Physically-based particle modeling for dance verbs

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Abstract

As quoting in the philosophy of free dance: «Understanding the directions for a Free Dance performer stems mainly from the qualities and energy of the movement rather from spatial criteria», we advocate that dance movement is not only to perform a desired motion but also to feel and to transmit "sensation (expression)" by body and energy. Dynamic models are particularly adequate for this objective. They generate the dance movements exhibiting energetic consistency as underlain by the philosophy of free dance. By designing its own dynamic model, the user has a high-level motion control to modify the quality of such dynamically generated movement, for example: light, heavy, stressed, sudden, sustained, etc. These dynamic models are hence well suited to produce spontaneous motion that looks natural and plausible. In this paper, we present a set of dynamic models based on physical-particle modeling. We started from a selection of typical verbs of dance representing relevant basic dance actions: "to sway", "to squat down", "to develop", "to walk", "to turn", "to half turn step over step". For each of them, we designed the simplest physically-based particle model. By combining such basic models, we show that it is possible to design less elementary dance figures as "salsa" and "waltz".

Keywords: *Physically based particle modeling, dance verbs.*

1 INTRODUCTION

The famous dancer Isadora DUNCAN once said that: «I was seeking and finally discovered the central spring of all movement, the crater of motor power…» *(1928, my life of Isadora Duncan)* For most dancers, there must be a cause or a central spring, which may be a change of the center of gravity or a loss of balance, to provoke all the movements. Inspired by this concept that is probably one of the most important concepts of the contemporary dance, our approach focuses on generating dance movements by energy transmission and keeps respecting the dynamic during all the process.

For a beginner, emulation "watch, copy and learn", is generally a way to learn dance. What to emulate here concerns always an explicit movement. For an intermediate dancer, the dance teacher could induce in order the movement by verbs of dance. Furthermore, a choreographer may progressively guide a well-developed dancer by some implicit concepts including imagination or some laws of nature. In this step, there is no more necessarily having an explicit movement; the dance movement is spontaneously provoked by a cause instead.

On account of this, our approach proposes dynamic models generating dance movements by physically-based particle modeling. Dynamic models emphasize more the way to generate dance movements than to reproduce a predefined movement. Among them, physically-based particle approach allows to focus on the transmission of energy, from a motor locus to other body segments. It allows to model and simulate in a modular manner, step-by-step and point-to-point, the dynamics of dance motions. By changing the motor locus, the way of energy transmission or the character's physical structure, the masses and their connectivity, we could have a block / soft, light / strong motion.

The work presented in this paper starts from a selection of verbs that represent basic dance motions, as defined in several dance and movement vocabulary [1]: "to sway", "to squat down", "to develop", "to walk", "to turn" and "to half turn step over step". We present minimal physically-based particle model we have designed for each of them. By combining these elementary models, we obtained more complex dance figures as "salsa" and "waltz".

2 RELATED WORK

In the survey of Multon [2], the applied techniques for generating character motion have been loosely classified as being kinematics, dynamics, and motion data based.

Motion data based animation can provide many nuances in the movement, and it is helpful for movement understanding and motion training [3]. However, it will be labouredly, costly to modify the data, and we should always have a predefined motion, that it is less suited for computer-aided choreography.

Key-framing with interpolation allows specifying explicitly the animation. Broadly speaking, key-framing is the most intuitive way to create the desired motions. For example, Sturman [4] proposed to control the motion of 3D articulated figures by specifying the joint angle over time. The powerful advantages of key-framing were spelled out by Lasseter [5]. However, as expressed in [6], the key-framing technique depends strongly on the animator's talent in order to get the desired motion. It leads to a labor-intensive method to cross the big gap of: how does an animator specify the amount of key poses to achieve a desired motion?

Several researches [7, 8] proposed to combine animation and the contemporary well-known Laban dance notation [9, 10]. More recently, another dance notation, the Benesh notation [11], has been use to represent ballet choreography [12, 13]. With the help of dance notation, the animator could focus on the important gestures more easily. Confronted to the difficulty of synthesizing dance motions whether with the symbolic Benesh notation system, or with the Laban description of body structure at specific time, several approaches focused on adding expressions to the key-framing based motion [14, 15]. Chi et al. [14] proposed the EMOTE model giving a well combination between key-pose and the Effort-Shape theory of Laban [16] to generate more natural synthetic gestures. Rose et al. [15] proposed methods of multidimensional motion interpolation.

