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Visualizing Isadora Duncan's movements qualities

Manon Vialle
manon.vialle@inria.fr
Univ. Grenoble Alpes, Inria, CNRS,
Grenoble INP, LJK
Grenoble, France

Vennila Vilvanathan
vennila.5432@gmail.com
Université Paris-Saclay, CNRS
Orsay, France

Sarah Fdili Alaoui
sarah.fdili-alaoui@lri.fr
Université Paris-Saclay, CNRS
Orsay, France

Elisabeth Schwartz
elisabeth.danse50@gmail.com
Independent Author
France

Mélina Skouras
melina.skouras@inria.fr
Univ. Grenoble Alpes, Inria, CNRS,
Grenoble INP, LJK
Grenoble, France

Rémi Ronfard
remi.ronfard@inria.fr
Univ. Grenoble Alpes, Inria, CNRS,
Grenoble INP, LJK
Grenoble, France



Figure 1: The group of Workshop 1 learning the Moment Musical dance with our expert Duncanian Dancer.

ABSTRACT

We present a new abstract representation of choreographic motion that conveys the movement quality of fluidity that is central to the style of modern dance pioneer Isadora Duncan. We designed our model through a collaboration with an expert Duncanian dancer, using five flexible ribbons joining at the solar plexus and animated it from motion capture data using a tailored optimization-based algorithm. We display our model in a Hololens headset and provide features that allow to visualize and manipulate it in order to understand and learn Duncan's choreographic style. Through a series of workshops, we explored our system with professional dancers and were able to observe how it provides them with an immersive experience of a novel visualization of Duncan movement qualities in a way that was not possible with traditional human-like or skeleton-based representations.

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CCS CONCEPTS

• **Human-centered computing** → **Visualization; HCI theory, concepts and models.**

KEYWORDS

Dance, Interactive Visualisation, Physical Models, Augmented Reality, systems for supporting creativity, Discrete Elastic Rods

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1 INTRODUCTION

Isadora Duncan's choreography is one of the foundation of modern and contemporary dance. Her work revolutionized dance because it sought to move away from the rigid technique imposed by ballet to uncover what she described as "the natural movement". In her

definition, natural movement is described as unrestricted, respecting both the structure of the body and the pull of gravity: “*Such movements will always have to depend on and correspond to the form that is moving*” [16]. That is, each movement that a dancer performs is seen through the lens of the dancer’s body.

Unfortunately, Isadora Duncan always refused to be filmed, because she thought that the frame rate of the camera at the time (about 24 frames per second) was not enough to represent the fluidity of her choreography. Therefore her choreographic knowledge was transmitted mostly orally and kinesthetically from one generation of Duncanian dancers to another [31]. Nowadays, only very few dancers are experts of the repertoire of Isadora Duncan and it is no longer transmitted in regular dance curriculum. One can even go as far as considering it in danger of extinction. Our work aims at designing a visual system to transmit the dance repertoire of Isadora Duncan to professional dancers. Such system is meant to be contemplated but also experienced physically by the dancers in order to contribute to their understanding and learning of Duncan’s repertoire.

In this paper we present our close collaboration with a connoisseur, Élisabeth Schwartz, a professional Duncanian dancer from the third generation of Duncan’s students to co-design a digital graphical model that represents a selection of Duncan’s choreographic pieces. We recorded Élisabeth Schwartz as she danced several pieces using motion capture at a high frame rate. Through multiple discussions and iterations with her, we were able to design a digital model that faithfully represents Duncan’s movement qualities and philosophy. Our final model is a star-shaped digital representation made of 5 flexible ribbons that can bend and twist and smoothly deform to follow the pre-recorded motion capture markers positions.

Through 2 workshops with professional contemporary dancers, we experimented with our digital ribbons that we displayed first on a screen and second in an augmented reality environment. These workshops allowed us to articulate how our abstract visualization provided the dancers with an immersive, embodied and expressive experience of Duncan’s movement qualities of fluidity and naturalness.

To summarize, the contributions of our work are three-fold:

- We describe the design of an abstract visualization of dance movement qualities based on the collaboration with a connoisseur dancer of Isadora Duncan’s repertoire.
- We describe the resulting digital model that uses elastic ribbons merged together in a star-shaped fashion and that can be deformed to fit the motion capture data.
- We present and discuss the results of a series of workshops with professional dancers who experimented with the model on screen and on an augmented reality headset.

2 RELATED WORK

The literature of systems visualizing dance movement shows a variety of purpose, ranging from supporting user’s kinesthetic creativity [24] and dance creativity [6–8], to learning a vocabulary [17] and teaching a dance piece [4, 34]. For the purpose of this paper, we review literature that deals specifically with the visualization

and transmission of dance using motion capture, and immersive technologies.

2.1 Dance visualization using motion capture

Motion capture brings many benefits for the purpose of archiving and transmitting dance. Mainly, when compared to video recording, it gives a much more faithful representation of spatial movements evolving in three dimensions.

De Booer et al. investigated which representations conveyed movement the best between textual description based on Laban and Benesh notations, auditory description, 2d and 3d animations and found that dancers preferred 3d animations [14].

Motion capture enables many different visualization strategies. The most prevalent style in dance is based on stick figures and stylized human-like avatars along the lines of the popular DanceForms software [5].

In an early study in VR dance education, Hachimura et al. compared several variations of their human-like virtual dancer, including wireframe, solid, solid+wireframe and texture, and found that all of them could be useful, according to the specific needs of each lesson [21]. In a later study, Tsampounaris et al. introduced additional visualization strategies on top of human-like avatars, including motion trails and particle systems, and show that they enhance the understanding and learning of the dance motion [41]. Other authors have chosen to explore more abstract visualization styles [17, 24]. Fdili Alaoui et al. have explored the use of physical models to represent dance movement quality [18]. They showed how these models have the potential to convey dance movement qualities and dynamics while disregarding the visualization of postures, trajectories or the form of the body [17]. Piana et al. used mass-spring systems to analyze movement fluidity [33]. Hsieh et al. [22, 23] associated a variety of instances of mass-spring systems to various dynamics of movement.

