Computational Aesthetics in Graphics, Visualization, and Imaging (2008)
P. Brown, D. W. Cunningham, V. Interrante, and J. McCormack (Editors)

Expressive Trajectories

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Abstract

This paper presents Expressive Trajectories, *a project for Interactive Digital Art and Contemporary Dance. The project has two main components: X-Motion, a real-time interactive system for live performances; and Choreographisms, an interface abstraction for graphical interpretation of motion-paths. This framework is demonstrated through an experiment that includes a choreography of the artist–collaborator for the piece Unsquare Dance.*

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications

1. Introduction

In recent years, the use of multimedia resources, such as live projection and dynamic lighting, has been increasingly exploited in music shows, dance presentations and art performances [Bul06, Mae04, DWC*01, Min84]. However, up to now, these powerful visual sources have been applied mostly as an additional element to the set background, thus transforming it into a visually dynamic stage [Sch93, SMC94].

The above context motivated us to develop a multidisciplinary project that aims to combine techniques from Computer Graphics, Vision and Animation with applications in Contemporary Dance, Stage Design and Art.Our goal in this project is to push forward the state-of-the-art by calling into the scene real-time interaction and vision techniques. In this way, by integrating motion capture with procedural graphics and live displays, we expand the creative possibilities enabling graphical elements to be used, not just as a mere passive set element, but primarily as an active one – a virtual agent capable of interacting with other actors in the scene under the guidance of the director-choreographer.

For that goal, we created the X–Motion system which enables the design of a virtual dynamic stage that is linked to the dance. The system uses movements of dancers as an input for the generation of graphisms that are projected on the set in real-time. Through the system, the choreographer directs not only the dancers' movements, but also graphical elements that are projected onto the set, which becomes dynamic and interactive. Thus, these graphisms act as virtual dancers, establishing a partnership and dialogue with real dancers mediated by the choreographer. They can be modified by actions of the dancers, instigating changes to the dancers' movements as well.

The system captures the motion of markers on the dancers' body to generate trajectories that are represented as curves parametrized in time. Authoring is based on graphical interpretation of movement, thus establishing an association of motion-paths with visual forms. These motion-paths are coupled with procedural methods which transform them into (re)active shapes. Expressive visual elements are programmed by the director-choreographer using an abstraction that we call *choreographisms*. This interface defines the syntactic and semantic graphical rules to be applied to motion paths during a live performance.

An experiment to evaluate the project was conducted with a renowned dancer/choreographer . She is a pioneer on dance-technology and also a specialist on the Laban method. She made use of the system to develop an artistic work called *Unsquare Dance*.

The rest of the paper is structured as follows. In Section 2 we describe the X-Motion system and its architecture. In Section 3 we discuss the concepts used for graphics interpretation in the interface Choreographism. In Section 4 we show some results of the performance "Unsquare Dance". Finally, in Section 5 we conclude with remarks and hints of future directions.

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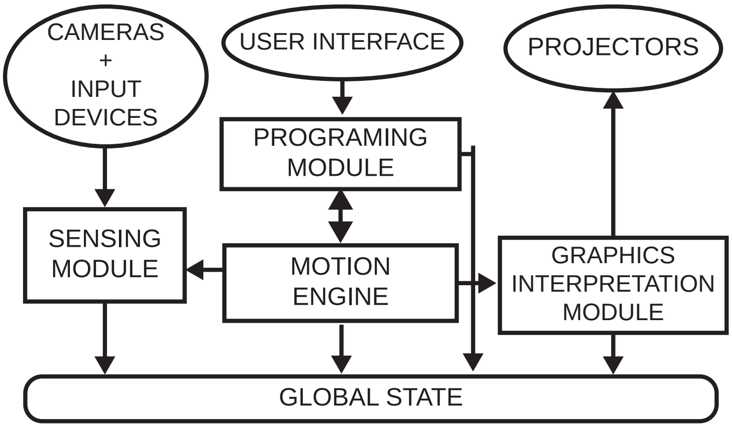


Figure 1: *X-Motion System Architecture.*

2. The X-Motion System

The X-Motion system analyzes a video stream of a dancer's performance and calculates the time-dependent positions of markers placed on the dancer's body. This data is then used as input to procedural rules that drive the interaction and the graphics output to be projected in real-time on a background screen.