However, these approaches are kinematical based, leading to the modeling of a predefined motion. Thus, such method may not be considered to assist a choreographer to design and create dance motion as with the usual high level metaphoric way: "be as a leaf fall to the floor" or "be as an apple fall to Newton", that focus more on the style of the motion or on the metaphoric conditions to create it than describing explicitly the motion itself. Therefore, Witkin and Kass [17] proposed space-time constraints for motion control by specifying what to do (from here to there) and how to do, without specifying the explicit motion trajectory.

Instead of the kinematics methods, dynamics approaches are able to generate realistic or plausible motions automatically. They belong to "generative models", in which the motion is not explicitly defined in itself but produced by an above model. Such approaches, as physical simulation, are generally considered as having drastic limitations. Beside the difficulties to design a new model and the high computing cost, the most important is the difficulty the user has in specifying precisely an expected motion and to control it. Conversely, these approaches allow producing various plausible and expressive motions, exhibiting complex evolutions and changing, from a few numbers of high-level parameters.

The constraint based method, developed by Barzel and Barr [18], aims to overcome the weakness of control, inherent to dynamic modeling. Constraint forces methods belong to an inverse dynamic research to find out a set of "constraint forces" to confine the motion. These methods allow following predefined key-framed trajectories.

Van de Panne [19, 20] used proportional-derivative (PD) controllers that are functionally equivalent to a spring and damper, to determine the internal forces and torques. In this work, a dynamic behavior motion is generated without an explicitly spatial motion trajectory. In [21], he synthesizes bipedal locomotion from a set of footprints by a global optimization of the center-of-mass trajectory. The concept of this optimization is to maximize the physical plausibility and to generate a comfortable motion. The cost of plausible simulation is less than in a real dynamic simulation. Moreover, it is a well-suited motion control because animator does not need to design laboriously the explicit motion of whole character. One has only to specify the precise footprints.

Another types of "generative methods" are those based on artificial intelligence. Sims [22] uses genetic algorithms by computing the evolution of the artificial creatures producing nice and suitable live-like locomotion. Gritez and Hahn [23] use genetic programming to generate automatically the character motion.

Generative models raise always the question of how to guarantee the resulting planned motion. However, they are a high-level motion design approaches, able to produce various and rich motions. Among them, physically-based models have the strength to model the energetic consistency of the system that produce motion, engraving in the motions themselves an inner energetic coherence, even in case of non-planned events, as collisions, fractures, sticking, meetings, etc.

Among physically-based models, physically-based particle systems allow to design a wide variety of physical phenomena, as shown by Greenspan [24]. They have the property to be designed by a non-scientist user, as illustrated by the Sodaplay Toy system [25]. Above all, their main underexploited property is to underlie a "modular design", allowing to design models "step by step", or "point to point", as shown in [26]. All the models are compatible, able to be mixed in order to build composed complex models. Thus, it combines in an elegant way the energetic consistency and the modularity in designing complex systems.

These are main properties needed to model complex and subtle features of free dance dynamic patterns. Another fair property is to be conceptually adapted to resume "the just necessary masses and interaction ways" from every type of models, as this paper will illustrate in the case of dance motion modeling, with a very few number of interacting "masses", that represent whether materials or functional components.

2.1 Concepts of free dance

The free dance was inspired from Isadora DUNCAN, and was inherited by Malkovsky. According to the fundamental basic movements of Malkovsky [27, 28], we found out some key points to observe the gesture quality of free dance style. The free dance bears mainly from the qualities and energy of movement rather than from spatial criteria. It seemingly implicates a relation to generate the free dance movement by physically based animation. Here we extract some thoughts of free dance classified by Bodak [27]:

- Principle of causality: The first principle is that each transfer is motivated by a shift of the gravity center. Namely, each step was propelled by the oscillation of the gravity center.
- Pattern of uniqueness along the movement: The process of dance has a single common formula: "trigger-let go-relax-new balance". When an almost imperceptible loss of balance occurs, then it propagates through the trunk and so that a movement is provoked. Moreover, the body movement also triggers the arm movement.
- Pattern of alternating laterality: Since the step is trigged by the oscillation of gravity centre, the bust is oscillating symmetrically to balance the body, as in triggering the right shoulder motion by the left leg motion.
- Leg movements: Movements of the legs come only as the result of a loss of equilibrium, namely the consequence of a transfer of weight. Such movements are autonomous, without no conscious control or explicit aim.