The question of how a digital dancer’s body should be represented graphically and visually is at the center of the Digital Body project by Alexander Whitley, an open competition asking what form the dancing body can take in the 21st century [42]. There is a long line of practice-based research exploring this theme. As early as 1999, digital artists Marc Downie and Paul Kaiser displayed giant hand-drawn color strokes derived from motion capture data on a transparent screen during performance of the ballet *Biped* by Merce Cunningham [26]. Denis Poulin and Martine Époque developed a concept of “dance without bodies” by using particle animation guided by motion capture data, as shown in their short movie *CODA* showing a virtual performance of Stravinsky’s *Rite of Spring* [40]. Zhang et al. [44] proposed a system, *MoSculp*, to display motion by creating a 3D surface of the moving parts.

Leach and Delahunta advocate a radically abstract representation of the digital body, using arguments from cognitive science [29], and taking examples from their long lasting collaboration with Marc Downie and Wayne MacGregor. Together, they designed an abstract body for the piece “Becoming”. They worked from three requirements, that the body should be three-dimensional, human scale and compelling. They achieved this by displaying a dynamic abstract shape on a giant stereoscopic screen.

The Choreomorphy project explored different visualizations of a dancer’s body [35], including abstract, anthropomorphic and cartoonistic with static or animated textures and distorted meshes. Users chose the avatar they liked best, irrespective of how well they represented movement qualities.

In our work, we also choose an abstract representation of the dancer’s body, where the articulated motion of the body parts is replaced with the fluid, wave-like motion of an elastic ribbon. Motion abstraction of this type has been proposed before in the context of computer animation by Bidinganavale and Badler [3], Neff and Fiume [32] and Coleman et al. [13] but never used before to visualize dance movement.

We also build on the work of Fdili Alaoui et al. and design a physical model to convey faithfully Isadora Duncan movement qualities of fluidity and naturalness.

2.2 Dance visualization using immersive technologies

Recently, researchers have started to use mixed reality setups for teaching dance in the classroom, rather than on a computer screen. Sra et al. describe a social VR system allowing students to take part in a dance lesson remotely [38]. Chan et al. describe experiments using real-time motion capture to teach dance in VR [9].

Both Anderson et al.[1] and Muneesawang et al.[30] propose systems that aim at enhancing the traditional teacher-centered demonstrate-imitate mode of instruction. Their systems are based on real time motion capture via Kinect and visual feedback. The interactive feedback allows the user to know how well their movement was performed. In Anderson et al., the feedback is displayed through a augmented reality mirror, which shows the user’s reflection as well as the target pose (using a skeleton) and the user’s skeleton[1]. While this method allows to visualise a variety of angles of the skeleton, it remains a 2D visualisation that lacks information and depth. Muneesawang et al. goes beyond by using a 3D cave to display the feedback as rigged characters. According to these authors, the interactive feedback is essential for teaching dance movements.

In this previous work, the focus is on learning the steps of a dance piece . In our work, we provide a more abstract representation of the dance, allowing more freedom in the interpretation and execution of each dance step. Closer to our work, Cisneros et al. describe the Blending Engine [11], a creator tool developed as part of WhoLoDance project [12] which lets dance students combine different movements together both in time and in space. They compare several visualization methods for the dancer’s body, including a stickman, an arrowman, a snowman and an android. In later work, Strutt and Cisneros describe a virtual dance system allowing a real dancer to interact with a computer graphics avatar [39] and argue that this is a promising direction for supporting dance improvisation and training. Building on this work we explore in this paper how digital visualisation of dance movement quality can support the transmission of a dance in immersive, mixed reality.

3 DESIGNING THE ELASTIC MODEL WITH THE EXPERT

3.1 Co-designing with a connoisseur

Our graphical model was co-designed [37] with Elisabeth Schwartz, the fifth author of this paper who is an expert dancer of the third generation of Duncanian dancers. Our design process is rooted in her connoisseurship of Isadora Duncan’s work. Elisabeth was taught the Duncanian repertoire by a dancer that was taught by Anna Duncan, one of the “Isadorables” who danced under the instruction of Isadora herself. Throughout this paper we name Elisabeth Schwartz E.S.

Our co-design[19] methodology involved the researchers as well as the expert dancer (Elisabeth) in all the stages of the design process, from defining the movement principles to assessing the prototypes that we produced to experimenting with the prototypes in the studio.

3.2 Understanding the Duncanian movement

We first invited E.S. to our lab for a day to build an understanding of Duncan’s work. E.S. made a presentation and performed examples that represented Duncan’s qualities of “natural movement”. We then had a long conversation and brainstorming session on possible visualizations of Duncan’s qualities.

E.S. explained to us what “natural movement”, as expressed by Isadora Duncan in her autobiography [15] and other writings, [16] meant through 3 main principles.

- Fluidity

One of the main characteristic of Duncan’s movement is fluidity. The fluidity in Duncan’s philosophy can be described as the perpetual motion of the body, its continuity. “*There is a quality of perpetual oscillation in Duncan’s work*” said E.S.. She added: “*This really gives a movement quality that is continuous, perpetual, always picked up by a curve, an 8 shape, a spiral. And so what we could define as a natural movement is a movement which sometimes accelerates, sometimes slows down, in suspension. It lets the momentum work its way, lets this game with gravity work. I think that would be her natural movement.*”

In order to visualise fluidity, E.S. suggested to use the metaphor of the ribbon. In fact she declared that Isadora Duncan always danced wearing fluid fabrics such as loose silk dresses. Moreover when artists would draw Isadora dancing, their drawing would look like she and her draped clothes are just one entity [36]. E.S. herself uses loose silk scarves with her students to support their embodiment of the fluid continuous movement in free flow. E.S. also suggested to visualize the ribbon in 3D in order to display the curves and spiraling movements in Duncan’s repertoire.

To visualize this quality, we proposed to use a physical model in the form of ribbons that can freely deform following motion capture data. Such model’s motion should be fluid and continuous while following the dancer’s movements.