The system architecture is composed of four modules: the *sensing module* which captures and analyzes the data coming from input devices; the *programming module* which manages the procedural library; the *motion engine* module which controls the interactive global state; and the *graphics interpreter* module which renders the results. An overview of the X-Motion System's architecture with its components is shown in Figure 1.

The system implements a finite state machine where a state is defined by a set of formal attributes that determines the appearance and behavior of the generated graphisms. Real-time interaction sets the machine in motion, scheduling procedural evolutions: i.e., changes through time, and possibilities of state alterations with transitions between them.

2.1. Sensing Module

The sensing module is responsible for real-time data input into the system. It performs primarily motion capture from the dancers and also acquisition of secondary signals from other devices.

The performer movements are captured using an infrared camera and retro-reflective markers that are attached to points on the performer's body.

First, the raw video is processed to extract the position of markers. This is done by subtracting the background from the captured frame and by thresholding the resulting image and computing the the center of mass of white blobs in the processed frame. See Figure 2.

input frame background processed frame

Figure 2: *Capturing Markers.*

Second, these markers are tracked through time using Kalman filtering to obtain point trajectories [WB95]. Finally, bicubic spline interpolation method is used to define time-dependent curves. The system calculates attributes of these motion paths, such as velocity, acceleration, etc. Figure 3 depicts a diagram of the sensing module.

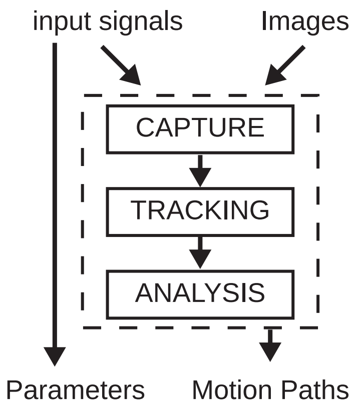


Figure 3: *Sensing Module.*

2.2. Motion Engine

The motion engine is the core of the system. It embodies a Finite State Machine (FSM) that controls the real-time interaction and the global state. The engine is composed by a scheduler, an event processor and a state transition manager.

The FSM is defined by states and transitions between these states. Each state is characterized by a drawing behavior associated with motion paths (i.e. we can define a state which draws a circle at several locations along the path, and we could define for this state that the circle radius will vary with the path curvature).

The scheduler implements the system's clock and activates all the other modules. It keeps track of the sequence of tasks to be executed by the system in real time.

Transitions will let the system change from one state to another. To define a transition we need to set the source and target state as well as the event that will trigger the transition. Events could be of different types: curve events, keyboard, mouse, midi, etc... The system analyzes the possible transitions for the current state and when a transition event occurs the system changes the drawing behavior.

A diagram of the Motion Engine is shown in the bottom part of Figure 4.

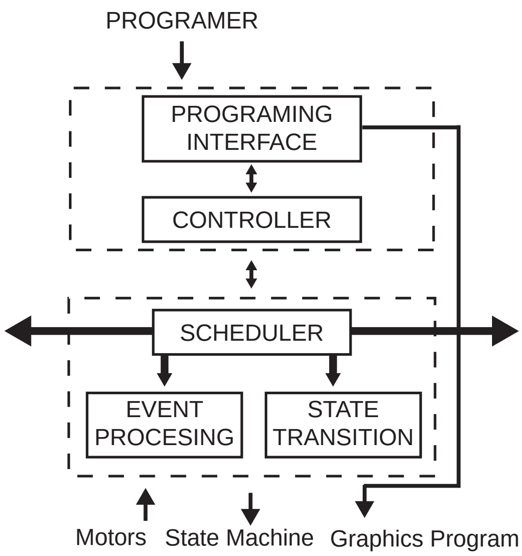


Figure 4: *Motion Engine and Programming Module.*

The programming module is the main interface of the system with the choreographer. It allows the development of motion behaviors to be used in the graphics procedures and the authoring of visual scores to match a dance choreography. A diagram of the programming module is shown in the top part of Figure 4. The module has a programming interface for input of scripts and definition of parameters. The interface also allows a preview of graphic effects and behaviors. The programming interface is used in the planning stage of a performance. There is also a controller unit that manages the system during a live performance.