2.2 The relation between physics and dance

Laws [29, 30, 31] focused on the physics of dance. He provided some interesting view of physics for observing a dance movement: center of gravity and balance, rotation and pirouette, jump and projection, friction and glissade, etc. Laws' analyses and some subjective points of view of dancers, lead to design the simplest dynamic representation of movements based on eigen mechanical functionalities that are just necessary to perform the movement, even if the performer is a complex biomechanical system.

3 THE PROPOSED METHOD

In this paper, in accordance with the philosophy of the free dance, the dynamic models are created according to the following procedure: (1) finding out the "motor locus" that trigger the selected motion; (2) generating the motions from the "motor"; (3) mapping a body shape on these motions.

3.1 The motor of the motion

For every selected verb of dance that represents a basic dance action, we will look for the minimum possible and physically consistent plausible cause – called "motor" - that triggers the movement of this verb. Applying a triggering procedure, then, we could produce all the evolutions of the positional data, namely the trajectories of movement. This "motor" is the origin of dancing movement. The process to find out such motor for every dance verb is not always easy, neither for a dancer nor for a researcher. It is an implicit feature nested in each performed dance motion that has to be elicited firstly.

According to the "principle of causality", a light transfer of weight is sufficient to bring the steps alive. In other words, the oscillation of the centre of mass involves the steps. Thus, the basin, i.e. the mass center, can be thought as the inner motor for many dance actions. In some other cases, especially for the locomotion, the force coming from the ground through the feet originates the displacement of mass center. That is why the locomotion is triggered only from the physical contact of the feet with the floor. Because of this, the foot-take-off could also be understood as an external and mobile motor.

These two types of motor: one being an "*inner motor*", the other being an "*external motor*", can be considered as the two main typical and complementary sources of motion. In the following, we will present different dynamic models of dance verbs classified according to these two types. Section 4 describes the dynamic models that are provoked by the basin as an inner motor. In Section 5, we develop the foot-take-off as an external motor.

Once the motors have been modeled, their force will trigger the motion of the other parts of the body, and will generate the natural movement automatically. That is exactly in accordance with the concept of contemporary free dance.

3.2 The deployment of the motion

The process by which motors provoke the whole motion is as mysterious as beautiful. Dancers exercise their body everyday in the aim to discover and rehearse how the motion of the whole is duly deployed from the motor locus. We identified two basic complementary processes: the "*inner propagation*" and the "*virtual momentum exchange*", on which we based all the following models presented in this paper.

Let us imagine a spine moving slowly as fluid wave motion. It exhibits an "*inner propagation*" from basin to head. "*Inner propagation*" does not only exist within the real material bones and muscles. It is what the skill of a dancer is able to get to the kinesthetic and visual feelings. A good example is the mimic of soft elastic flying with rigid articulated arms. We can model such "*inner propagation*" with mass-spring-damper force.

3.3 The transfer of energy

Another typical situation is when movement stops suddenly, without any material apparent reason and restart surprisingly. That is the case when skilled actors mimic the presence of an imaginary wall with their hands. All seems as there is a perfect momentum exchange between the real body of the dancer and the non-real object, evoked by the mimics. We call this phenomenon, a "*virtual momentum exchange*" and it can be modeled as a collision during which there is a complete motion quantity exchange from one body (that can be real) to the other (that can be imaginary). It is the skill of the dancer to render believable the reality of this perfect momentum exchange between a real body and an imaginary one. We can say "*Imaginary physically consistent*" action.

To sum up, the approach here is not to model the effective material body, but to design a physically-based model of all what can be the interiorized possible causes of the dance motions as they are felt by the dancer and by the watcher.

3.4 Expressive visualization of motion

Usually, animators design firstly a 3D model that will be animated by changing (translation and rotation) its coordinates. Because the motion is more important in our approach than the morphological features of the moving object, we will focus firstly on the motion itself with the triggering and deploying motion process and its physical consistency, rather than on 3D shapes. Thus, the methodology is to coat the motion produced by physical particles in another stage of modeling. This coating may be simple, as in motion-capture philosophy, for which motions sensed by markers are applied directly on several morphologies. It could be understood in a more general way as a clothing of a point-based skeleton. Such understanding leads to more changeability and more continuity of the form. Figure 1 illustrates this process: on the left, the figure shows the point based skeleton; on the middle, it shows a specific cloth made by deformable like-spring patterns; on the right, it shows cloths as spline-like body contours. This process can be followed *ad libitum*, realistic as well as non-realistic clothing.