- The Solar Plexus

E.S. also described how Duncan attempted to find the origin of movement and how she located it near what she refers to as the solar plexus: “*I know only one dance and it is this movement: drawing back your hands to the solar plexus, whereupon an inner force opens up your arms and raises them*” [15]. In giving the solar plexus metaphysical overtones and locating it between the breasts, Duncan obviously

uses the term in a nontechnical, that is, non-anatomical sense [28] and rather in a poetical sense. E.S. referred to the solar plexus as “the location of the reception and distribution of the undulating forces of movement”.

In order to visualize this characteristic, we proposed to work with geometric representation of a virtual dancer organized around a center located on the chest, which we also call the solar plexus for convenience.

- The Wave

Another important element of Duncan’s natural movement that our expert emphasized is that motion should propagate along the dancer’s body like a wave. Duncan writes: “all movements in Nature seem to me to have as their ground plan the law of wave movement” [16]. E.S. emphasized how the wave presents a duality: “how matter moves and how the energy propagates. The wave involves the asymmetry of opposing forces. The asymmetry of the supports reflects the acceptance of this double polarity in movement”. The wave organizes movement in such a perpetual undulating rhythm.

In order to visualize this characteristic, we proposed a model where movement always progresses in a wave from the center to the peripheries of the representation.

3.3 Capturing the dances

For our initial design, we worked on three different dances (Prelude, Moment Musical, Folatrerie) choreographed by Isadora Duncan. We captured E.S. performing these dances using Vicon Motion Capture system. Our mocap set-up relied on 64 spherical markers whose positions in the 3D space are recorded at 100 frames per second (see Figure 2 for an illustration of the marker locations).

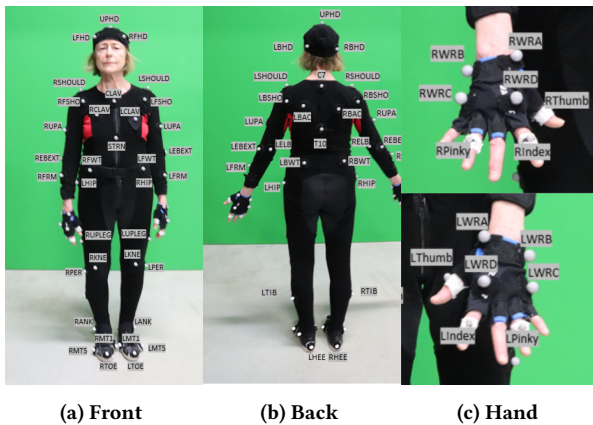


Figure 2: Positions of the motion capture markers on the dancer’s body.

3.4 Iterative ribbon design

Initial design of the model. Based on our conversation with E.S., we proposed a first version of the model, representing the arms of the dancer, taking the form of a straight flexible ribbon going from one hand to the other as shown in Figure 3a. Our ribbon was computed to follow the motion captured data of E.S. performing the dances.

Using a ribbon instead of a rigid skeleton would correspond to the fact that the dance of Isadora Duncan is unconstrained to one’s body. This would convey the fluidity of the movement better, as ribbons are not restricted to bend and twist at a fixed set of locations only (the joints of a skeleton).

We discussed this representation with E.S. via emails and a video call. We showed her the ribbon for the Prelude and Moment Musical dances. She thought that the use of the ribbon to model dance movements was coherent with Duncan’s philosophy. She highlighted some of the qualities of the model: “They make the Duncanian movement more visible and more readable, which lets us have a more precise analysis. We can really see the quality of the gestures, the momentum, the looseness and the suspension, the stretching of time.” She also thought that the model represented the arms movement in a quite accurate way.

She suggested to create more ribbons representing the limbs, all around the solar plexus. “As a dancer and interpreter of Duncan, I can spot the arms’ movement really well in Prelude, beyond the difficulty of the half turns and pivots. It will be amazing when the other ribbons linking the arms to the solar plexus and other parts of the body such as the bust and the head will be created. A stylistic Duncanian rendering through this abstraction will be visible.”

She emphasized the need for a representation with legs, as the interactions between the feet and the ground is essential in Modern dance in general, and more precisely in Duncan’s dance: “The question of support needs to be treated, because it is central in dance, thus the idea of creating a ribbon which takes into account the feet. Modern dance in its early ages took a close attention to the extremities”.

E.S. also mentioned the ways in which the ribbon can move and how it conveys the Duncanian movement philosophy: “The ribbon with three parameters (stretch, twist and bend) also shows the importance of the looseness and of the informal wholeness of Duncan’s dance because from an aesthetic point of view, we are not in an articulated body, formally defined.”

First iteration on the model. Following E.S.’s above recommendations, for the second design, we focused on the creation of legs, as E.S. emphasized their central role in Modern dance. As suggested by her, we tried 2 different settings: one with one ribbon for the arms and one ribbon per leg, starting at the solar plexus (Figure 3b), that we tested on data captured of E.S. performing Prelude, and the other in the shape of an A, with one common ribbon for the arms, and one ribbon for each leg-to-head line (Figure 3c), that we tested on the data captured of E.S. performing Moment Musical.

However, while both those representations brought something interesting to the model, the A shape did not highlight the fact that the solar plexus was the center of movement. Indeed, as E.S. explained when referring to the plexus: “It is a center and all the body irradiates in succession: the arms, the top of the head down to the neck, the lower back, the legs. A center, movement in successions which gives a construction almost like a starfish. A really flexible starfish.” This also highlighted the fact that the head was a very important part of the body and therefore that it also needed to be represented.