2.3. Graphics Interpretation Module

The graphics interpretation module is responsible for the visual output of the system. It executes the graphics programs associated with a determined state of the visual score and generates the dynamic shapes associated with motion paths. Rendering is done using OpenGL and GPU primitives.

Figure 5 depicts a diagram of the graphics interpretation module.

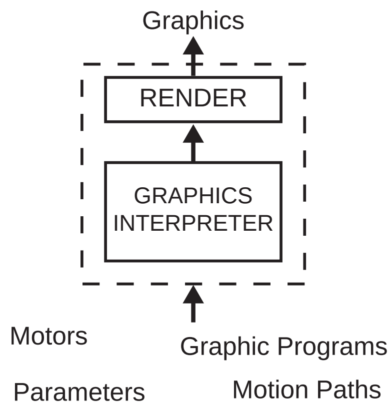


Figure 5: *Graphics Interpretation Module.*

3. Choreographisms

Choreographisms is the conceptual abstraction used to develop visual scores for the X-Motion system. It defines the generative rules that transform a motion path into an active dynamic shape. In a sense, a choreographism is the grammar for visual interpretation of an interactive dance piece. This grammar is embedded into the FSM of the system that applies graphical embodiment procedures to motion captured from the dancers. See Figure 6.

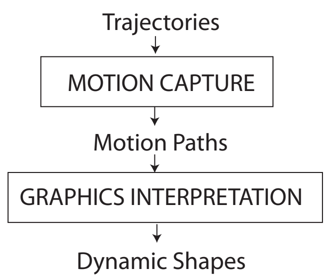


Figure 6: *Generation of Dynamic Shapes.*

3.1. Motion Paths

Motion paths correspond to point trajectories of markers tracked at the performer's body by the X-Motion sensing module. They are represented as 2D curves, $f : \mathbb{R}_+ \to \mathbb{R}^2$, parametrized in time. Thus, the location (x,y) of a marker in camera space at time t is given by $(x,y) = f(t)$. The first and second derivatives f' and f'' give respectively the velocity and acceleration of the trajectory. See Figure 7.

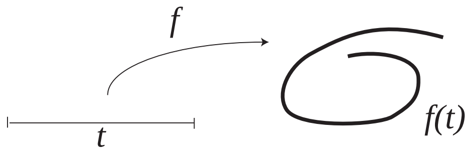


Figure 7: *Motion Path.*

On the other hand, the motion path can be reparametrized by arc length and can be seen as a regular spatial curve in screen space. This setting allows the computation of normal, curvature and other geometric properties.

In this way, trajectories of tracked points become the system's central mathematical abstraction. They embody the essence of spatial-temporal aspects of the movement.

3.2. Dynamic Shapes

A dynamic shape is the result of applying a choreographism to a motion path.

The rules of a choreographism can be classified according to three distinct dimensions: spatial, temporal and behavioral structure. Each dimension is related to qualitative characteristics of the dynamic shape that are manipulated as part of the authoring process. These characteristics are summarized in the table below:

- Spatial Structure
  - Brush Type
  - Curve Granularity
- Temporal Structure
  - Synchronicity
  - Persistence
- Behavior
  - Mapping
  - Animation

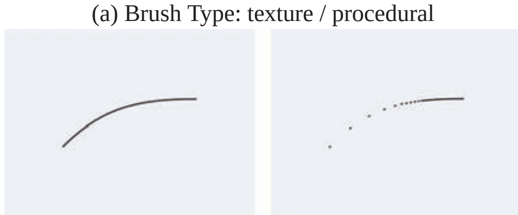
The spatial structure determines the shape formal parameters, were the brush type can be *Geometric* (i.e, point, polygon, star, etc) or a *Texture* (i.e., image, procedure). The curve granularity can be *connected* or *disconnected*. Further control is included for smoothness of the curve and spacing of elements along the curve.