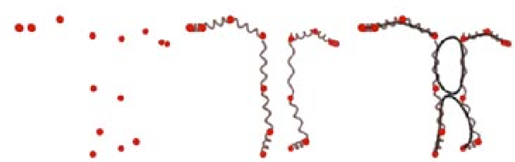


Figure1: *Expressive clothing for a point-based skeleton*

4 BASIN-TRIGGERED MOTIONS

For many dance verbs, the basin can normally be thought as a "motor". For instance, the base of hip-hop dance is actually a rhythmic movement focused on the hips. In the Latino dance, there are also many movements of rotating and twisting the hips. According to the view of free dance, we are interested in finding out how the basin motor triggers the body and the arm motions.

Some dance verbs that have the basin as motor are: (i) to sway, (ii) to squat down, (iii) to develop, (iv) to turn. In the following, we describe the simplest physically based particle model we designed for each of these verbs, having a very few number of interacting masses.

4.1 "To sway"

In "to sway" motion, a swaying movement is regularly repeated, like granting it with the rhythm of music. By observing the movement of hip, there are several types of trajectories of the hips, for example: rotation around a circle, twist around curve "8", swinging around "U", etc. The simplest physical-based particle model able to produce such type of motion is constituted of 2 masses linked with one spring. The parameters, masses M1 and M2, elasticity K, viscosity Z, the initial positions and velocity of masses, allow to control with a physical intuition the relevant phenomenological behaviors of such swaying motion. The pulsation, the phase and the amplitude of the oscillations of the sway depend respectively on the mass/spring ratio, the initial position and the initial velocity. Many of trajectories of hips motor can be thus obtained. Since the movement of the hip is defined, we can generate automatically the movements of the legs. Furthermore, by changing the strength of interactions between the motor (here the basin), and the driven parts (knees, legs and arms), we could obtain different qualities of motions.

4.2 "To squat down"

The movement "to squat down" leads to a transversal translation of the knee. How this translation is performed is decisive. Such translation is the result of simple physical actions combination: one is the relaxed descent of the basin under its weight and the other is the effect of an external force coming from the ground through the foot. These two forces push together the knee, so that it operates spontaneously a horizontal translation. It is of course what the dancer does without a conscious thinking of what the explicit movement of knee should be.

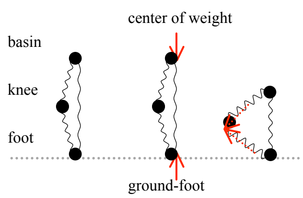


Figure 2: *Dynamic model of "to squat down"*

Such mechanism can be easily modeled with only three masses, one for the hip, one for the knee and one for the foot, linked by three viscous-elastic interactions between each of them (Figure 2). They defined a deformable planar triangle. As the mass of knee must undergo, the mass of the knee must be chosen the smallest. As the length of leg is fixed, the interactions knee-hip and knee-foot are chosen to have the largest stiffness parameter k (high rigidity). If the mass of the hip goes down, the mass of the knee will be pushed toward down and outside. Then, the force coming from the foot actuates the knee to be turned back to its rest position, in a static balance. We thus model well and in a simple way the action of folding.

4.3 "To develop"

The "to develop" movement is a very slow and continuous movement of unfolding an arm, obtained by pulling the motion of the elbow, that induces the motion of the others arm segments (wrist, hand, fingers). The motion along the arm is like a propagation of a sea wave from the elbow to the fingers. We modeled this motion with four masses, respectively for the shoulder, the elbow, the hand and the finger, linked with simple visco-elastic interactions. Figure 3 shows two snapshots of the simulation of such model corresponding to two types of "developing". Red spheres are masses of different values (represented by the radius of the spheres). Blue lines represent visco-elastic interactions. The visco-elastic interaction force can produce a jerky/bounded movement (Figure 3 on the left) or a soft/fluid movement (Figure 3 on the right), according to the values of masses (m) and of visco-elasticity (k, z) between the elbow, the hand, and the fingers.