Last iteration on the model. Taking into account the need to convey the importance of the solar plexus and the mention of a “starfish” shaped body, from where “an inner force opens up your

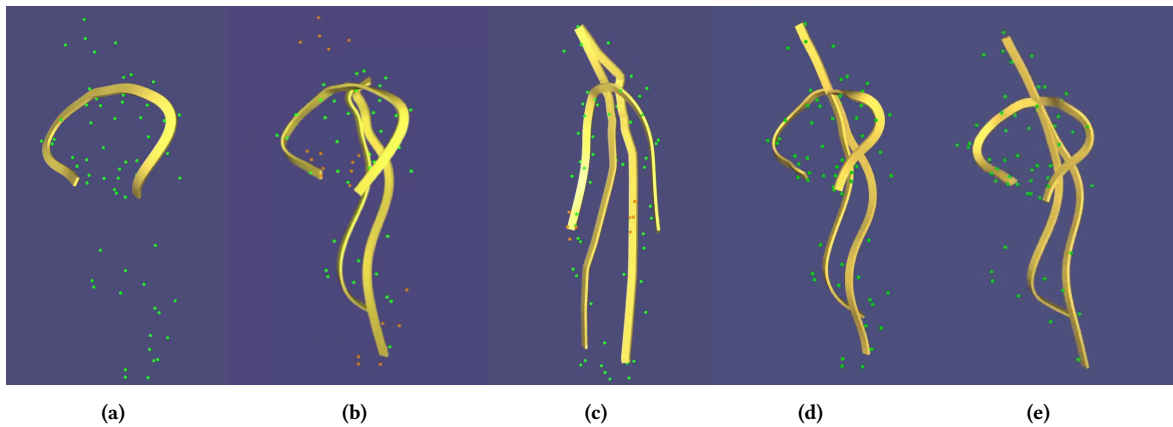


Figure 3: The successive versions of our ribbon model, co-designed through multiple iterations with E.S., our expert Duncanian dancer.

arms and raises them”, we broke the arms ribbon into two pieces, one for each arm, added a ribbon for the head and used a ribbon per leg. All ribbons were joined at a common point that we located on the chest of the dancer and were kept connected to each other throughout the dance at this same position on the chest. This fourth version of the model is thus an abstract figure in the shape of a starfish, with five ribbons attached together at the solar plexus, as shown in Figure 3d. We then decided to better constrain the movements of the ribbons so that they better follow those of the solar plexus. Indeed, while the ribbons of our previous model could freely rotate around themselves, we decided to fix their orientation at the solar plexus, so as to make it match the solar plexus’s normal, and let their orientation freely propagate from this point according to the physics of the ribbons. This model is displayed in Figure 3e and in Figure 6.

We discussed this last version with our expert in person. She still thought that the representation was aligned with Duncan’s philosophy of movement. *“I like the ribbons. I think that with respect to Duncan there is a coherence. I like this physical rendering. To show the continuous movement, the continuous rhythm.”* She also mentions how the ribbons display the characteristics of Duncan, the “8” shape drawn by the hips and the particular way that the head is moving. *“What I really like is that it gives us to see how the whole body moves. The hips from left to right, the freedom of the head, etc.”* She also mentions that the model shows how the movement comes from the plexus. *“In fact I perceive something really accurate style-wise. These are movements that deploy starting from the center. Yes, that is why I insist on the plexus being the center of movement.”*

4 IMPLEMENTATION

Throughout the design process, we implemented the ribbon following three main stages displayed in Figure 4. From the motion capture data, we generate a 3D animation of an abstract ribbon. The output of our algorithm for the three dances considered in this work is summarized in Figure 6.

Ribbons’ representation. In practice, our ribbons are modeled as isotropic rods, i.e. have a circular cross-section, which let them



Figure 4: System overview. From left to right: mocap recording, mocap data extraction, ribbons generation.

equally bend and twist in any direction. However, we *display* them as *flat* ribbons to better visualize their twist. Moreover, we assume that the rest shape of each rod, i.e. its shape when there are no external constraints, is straight, so as not to favor any particular direction for bending and twisting, while simplifying modeling.

Initialization. We define the rest shapes of the rods by using the mocap data when the dancer takes a T-pose, a pose most mocap systems ask the user to take to calibrate the system and is present at the beginning of all our recordings. This pose also has the advantage of exhibiting low bending of the limbs, which is coherent with our assumption for the rods to be straight at rest (Figure 5, left).

We process each limb and the head separately and create a rod for each. To this end, we first manually group all the markers according to their body location. To make sure all rods join at the solar plexus, we precompute the position of the later (defined as the midpoint between the markers CLAV and C7, see Figure 2) and make the centerline of our rod start at this position. To define the direction of the rod, we perform principal component analysis on each group’s markers and use the vector associated to the largest variance. We size the rod by projecting the markers of the group onto the line

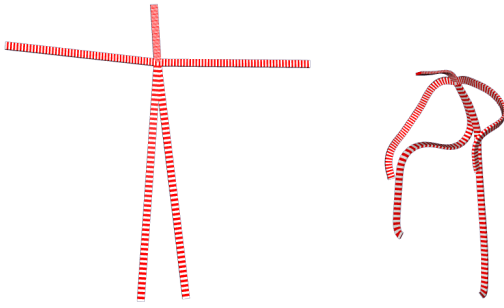


Figure 5: Left: the rest pose, i.e. reference pose, of our model with straight ribbons. Right: the deformed pose with stretched, bent and twisted ribbons.

defined by the solar plexus and the direction computed above and set as rod’s endpoint the projected point furthest away from the solar plexus.

Finally, to ensure all the ribbons are orientated consistently (in practice, the arms are slightly tilted forward), we rotate them around their respective centerlines so that their normals match the normal to the solar plexus, defined as the normal to the plane passing through the markers RCLAV, LCLAV and CLAV.

Ribbons’ numerical model. In order to deform our ribbons and animate them, we then need to associate them to a numerical physical model for rods. We choose *Discrete Elastic Rods* by Bergou et al. [2], a popular model in computer graphics that allows to simulate rods that can stretch, bend and twist. We discretize our rods using 100 segments per limb. To make the rods follow the dancer’s movements, we “attach” each marker to the closest ribbon using a linear and angular spring: the linear spring penalizes changes in the distance between the ribbon and the marker, while the angular spring penalizes changes in the angle formed by the marker and the ribbon’s normal. When changing positions as the dancer moves, the markers, connected to the rods, will then attract the rods towards them and make the rods deform, i.e. bend and twist. We process the frames successively and compute the deformed shape of each rod independently by minimizing the total energy of the physical system.