The temporal structure specifies the time-dependent aspects of the shape. The synchronicity establishes a temporal relation between the captured trajectory and its depiction, such as a delay and/or an expansion. It can be absolute or relative. The shape persistence controls the translation between the time and spatial parametrizations. It can make the shape appear as a moving point or as a curve, for example.

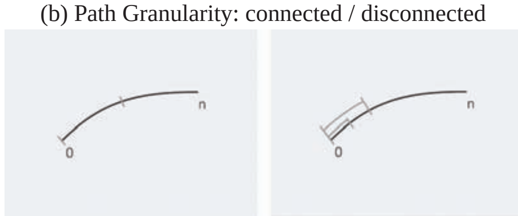
The behavior pattern defines the actions and reactions of the object. It includes a time-varying mapping, which can be a transformation (i.e., affine, warp, etc) or a projection, and animation functions, which could act locally or globally on the shape.

Some examples of dynamic shape characteristics are shown in Figure 8.

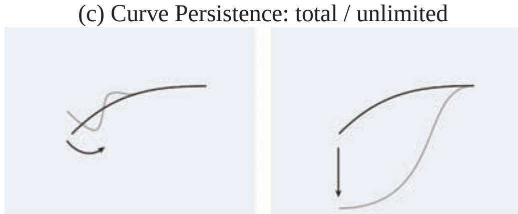
(a) Brush Type: texture / procedural



(b) Path Granularity: connected / disconnected



(c) Curve Persistence: total / unlimited



(d) Shape Behavior: local / global

Figure 8: *Examples of Dynamic Shape Characteristics.*

The choreographism authoring interface provides various resources for building dynamic shapes. For example: brushes can be constructed from basic forms, such as geometric primitives and texture samples; motion behaviors can be programmed using elements, such as motors, oscillators and control signals.

This repertoire of brushes and behaviors are stored in libraries in order to help the specification of visual scores by the director-choreographer.

Furthermore, dynamic shapes can be replicated by instancing very much in a object-oriented programming spirit, thus greatly enhancing the expressive power of the system.

3.3. Visual Scores

A visual score is the counterpart of a musical score and choreography in a dance piece.

The visual score consists of the definition of time-varying graphics states and transitions between these states. In that sense, a visual score is essentially a finite state machine that implements the interaction and visualization of expressive trajectories. Figure 9 illustrates this concept by an example of a finite state machine with three states and four transitions.

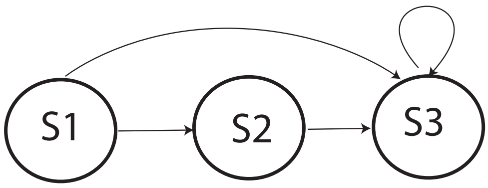


Figure 9: *Example of a Finite State Machine.*

Within a visual score, each graphics state is defined by rules for graphics interpretation of a choreographism, as discussed in the previous subsection. For example, Figure 10 shows instants of two different states of the visual score for Unsquare Dance. Note that the nature of graphics are quite distinct in each of them.

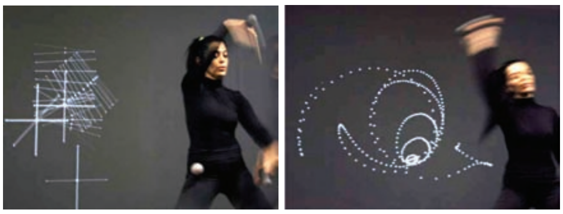


Figure 10: *Two different states of a choreographism.*

The transitions between graphics states are generated by events of the system. Events may be linked to variables such as motion path parameters, clock time, procedural animation objects (motors, oscillators, etc.), or even randomness.

A transition is specified by a logical expression of events, which is triggered when that condition becomes true. For example, if the clock time reaches 100 seconds or the trajectory velocity is greater than 10 cm/sec, i.e., the expression $(t = 100 \quad | \quad f'(t) > 10)$.

When defining a state, the director–choreographer is in fact programming the way the dancer can interact with the graphisms, since the shapes are dynamic within states and may depend on parameters controlled by the dancer. The dancer, on the other hand, also controls the sequencing of states through transitions that can be triggered by the dancer.