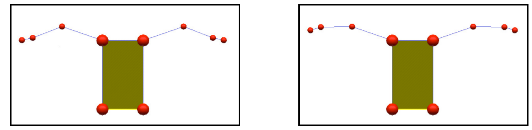


Figure 3: *Snapshots of the physically-based particle model of the verb "to develop". On the left, "rigid-like jerked propagation". On the right, "fluid-like soft propagation".*

4.4 "To turn"

"To turn" is an essential movement of dance and includes some styles of turn, for example "pirouette", "spin turn", "pivot turn", etc. "Pirouette" is a rotation where the dancer supports himself on one leg, while the other leg is in a retire position. "Spin turn" is a turn stepping on one foot and bringing both feet together during the turn. "Pivot turn" is a turn in place on a foot while the other is kept on the ball of the turning foot, etc.

"To turn" motion starts always with a transfer of the weight on one leg, followed by a torsion of the hip. For example, the right leg folds, followed by a transfer of the weight on the right. A small rotation of the basin relatively to the legs causes a force of torsion.

This movement gives the same impression as a helix motion. A simple dynamic model of "to turn", is composed of four masses, two for the two hips and two for the two feet, linked by six interactions, one per each pair of masses. After a little change in the initial positions of the masses representing the hip, a torsion force appears immediately between the hip and the feet, trying to return to the rest state. The snapshots of figure 4 show the results of the simulation of this model at four instants and illustrate the torsion motion between the basin and the feet.

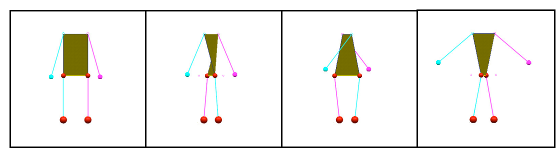


Figure 4: *Snapshots of four instant of the physically-based particle model for the verb "To turn". The two sides (right and left) are represented by two different color.*

If all the masses have equal values, the masses of the hip turn around the central axis. If the masses of one side are higher than the masses of the other, the axis of the turn is displaced on the heavy side.

Figure 5 presents snapshots of a film produce by the simulation of this model. The trajectories of the hands enable us to observe the variation of their velocities during the turn. The movements of the arms are completely triggered by the body.

Figure 5: *Snapshots of Pirouette" Movement"*

Figure 6 shows the same motion with another type of visualization as explained in paragraph "Expressive Visualization, of motion". It has been performed by clothing the motions produced by the previous physically-based model with the Maya software.

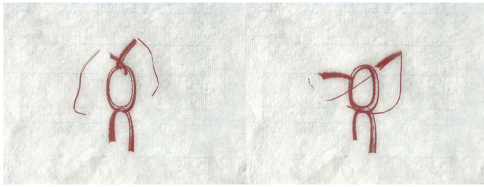


Figure 6: *An expressive visualization of "Pirouette".*

5 FEET-TRIGGERED MOTIONS

The majority of locomotion is concerned with a form of physical movement progressing from one place to another. It occurs not only as triggered by basin but also as moved by an external force that, in general, comes from ground-feet interaction. For this type of movement, we have to insist most on the stepping phenomenon, also called "pas" in dance. Usually, one starts learning dance with the learning of basic "dance steps", for example "cha-cha step", "waltz step", "pas de deux", etc. We will propose dynamic models for three basic dance steps: (i) walk, (ii) half turn step over step, (iii) swinging steps.

The common pattern that features all the step motions is the transfer of weight from one leg to other, provoking then the movement of body and arm by maintaining the equilibrium. Therefore, we can make an opposite (ex. the left leg involves the right arm) or same-side (the left leg involves the left arm) arm movement compared to the footstep.

5.1 One Foot locomotion model

In the direction of the displacement, when the foot stops, all it happens as if the foot looses its momentum in a similar way when it hits an imaginary medium and this medium returns the momentum back to the foot after a certain time (exactly after the period of the step), letting the foot to be propelled. Such process is what we called previously, "virtual momentum exchange", able to stop the motion and to restart it under an energy conservation condition.

We model such "virtual momentum exchange" by means of two identical masses (for example, one for the foot and one for the imaginary medium) linked with two conservative attractive and repulsive collisions. The attractive (resp. repulsive) collision is playing when the distance between the two masses are less than a threshold Da (resp. Dr). When thresholds are reached, there is a complete motion quantity transfer from one mass (from v1=v to v1=0) to the other (from v2=0 to v2=v).