We implemented the optimisation in C++ using the *ipopt* library [43] for the minimisation process and *libigl* library [25] for the visualisation process.

5 DANCERS’ EXPERIENCE OF THE RIBBON

We conducted a series of workshops with professional dancers to articulate how they perceived and interacted with our 3D model. Our experiments aim at assessing whether our model conveys Isadora Duncan’s principles of fluidity, solar plexus and wave-like movement and whether it supported the transmission of Duncan’s repertoire to professional dancers

5.1 Workshop 1

Designing the set-up. For the first workshop we decided to introduce the ribbon model in the simplest set-up possible: projected on a white screen using a projector. The idea was to put together

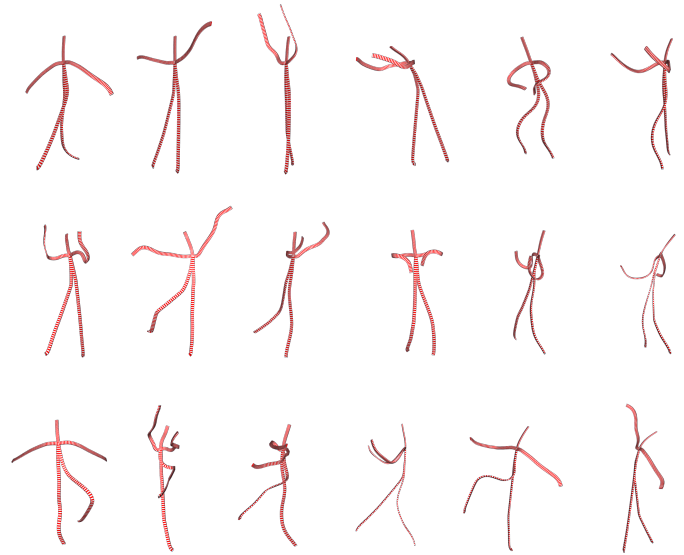


Figure 6: Final ribbon model. Each line corresponds to one dance (from top to bottom: Prelude, Moment Musical, Fola-terrie), from which we extracted representative poses.

conditions for the dancers to interact with it on screen and observe how they experience it and what it inspires them to do.

Participants. We invited 4 professional contemporary dancers to participate in a half a day workshop. We refer to them as W1P1 through W1P4. All of them were female with 20 to 40 years of experience. They had no previous experience in Isadora Duncan’s dance. E.S. as well as the second author of the paper led the study together. Second author is a researcher and also a trained dancer/choreographer. She introduced the workshops goals and walked the participants through the interactions. E.S. was in charge of teaching a Duncanian Dance to the participants. First author of the paper was in charge of setting up the model and gathering data (video, audio, handwritten notes etc.).

Procedure. The workshop took place in a local dance studio, which had chairs and a table. E.S. first led all participants and researchers (including the first and second authors of this paper) through 1h30 warm up that prepared them to dance Duncan’s repertoire. Subsequently, she taught all participants and researchers the “Moment Musical” dance of Isadora Duncan without technology for approximately 1h.

We then asked the dancers to observe the final starfish ribbon model performing “Moment Musical” projected on a white screen using a projector. The video was mirrored so that it was easier for the dancers to follow the models’ movements. We asked them to dance with the model all together in one group. We had the dance shown to them as long as they wished. They danced with the video for approximately 30 minutes.

After this experience we sat all together on the floor, and run a conversation with all the participants on their experience of the model as shown in Figure 7.



Figure 7: Dancers discussing their experience.

Data Collection. We placed a camera on a tripod in a corner of the studio to record video and audio of the session. We also set an audio recorder during the group discussion to record audio of what the participant told us. We took pictures at various moments of the workshop. We also took personal notes on what we observed during the workshop.

Data Analysis. First and second author analysed the data. We revisited all of the audio-visual material and took notes of significant events in the videos. We also transcribed the audio material. We analysed all of the transcriptions using a thematic analysis approach[20]. First, we defined concepts using our original words (open coding) and grouped them in themes (axial coding) that are represented in each subsection of the findings. Our themes represent common patterns across participants that capture their perception and experience of the model and identify opportunities and limitations that might trigger new design and experimental ideas.

5.1.1 Findings.

Dancing with an abstract body. Dancers were inspired by the fact that the star-like model did not refer too closely to a human: “*And it’s crazy how we can reconstruct from something so minimalist and rudimentary and how it could capture the ‘essence’ of the movement*” (W1P1). This made them focus on “the essence” of the movement and the lines of the body: “*It is the body reduced to its elementary lines*” (W1P2).

One participant emphasized how the model could be perceived as a representation without gender nor cultural references to it which allows to focus on the movement rather than its context. “*And what I find funny is that the character which does not have any muscle nor bone, we don’t know who he is, since it is so abstract, that with respect to the dance, I find it really interesting, it would enable a non connoted knowledge. It is interesting this lack of connotation. No gender, no cultural connotation. To which time frame does it belong. If I propose this to a student-dancer right now, who would not know who Duncan is, I would like to know what they would say*” (W1P3).

Another participant found that an abstract representation brought forward the poetry that is inherent to movement besides

the costumes and the historic context of the dance: “*I found it poetic, even if we removed the costumes, the dancer’s body, all of the imaginary world of Isadora Duncan, and everything that she put behind her philosophy of dance. Even if we remove all of it, this character and the music there is already a lot poetry that comes out*” (W1P4).

Dancing with a natural body. Fluidity of the movement is also a main quality that the dancers could see in the ribbons’ movement: “*We really see the liquid, the fluidity, we really see it a lot. There is a big fluidity of the spine, an opening of the spine. There is a continuum*” (W1P2). Because the ribbons were so simple yet their motion was implemented to account for the wave-like fluid quality of movement in Duncan’s repertoire, dancers were able to distinguish such quality in the movement of the model accurately. One dancer said: “*We can really recognize something that can connect to the intention of the body which is clear. We can see that it is E.S. that is dancing. That there is something regarding the intention of the movement, without the hand, without the eyes, in the fluidity, the musicality*” (W1P4).