In sum, the visual score is a description of a non-linear graphical interactive narrative for a dance piece, where the space of possibilities is set by the director-choreographer and the realization is controlled by the performer.

4. Unsquare Dance

Unsquare Dance was an experiment to evaluate the Expressive Trajectories project. This experiment was realized during December of 2007 at IMPA and included a series of dance performances based on a choreography created by the artist Analivia Cordeiro. The title of the work comes from the music "Unsquare Dance" by Dave Brubeck. The piece consists of a live performance by Analivia in a dynamic stage made by projected computer graphics elements.

4.1. The Experiment

The experiment used a stage assembled at our laboratory. The physical space was the Lab's studio for computational photography and video, which has dimensions of $8m \times 12m \times 4m$ approximately. For the performance, we built a backdrop screen of $6m \times 2.5m$ and used a DLP projector, fluorescent lighting, an infrared camera for motion capture and two computers: one for data acquisition and the other for rendering. The stage is shown in Figure 11.

The whole experience was recorded in a series of videos with different graphic interpretations. In each performance, the dance movements were exactly the same, but the choreographisms very distinct. in order to exploit the possibilities of the X-Motion system. Figure 12 shows a sequence of frames from one of the performances, revealing the evolution of a visual score by Analivia Cordeiro.

4.2. The Manifesto: *by Analivia Cordeiro*

– How did this work appear? Motion language broads any spatial change of the body, from delicate gestures to expansive, exalted ones, which cause strong impression. These spatial changes, apparently invisible, are captured through the eyes as ways to its capacity of visual persistence. This interpretation isn't new, since it comes from Ancient Times: the Greek defined dance as drawing in the space.

The exhibition of a movement trajectory is secular: male private dances, made with fire torchs, describe circles in the air, like, for example, the Polinese dance called Sivanofaoti. The study of the movement by its trajectory is more recent: it starts with photographic recording of light moving

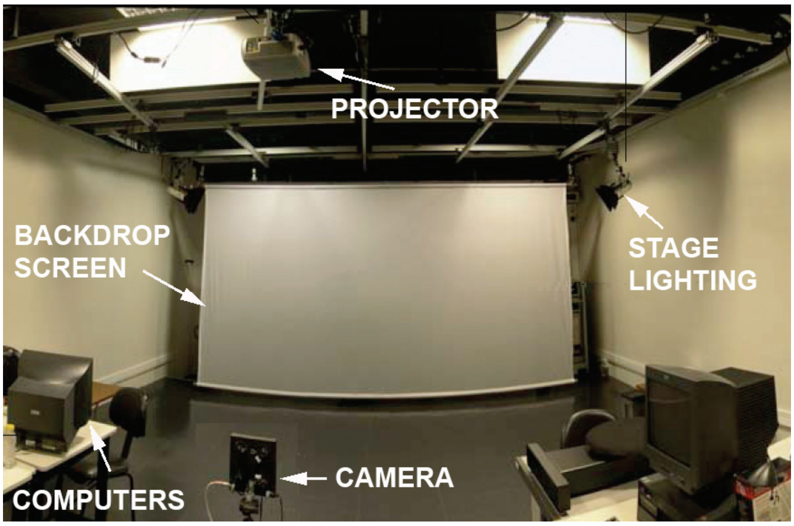


Figure 11: *Stage for the performance Unsquare Dance.*

in the dark. With the advent of computers, the capturing technology improved, and it made possible various analysis in time and space. There is a large body of research in this area, for example, we can cite the projects *Nota-Anna* [Cor06] which is based on the Laban method, *Still Dancing* [SMC94], among others.

The choreography for "Unsquare Dance" was born from observations of Analivia Cordeiro which originated from her practical–theoretical studies of human motion seen through electronic media. This line of investigation points to the need of giving texture to time curves described by motion paths in the computer. Such texture could give visual meaning to the musculature/weight relation.

The X-Motion system brought to life this dance piece. A characteristic of the software is to create different visualizations for the movement varying parameters such as: color, line types, stroke weight, and other effects that can be manipulated in real-time. The system gives infinite textures to lines, to be imaginated and defined by the artist, transmitting expression.