The foot-mass is starting its motion by means of an initial velocity (Figure 7a). The initial distance between the foot-mass and the medium-mass is less than Da. Since Dr is reached, the foot-mass and the medium-mass are colliding (Figure 7b) by a conservative hit. The foot-mass stops and the medium-mass starts to move. Since Da is reached, the foot-mass starts to be attracted by the medium-mass (Figure 7c), receiving all the medium-mass momentum and the medium-mass stops.

By means of such pure momentum transfer, alternatively from (to) the foot-mass to (from) the medium-mass, this "virtual momentum exchange" is able to produce footprint that respects the physical consistency of the motion: the foot restarts with its last motion quantity, temporarily stored in the virtual medium that stops the motion. Such metaphor is also able to represent the idea that a dancer always keeps dancing even if he is staying, i.e. without motion.

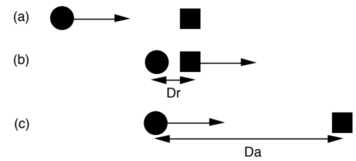


Figure 7: *Physically-based particle model of "virtual momentum transfer". The foot-mass is the circle and the medium-mass is the square.*

5.2 Two feet motion model: "to walk"

Walking is a typical locomotion among all the human motions. At a first glance, this movement is similar with the "sway" motion. Thus, it should be derived from the model of "to sway", if we connect arms and legs to the basin. The basin makes the swing movement regularly, and then, it makes oscillating the arms and the legs. With no other force than the driving force of the basin, this model produces a kind of slipping walk. This model presents the same problem "to slip" with "direct kinematics" for human walking. Such failure is due, not to the simplicity of the model, but to a conceptual bias: the driving forces have to come from feet and not from the basin.

Biomechanics [32, 33] describes walking as composed of "right foot swing", "left swing" and "double support". Such patterns can be modeled by improving our basic model of "one foot locomotion" described in the previous paragraph. We need three masses, one for each foot and one representing the imaginary medium able to stop and to restart the feet motion in the direction of the displacement. The two feet and the medium mass are linked as in the basic "foot motion model" developed in the previous paragraph by two attractive and repulsive purely conservative collisions.

The difference is that the medium-mass transfers alternatively its momentum to the left-foot and to the right-foot. This dissymmetry is easy to implement, with no other conditions, only by tuning the initial conditions of the feet. The two feet are initially at the same distance of medium-mass (less than Da) and one foot (the right foot on figure 8) has an initial velocity. When the right-foot is at Dr of medium-mass, it stops and the medium-mass starts to move (Figure 8b). The first mass that will be at Da of the medium-mass is the left-foot. Thus, the medium-mass stops and left-foot starts to move (Figure 8c). Thus, the medium-mass give alternatively its energy to the left-foot (figure 8c) and to the right-foot (Figure 8e) after having received its energy alternatively from the right-foot (figure 8b) and from the left-foot (figure 8d).

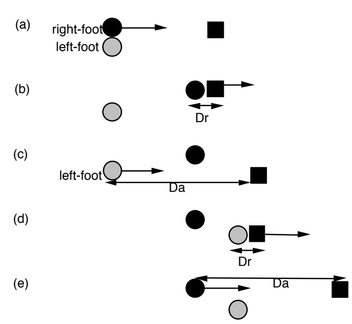
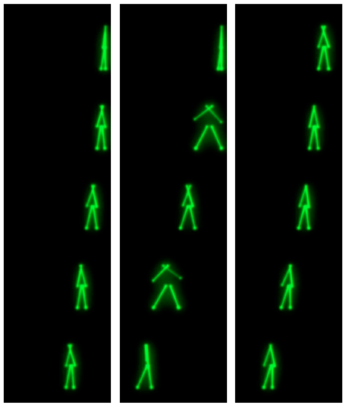


Figure 8: *Improvement of the physically-based particle model for the two feet walking. The right foot-mass is the black circle and the left foot-mass is the grey circle.*

By applying different values of the parameters for each foot (Da and Dr, initial velocity, initial positions), we obtained various types of walking: symmetric, non-symmetric, fast, slow, etc. The first film (figure 9a) shows the generation of a regular running. The second film (figure 9b) shows the generation of an asymmetrical walking. The third film (figure 9c) is a walk that is composed of two steps having different velocities.