Additionally, dancers considered that the star-like representation visualized how the movement was initiated from the solar plexus: “*We can see movements starting from the plexus*” (W1P2).

Dancing with a flat screen. Although the dancers appreciated and recognized the movement qualities of Duncan in the simple yet expressive motion of the ribbon model, they reported on the difficulty to look at it on a flat screen. And more so, the dancers found it difficult to look at it while dancing. One participant said: “*When we turn around we don’t see the screen*” (W1P3). Another dancer (W1P4) reported that they were more likely to look at other dancers around them before looking at the screen and that it was their last resort to understand the choreography. Additionally, the dancers expressed that such a visualization of the model lacked information on depth, and that therefore it was difficult for them to follow the model while dancing. They suggested the possibility to slow down the model to decipher more information on the dance.

This showed how a 2D representation through video was limited and did not convey enough information from the 3D model for dancers to learn and experience from.

5.2 Workshop 2

5.2.1 Designing the set-up. For the second workshop we decided to move away from the projection on screen and experiment with virtual reality. We explored the HTC Vive 2 headset. However that set-up constrained the space to 3 by 3 square meter. Moreover, the headset was too heavy, and the cables and space limitations restrained the movement. Additionally, handling the controllers was cumbersome. Following these explorations, we decided to experiment with a Hololens 2 which is a wireless mixed reality headset. This device allowed us to display our model in 3D. Moreover, the Hololens headset is wireless and does not require controllers because it can track the hand movement. Therefore, the dancers can use their hands to select options. Finally, it does not require a constrained space, and the dancers can share the same space as the animation.

To put our ribbon model into Hololens, we first converted our results (one mesh per frame) into Blender using blendshapes. We then created one blendshape per frame and baked the animation

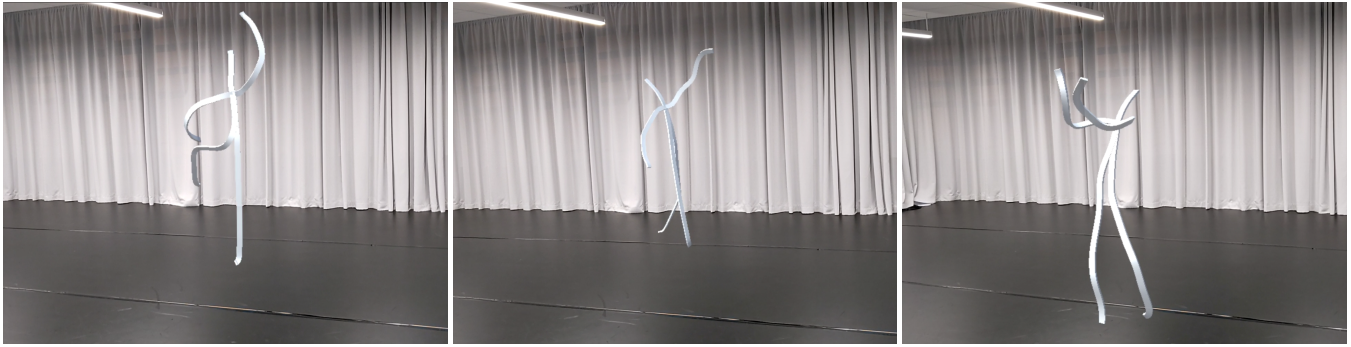


Figure 8: Different poses of the ribbon model as seen through Hololens.

and exported it in the FBX file format. Finally, we imported the FBX file in the Hololens headset using Unity. Figure 8 shows how the ribbon model is displayed inside the headset.

We implemented different features in an interface in Hololens, following some of the dancers suggestions. Our features allow the dancers to start and stop the animation and they could slow it down and speed it up. All these features were accessible to the dancers in the main menu which they could access by raising their left hand in front of them and selecting the desired feature by clicking with their right hand, as shown in Figure 9.

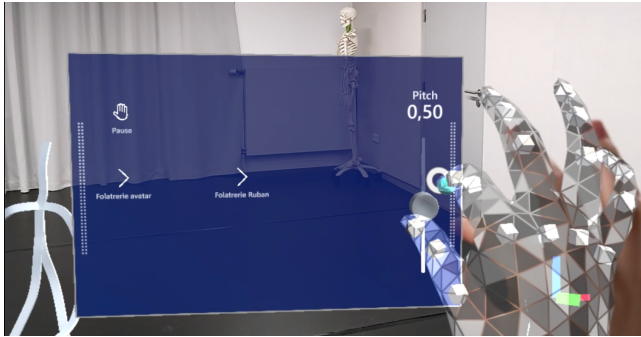


Figure 9: User Interface in Hololens.

Participants. We invited 5 professional contemporary dancers to take part into the second workshop. We refer to them as W2P1 through W2P5. All of them were female with 20 to 40 years of experience. 3 out of the 5 took part into the first workshop (W1P1, W1P2 and W1P3). They kept the same participant number as the first workshop. They had no previous experience in Isadora Duncan dance, except what they learnt in the first workshop. E.S. as well as the second author of the paper led the study together in the same fashion than in the first workshop. First author of the paper set up the model and the Hololens experience and gathered the data.

Procedure. The workshop took place in the same local dance studio. E.S. first led all participants and researchers (including the first and second author of this paper) through 1h30 warm up that prepared them to dance Duncan’s repertoire. Subsequently, all participants and researchers were taught for 1h30 the “Folaterrie”

dance of Isadora Duncan by E.S. without technology. Then we had the dancers visualize the ribbon model performing “Folaterrie” in the Hololens headset.

E.S. and the 5 participants were introduced to the Hololens experience. Subsequently, each one had 10 minutes to experiment with the model in the headset individually. We suggested them to visualize the dance as many times as they wanted. During the time with the headset, they were able to freely move in the dance studio as shown in Figure 11.