While the performer executes the movement, the choreographer interprets the motion giving it an artistic expression. Thus, the same performance can generate many visual results depending of the visual interpretation that creates active shapes with it. Therefore, X-Motion is foremost an aesthetic instrument. Unsquare dance was born from these principles.

The lines and shapes that the Unsquare Dance choreography produces are not abstract, they result from the body motion in real-time. They stimulate thinking about motion, an act made possible by the "sixth sense" of human beings. The cinesthesic, the one that tells us where each joint is located in our body and in space in each instant in time.

In this context, the following question can be posed: *would the spectator that watches a performance of Unsquare Dance be able to see the lines which describe the movement without the visual help of the computer?* Maybe not yet. Our eyes are not trained to look in such a way to someone that is moving. We pay attention in a person, to his/her expression, clothes and colors. But, who is conscious of the paths that each part of a moving body describe in space? Very few. Currently, these trajectories say little to the layman, however in the future they will tell a lot. This is the way to motion education in the future.

The motion capture of human joints and its trajectories in space induces a new kind of performance (be it in contemporary dance, sports, fights etc..). A novel way to learn, practice and create movements. This leads to a new look about performance, showing its essence, because it reveals pure motion, independently of physical aspects of the person moving, and at the same time, it characterizes very clearly the way each person moves.

This record of motion introduces with property, the performance in the digital world, but respecting the organicity of our body. The virtues and acrobatics, in the future, will be able to describe perfectly the plasticity of circles, straight lines and elaborate shapes. For this the body joints should be free and perfectly coordinated within the unity of the body. Which is a big challenge!

In general, the motion education is undergoing deep changes since the beginning of the twentieth century, seeking, particularly in the contemporary dance, to overcome the rigidity of the classical ballet. A lot has been done. Many techniques appeared with the purpose to reconquer the organicity of the natural motion of human beings. But, an effective instrument for motion evaluation that has surpassed the rules of ballet dos not exist yet [KSD52, Bou94].

An instrument for describing the execution of any movement of the body in space and time can point to flaws and locate them with precision in the specific body joint. This can lead to a new vision of movement.

The choreography Unsquare Dance is composed by natural movements, which are based on the passive release that uses the impulse of the springs generated by the musculature / force relation of gravity, maintaining the consciousness of the joints "open". It didn't look for references in ballet movements, modern dance or contemporary dance. The goal was to show the anthropomorphic of the generated trajectories, that can be easily observed on the rhythm, on the line's drawing and on the "organic" geometry generated by the movement of the markers placed on body joints.

The expression of the movement is exactly located on the relationship between the mathematical form of a line and its execution by the body: *How round is a circle?* In which instant of its realization does it curves? There is an expression of movement. Individual expression: if another dancer performs the same dance, the trajectory is going to be similar, but not equal. The difference is the expression.

In the same manner if two choreographers, using the X-Motion system, create visual effects for the same dance, the results would be diverse. Considering the dual of creators performer / choreographer, the performance of the body imprints (i.e. stamps, marks) the final work. It is a new body-art, placed between the electronic environment – instead of ink over canvas as a traditional form of body-art.

Why body-art? First of all because without a body it doesn't exist, it is the essence. Second of all, what can be seen is a trail made by the body; the impression of the body; and not the own body. Third, is the unit performer / choreographer that generates the work. Directly. The result is function of body performance. Infinite art pieces can be created. Everything depends on how many performers and choreographers are acting.

One characteristic is significant: the possibilities offered by the X-Motion system suggest an imaginative flexibility for the choreographer (as well as for the performer), because they allow the creation of visual effects in a direct, simple way. It activates imagination and genuine creativity, "creativity from the start". It means: who uses the system defines which, when and how the visual elements will be depicted. It opens a true new universe.

5. Conclusions

In this paper we introduced a framework for live performance in interactive digital art and contemporary dance. The project Expressive Trajectories builds upon real-time capture of motion paths and is implemented by through the X-Motion system and the authoring interface Choreographisms.