(a) (b) (c)

Figure 9: *(a) Regular symmetric walking; (b)Asymmetric walking; (c) Composed walking of two different walking velocities.*

5.3 Half turns "step over step"

"Half turns step over step" is a movement composed of half-turns, successively inside and outward the face of the body, i.e. in the same rotation direction, that are carried out very quickly and in series, generally along a diagonal. Figure 10a shows the spatial trajectories of both feet for this movement.

Figure 10b shows the trajectory of one foot and indicates that, at each time, there is only one foot that is moving. We use here also, our basic model of "virtual momentum exchange". In this case, the motion is composed of two motions: "a walk" motion described before, along the displacement direction X and one half period oscillating motion along the Y direction, perpendicular to the displacement direction X.

The movement along the Y axis can be modeled by linking each foot-mass with a fixed ground at Y=0 by an one-dimensional elastic interaction, called SDy (spring-damper on Y direction) which produces a periodic sustained oscillation on the Y direction. By adding the momentum exchange with the medium-mass, as in the previous model of walking, the Y oscillation is stopped when the foot-mass collides with the medium-mass. The Y motion component of foot-mass is then composed of the positive Y part of the oscillation and by a stop while the medium-mass draws the negative Y part of the oscillation, as shown in Y(t) curves of figure 10c. By adding an initial velocity in the X direction, we obtain thus for the foot the deployment of this half-sinusoidal motion with the consistent momentum transfer from the foot-mass to the medium-mass during the stop, and from the medium-mass to the foot-mass during its motion.

As in the walking, the alternate motion of the two feet is obtained only by tuning the initial velocity V_i of the foot that starts the motion. In this case, this tuning has to guaranty that the foot will perform a half period on the Y direction before colliding the medium-mass. The initial velocity of the foot that initiates the motion is then:

$$V_{xi} = (Dx / Pi) * sqrt (k/m)$$
$$V_{yi} = (Pi / 2) * V_{xi}$$

Where Dx is the initial distance between the foot and the medium-mass.

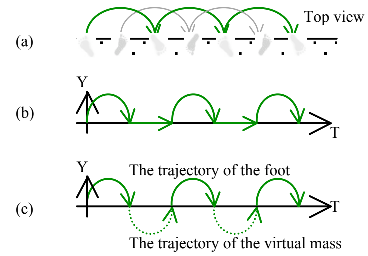


Figure 10: *(a) Spatial trajectory of feet; (b)Y-directional space and time of one foot; (c)Trajectory of virtual medium.*

As for the previous models, the advantage of this model is to exhibit coherent dynamic between the different phases of the motion (move and stop) and between the two feet, in a very simple physically-based particle model, composed only of three masses, a fixed point, two conservative collisions implementing a pure momentum conservation for the attractive as well as for the repulsive ones and an elastic one-dimensional interaction.

Figure 11 shows an expressive visualization of the simulation of "half turns step over step".

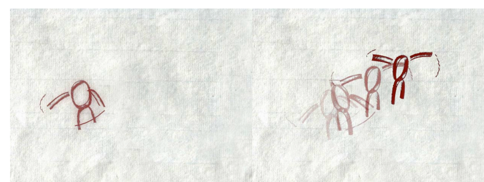


Figure 11: *Visualization of "half turns step over step".*

5.4 Swinging steps

Swinging steps is a movement in which right foot goes and triggers left foot; left foot comes back and then triggers back right foot (Figure 12a). The gravity center is usually transferred from one foot to another during every step. This movement is the basic footstep of a wide variety of dance from hip-hop to waltz (Figure 12b).

Such footsteps can be implemented simply with two masses, one for each foot, having independent oscillating motion on the X axis caused by the SDx (spring-damper on the X direction) interaction with a fixed point and linked with purely conservative attractive collision as those previously defined. This attractive collision implements a complete momentum transfer from each mass to the other according to a Da threshold. Let right foot starting the motion by means of an initial Vx velocity. It performs its own oscillation. As long as the distance between the two foot-masses is greater than Da, the right foot-mass completely transfers its momentum to the left foot-mass. Right foot-mass stops its motion, while left foot-mass starts its own oscillation. That is a simple physically-based particle model of the dance pattern illustrated in figure 12a.

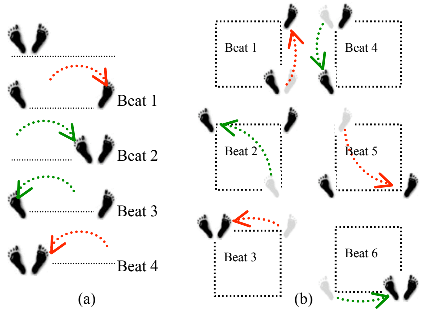


Figure 12: *(a) Swinging steps; (b) The primary waltz steps.*

By adding similar motion in the Y direction, we obtain the 2D waltz footsteps, as drawn in figure 12b.