After this experience we sat all together (E.S., first and second authors as well as all participants) on the floor, and run a conversation with all the participants on their experience of the model.



Figure 10: Two dancers using Hololens menu at the same time.

Data collection and analysis. The data collection and analysis was performed in the same way as in Workshop 1.

5.2.2 Findings. All participants thought that the ribbon viewed in augmented reality was visually appealing and allowed them to appreciate and “contemplate” the choreography. Dancers particularly appreciated how the model helped them learn the choreography. Overall they reported on how the model was suitable to convey the movement qualities of Isadora Duncan.



Figure 11: One dancer dancing with the Hololens headset on.

How the star-shaped body represents a Duncanian body. The dancers appreciated this visualisation of the body and considered it representative of Duncan's quality of fluidity. Because the model used in the second workshop is the same as the one used in the first workshop, we received very similar feedback on the perception of the inherent movement qualities of the ribbons, which were seen to accurately display the qualities of the natural movement of Isadora Duncan. One participant said "It is a perception that I really like. It lets me see lines, moving curved lines in a form of fluidity which lets us see how the movement circulates" (W2P2).

They discussed different possible representations, including one with one line for the arms, one line for the legs and one line for the spine and a circle for the head as shown in Figure 12, but thought the one we chose fits the aesthetics of Duncan's choreography. "I don't know if this model (see Figure 12) is suitable" said one participant (W2P5). To which E.S. responded "Yes I prefer the model that we saw. I think there has been a choice that corresponds to an aesthetic. And I think it is important to make a choice. If this was Martha Graham maybe the choice would be different. But for Duncan it needs to fit the aesthetic of the body".

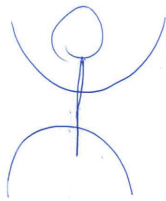


Figure 12: Doodle of another possible representation of the dancer's body proposed by workshop participants.

Hands, Feet and Head. Four dancers did not notice or were not bothered by the lack of fingers, correct feet representation and lack of a round head. However, the lack of feet was interpreted as a

lack of anchoring to the ground: "Maybe it would be good to see the ribbon anchoring itself to the ground" (W2P3).

In fact the idea of anchoring to the ground was central in the participants answers and was somehow controversial. Some found that the lack of feet did not carry the information on the relationship to the ground, and other thought that it showed it even better. One participant thought that the lack of feet was keeping her from understanding the relationship to the ground: "it seems to be floating and we don't understand because the choreography demands a lot of grounding" (W2P1). The floating feeling was however perceived by another dancer as showing the wave propagation of the movement (W2P5). E.S. considered that the lack of explicit reference to the feet showed the relationship to the ground even more: "And it's funny paradoxically we can feel the ground better almost" (E.S.). One participant noted that "we see the ribbon deforming from the feet to the hips, we feel the resilience, we feel the relationship to the ground, and then how the wave propagates in the body. And the ribbon lets us see all that" (W2P4). Another participant stated that "There is maybe less of a relationship to the support of the feet where you see more weight. But here we are less focused on support, but more on moving lines, and how energy circulates in a curved way, there are really few straight lines" (W2P2).

Fluidity and Ripple. All dancers agreed that the ribbon model displays the fluidity of the movement. "Yes the ribbon gave visibility to the fluidity of the speed of the spine and the arms" said (WS2P5). Another participant said: "With the ribbon I saw the small loops described by Duncan's expert, the small fluidity" (W2P1). A quality of movement that the participants also linked to the fluidity is the ripple of the body, meaning the way the movement circulates through each body part. The participants also thought that the ribbon model is relevant to transmit such a quality of movement: "[Talking about why they like the ribbon] I think it's the elasticity, we really see the ripple" (W2P5). Another participant said: "I took note of nuance of articulations but it's also the ripple effect, circulation of the movement between the top and bottom of the body" (W2P4).

On abstract visualization. All the dancers reported on how the model was particularly suitable for a dance like Isadora Duncan's where the focus is not on the body per se, or specific postures or movements to perform, but rather on the movement qualities themselves. The abstraction of the ribbon allowed them to observe and embody such qualities instead of focusing on the form of the body. The dancers reported on how the ribbon better conveyed the properties of fluidity and undulation than a "normal avatar": "I have appreciated the choreography with the ribbon, maybe because the image of the ribbon is more poetic than an avatar, more aesthetic and because we can better see and with more precision the fluidity of the movements and motions" (W2P3).

They mentioned that the ribbon was smooth and nice and "not aggressive" which invited to dance with it even more: "Spontaneously I find it really nice to see. It is really smooth and not aggressive. [...] The ribbon seduced me a lot" (W2P2).

On the use of augmented reality. While in the first workshop we could observe how the dancers were not able to follow the ribbon on screen, when using augmented reality, we saw them follow it,

replay it multiple times and play with its speed to learn different aspects of the dance from the model.

The device itself presented multiple challenges to the dancers as many had difficulties using the menu with air gestures. Additionally dancing with a headset was a completely new experience to them. *“There is still an adaptation time, to understand how it works”* (W2P3)

Because of the challenges and novelty of such a set-up, some dancers first observed the dance in the headset. They then marked the movement slowly with their body while following the ribbon in slow motion (they used the slow down feature in the interface to do so). Marking a movement in dance means executing it in a simplified, schematic or abstracted form. The dancers then progressively started performing it following the ribbon with the normal speed. One participant said: *“There is first a time of observation, then a rapid need to enter the dance”* (W2P2).

They reported on the need to get used to the technology in order to fully appreciate the dance: *“My visual perception wasn’t trained for that but I like to discover and acquire new skills”* said another participant (W2P4).

Despite the limitations of displaying the model on HoloLens, we could still observe how the dancers explored the features of the interface (mostly slowing down and stopping the ribbon) and embodied the dance with the ribbon. With the headset on their head, they performed the dance using a large part of the space of the studio and paying attention to the qualities of fluidity, the wave and the initiation from the solar plexus.