Future work includes research of advanced capabilities for graphics interpretation, three dimensional morion capture and a more complete investigation of interaction mechanisms with extension of the system to a distributed environment composed of multiple stages, cameras, projectors and computers.

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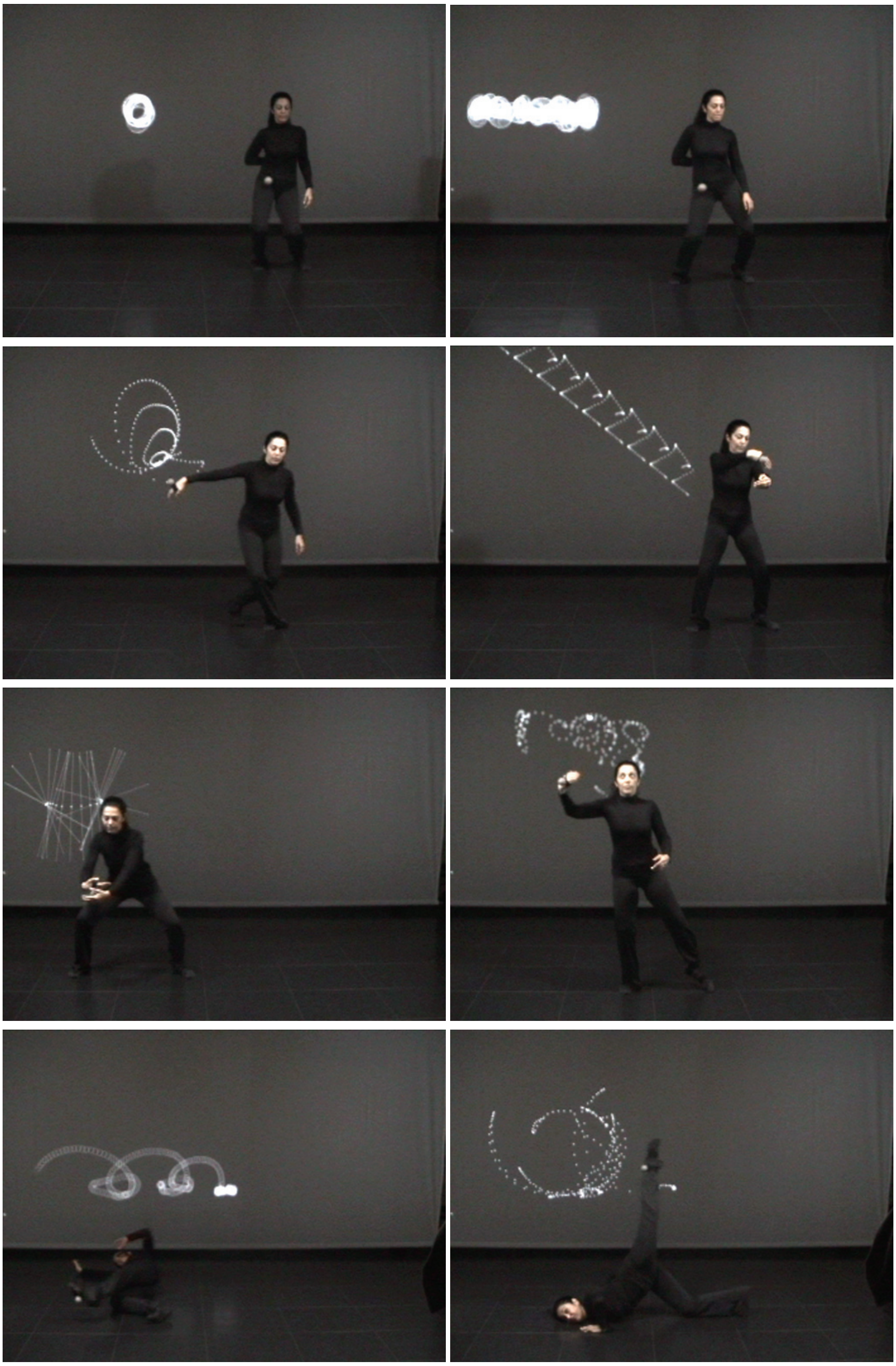

Figure 12: *Dance Performance.*