6 COMPLEX DANCE FIGURES

In this paragraph, we will illustrate the modularity of such modeling approach, which allows to combine simple models to design more complex models and motions, without re-designing them.

6.1 « Salsa »

In the basic salsa movement (figure 13), the basin balances (to sway) and involves the swinging of the knees (to squat down) and of the shoulders.

We combine two models: “to sway” and “to squat down” by means of interacting forces and we implement a mass of basin relatively heavy comparing to the knee mass. The basin motion generated in “to sway” model is consequently a driving force furnishing kinetic energy into “to squat down” model. This means that the motor locus of the “to squat down” model comes from “to sway” model. All the movement follows thus the same rhythm.

Then, the movement of the arms is added to this motion without interaction between them (Figure 14 down). The movement of the arm is based on “to develop” motion (Figure 14 middle) that has its own motor locus and its rhythm, different from that of the "salsa movement" (Figure 14 up). This is an example of movement composition by the superposition of two dynamic models representing the movements of parts of the body.

Until now, we describe two possibilities of combining a complex dance figure. One is the interacting connection when the movement accords the same rhythm; the other is spatial adding without interaction that leads to different rhythms and different motors for the parts of body.

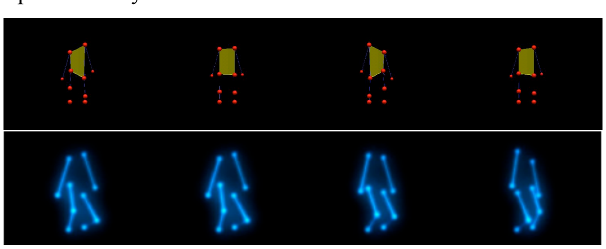


Figure 13: *Basic Salsa pattern obtained by combining two physically-based particle models of « to sway » and « to squat down ». On the down shows the film snapshots with rendering effect.*

Figure 14: *Salsa with arms*

6.2 Waltz

The basic footstep of waltz is derived from the « swing step », by developing it on a plane as shown is figure 12b. Figure 15 shows snapshots of film produced by this associated « swing model ». Snapshots correspond to the six basic beats that characterized the footstep of the Waltz, as drawn in figure 12b.

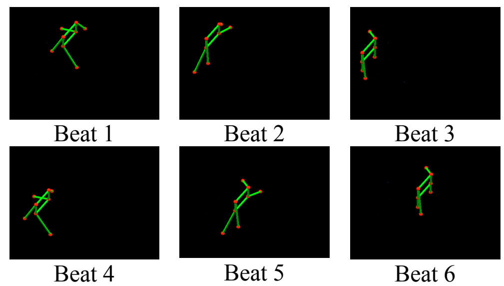


Figure 15: *Physically-based particle model of Waltz*

7 CONCLUSION

The physically based particle modeling allowed to generate the dance movements in an implicit way instead of defining explicit trajectories as in key-framing or kinematic-based approaches. The proposed method is well adapted to the philosophy of free dance, in which the movements of body parts are not explicitly dirigible in a prescriptive way but provoked by the dynamic status. Differently that approaches copying with the replication of the real body as in biomechanical modeling, such physically-based particle models lead to define physically-based metaphors as they are lived by the dancer and used by the dance teachers: motors of motion, propagation, external resistance, full momentum transfers, etc. It leads to a type of minimal model, producing the quality of the motion in a “natural way of performance and thinking”. In addition, these models allow to be combined in order to produce more complex dance motions. The future work would be to constitute a library of dance verbs models, and to progress composition methods of these models.

APPENDIX

Our physically-based particle system, called Cordis-Anima, is based on elementary components: inertial type (mass) and interaction type (force). The position of a mass is computed from a force input according to Newton’s second law. The interaction force is generated according to the position and velocity of the masses. Broadly speaking, there are three kinds of interaction forces: *Elastic-Damping*, *Collision-Damping* and *Attraction-Damping*. The driving force could be designed by defining the potential energy (initial position and stiffness parameter) or the kinetic energy (initial velocity and mass). More details are to be found in the paper [26].

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