6 DISCUSSION

6.1 What have become of our design principles?

The three main Duncanian principles that we delineated from our discussions with E.S. were the fluidity of the movement, the solar plexus as a center of energy and the wave-like propagation of the movement. Our co-design consisted in multiple conversations with the expert Duncanian dancer in order for her to assess how the prototypes that we produced embodied fluidity and wave-like movement that initiated from a place that could be perceived as a solar plexus. In the workshops where professional dancers experimented with our graphical models, we found that they strongly perceived the ripple starting from a center that was seen as a solar plexus and circulating towards the extremities of the star like ribbons. Moreover, they expressed how the ribbons embodied qualities of fluidity, naturalness, undulation, propagation, elasticity and continuous movement that are central to Isadora Duncan’s repertoire. These rich perceptions of the ribbon supported their embodiment of the Duncanian dances. Our model was seen as an expressive re-enactment of Duncan’s dance that made them reflect on the specifics of this vocabulary either by praising its qualitative capacities or by critiquing how it ignored an important aspect such as “ground support through the feet on the floor”. Moreover, they saw its abstraction as ‘interesting’ and allowing to focus on the “essence” of the Duncanian movement rather than the form of the body, which is irrelevant in Duncan’s repertoire. The richness in the perceptions of the movement were possible because of the elaborate physical model that we computed. This echoes Fdili Alaoui et al. [17] that showed the potential of physical models to express

movement qualities in dance. It was also possible because of the methodology that we used centred on the connoisseurship of Elisabeth Schwartz and where we explicitly iterated on our choices according to her feedback which helped us to design a model that conveys faithfully Duncan’s movement qualities.

6.2 Simple interactions and complex perceptions

Our system (the ribbon model viewed in augmented reality) provided simple interactions such as slowing down or accelerating the model. Through these interactions, the dancers were able to play with the system in order to observe the ribbon in the speed that they wanted. They started by slowing the ribbon down and observing it while marking the movement. As shown by Kirsh[27], marking movement in dance (to execute a dance phrase in a simplified, schematic or abstracted form) allows dancers to think with their body and facilitates their real-time reflection on the dance. We were able to observe how the dancers used the system to mark the dance phrase prior to performing it fully which supported how they embodied and memorized it. The dancers also moved in space with the HoloLens headsets to observe the ribbon from the perspectives that they wanted. This allowed them to adjust the conditions to follow the ribbon and observe details that were not accessible to them. Nevertheless, our results illustrated the tensions that come from using a device such as HoloLens in a context such as dance. Indeed the headset provided an opportunity to see the dance in a novel and insightful way through the visual ribbon displayed. However, it also limited the embodied experience of the dancers, as they had to move carefully within the space allowed by the interaction and at times shift their focus outwards to perform the mid-air gestures that control the menu.

A limitation of our system is that it does not provide elaborate interaction scenarios where the ribbon could for example respond to the participants’ movements or deform according to their movement qualities. Indeed our physical model is currently difficult to compute in real-time. Making it interactive in real-time would require to compromise precision and thus to represent somehow less faithfully the fluidity of the dance. The question is thus: how much would such extended interaction capacities (with a less expressive physical model) contribute to the participants’ embodied understanding of the dance?

Another limitation of our system is that it requires motion capture data captured with sophisticated costly equipment. In future works, we would like to adapt the model to fit skeletal data captured through simpler settings such as Kinect or computer webcams.

6.3 Valuing embodied knowledge above all

We describe the co-design of an abstract visualization of dance movement qualities based on the collaboration with a connoisseur dancer of Isadora Duncan’s repertoire. We value in this work the extensive and precious input from E.S.. More than simple input, E.S. was one of the initiators of the project and co-author of the paper. She was curious of how technology could carry information on dance and how computer graphics have the capabilities to represent the qualities of Isadora Duncan. Her knowledge of the dance, both theoretical and embodied, was built over 40 years of learning this

repertoire and transmitting it to other dance artists. She dedicated all her career to building an intimate understanding of Isadora Duncan's repertoire. She used her knowledge in accompanying every step of the project, from infusing ideas on possible designs, to giving feedback on the models, to demonstrating the movement when necessary to translate its qualities to non-dancers. We believe that such collaboration putting at the center the expertise of a connoisseur is fundamental in the design of technologies to support dance and kinesthetic creativity. Moreover, we value approaches of dance that dig into specific vocabularies in a deep and committed way, avoiding the universality of generic and all-encompassing dance languages. The diversity of styles and choreographic approaches in dance is an endless source of embodied knowledge that HCI researchers have started digging into [10].

Our work does not seek to provide standard generalizable and universal models of dance movement. Instead it contributes with a model specifically tailored for the work that we spent a long time learning and dissecting.

6.4 Transmitting a vocabulary to safeguard a human heritage

Our experimentations allowed both the researchers and the dancers to deepen their knowledge of a dance style that is in danger of extinction. Indeed, the experimentations were situations of building and circulating an embodied knowledge about Isadora Duncan's work. In our co-design, we cared that both researchers and dancers engaged physically with the material and performed the pieces with their own body to better articulate what the Duncanian style meant for them. The researchers used that knowledge to reflect on the ribbons' design. The dancers used that knowledge to enrich their palette of embodied capabilities with a dance style that they had no previous opportunities to learn nor to perform. Thus, we consider our experimentations as attempts to make Isadora Duncan's heritage alive again, in the studio. The transmission sessions with E.S., mediated by technology gave the dancers an embodied experience of an archive that so far is stored only in the embodied memory of the expert Duncanian dancers that remain. Therefore, our contribution could also be seen as building a living archive of a repertoire that was almost dead but that is fundamental to what has become today's modern and contemporary dance, with its freedom and poetry.

7 CONCLUSION

In this paper we presented a ribbon model for visualizing dance motion, with the special goal of transmitting important principles in Isadora Duncan's dance heritage. Our model was co-designed with a Duncan connoisseur, and experimentally explored through 2 workshops with professional dancers. Our results show how the model displayed in an augmented reality headset faithfully represents Duncan's qualities of fluidity and undulation and supports dancers in embodying the Duncanian repertoire.

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