diverse parameters of each visualisation.

Every Scene also had its proper functions and parameters used for the rendering and the real-time control of the visual parameters.

Class SceneManager was implemented to manage the order of the init/close functions execution when a change between two Scenes occurred. It was also responsible for saving the list of all available Scenes, as well as the currently active Scene.

Appendix B

Body capture with Kinect

Skeleton tracking algorithms used in SimpleOpenNI library [213] presented various problems during the development of the performance pieces. A relatively long (at least 6 seconds) time was necessary for user detection. It made it inappropriate for a dynamic appearance of the dancers because the effects could not be immediately synchronised with the performer's actions. Also, the estimation of the joints positions was not always correct, and frequently totally incorrect in the not-standing poses (performer on their knees or lying on the floor).

Another technique used to track the performer's position was based on *SimpleOpenNI.userMap* function. This function returns an array of integers where each position in the array corresponds to one pixel of Kinect image, and the value saved at that position indicates if at that place of the camera image a user was detected (values > 0) or not (value $= 0$).

Using these data to define the performer's position was much more reliable than skeleton tracking, but presented some problems with user detection

Figure B.1: User detection using *SimpleOpenNI.userMap* function. Pixels that correspond to detected person are painted blue.

when the dancer's movements were particularly slow. In these conditions, the performer was frequently recognised as a part of the background, not a user to track.

To improve user detection, we added a control filter based on depth values to this technique. The function *SimpleOpenNI.depthMap* provides access to the depth value of every pixel captured by the Kinect camera. We used this method to obtain the three-dimensional map of the stage environment before the beginning of the performances and used it as a reference. During the performance, the depth map of the stage was constantly captured and compared to this reference. The differences between the current depth values and reference values were used to define the significantly changed zones, which indicate dancer's presence. These results were compared with the number and position of performers detected using *SimpleOpenNI.userMap* function. They were used, if necessary, to complete the missing data.

The combination of both SimpleOpenNI functions (*userMap* and *depthMap*) gave the best results in performer tracking. Both techniques allowed defining the image regions where the performers were present. These regions were also used to define the reference points for each performer:

- point most to the right of the performer
- point most to the left of the performer
- the top point
- the middle point

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