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Grammar of Physically Based Modeling of Dance Movements: Use for Choreographic Composition

Chi-Min Hsieh

► **To cite this version:**

Chi-Min Hsieh. Grammar of Physically Based Modeling of Dance Movements: Use for Choreographic Composition. Musicology and performing arts. Institut National Polytechnique de Grenoble, 2007. English. NNT: . tel-01197407

HAL Id: tel-01197407

<https://hal.science/tel-01197407>

Submitted on 15 Sep 2015

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$$d^2q/d\tau^2 + 2\zeta(dq/d\tau) + q = e^{j\omega\tau}$$

$$q(\tau) = q_{\text{transient}}(\tau) + q_{\text{steady state}}(\tau)$$

$$\approx A(\zeta, \omega) * \cos(\omega\tau + \phi(\zeta, \omega))$$

$$\approx A e^{j(\omega\tau + \phi)}$$

Thinking

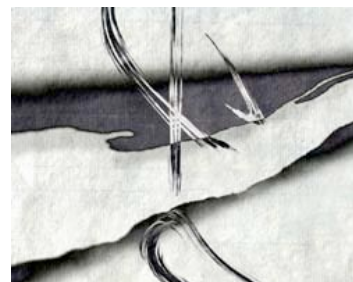
$$F_{1 \rightarrow 2} = -F_{2 \rightarrow 1} = k(\Omega_1 - \Omega_2) + z(\Omega_1' - \Omega_2')$$

$$\Omega_{n+1} = \Omega_n * [2 - (k+z)/m] + \Omega_{n-1} * [(z/m) - 1]$$

Modelling



Creating



À Mamma

Acknowledgements

The intention to combine dance and computer animation started on 13th September 2002 when I came to France. My first proposal for asking the internship of Master 2 Recherche was written on 4th November 2003. This moment, when I am reviewing my first proposal and the present thesis, there are many thanks that I would like to address.

First, I am thankful to work with my co-supervisor, Annie Luciani, whose encouragement, kind tolerance and patient reading have helped me through the research. Thanks to Annie for accepting the topic as my internship and PhD thesis. I would also like to give my sincere gratitude to my supervisor, Claude Cadoz, whose intelligent humour and knowledge in music inspired me to combine music and computing dance. I appreciate all the supports from the friends at ACROE and ICA-INPG during these four years. I see myself as a very simple man reaching for his goal, but Maria commented about me with her sense of humor as a simple man sometimes still having complicated struggles. Here are many thanks for Maria Guglielmi, Jean-Loup Florens, Aurélie Arliaud, Daniela Uma, Olivier Tache, Matthieu Evard, Damien Couroussé, Alexandros Kontogeorgakopoulos, Sylvain Marliere, Nicolas Castagné, Geoffrey Cerna, Ali Allaoui, and more others.

Next, I am grateful to my dance teachers, Fabienne Saint-patrice and Rodolfo Araya, whose teaching has opened my mind to appreciate dance. Many thanks go to Bruno Amilhastre and Viviane Serry who accepted me to pursuing dance learning at conservatoire Grenoble. I would like to thank many friends: Yves Riazanoff, Cécil Tremeaux, Santiago Sempère, Pauline Brottes, Alice Gautellier and more other classmates at conservatoire, with whom I really had great time in dance.

Moreover, I would like to express my appreciation for the friends with whom I met at Monaco Dance Forum 2004 and 2006. Thanks to Philippe Baudelot for the wonderful forum, where artists can communicate, exchange ideas and illustrate their dreams. Mélanie Freguin's hospitality with sweet smiles always cheered me up, as well as Daniel Larrieu's sensible understanding.

At last, I would like to thank the jury: Benoît Bardy, Philippe Baudelot, Ronan Boulic, Jean-Claude Risset and Jean-Luc Schwartz. I would like to thank the prix of EDISCE for encouragement. Many appreciations to Jean-Claude Gallotta, Mathilde Altaraz, Nicole Saïd and Dominique Brun for their listening about my digital dance project. Thanks also go to Chun-Hung Wu, Daniela Uma, Annabelle Gaudet, Mathieu Wade, Matthieu Evard, and Olivier Tache for the helpful corrections.

I also want to express my gratitude to my roommate Chia-Chun Ho and his family for sharing our studying life in France. I have often thought of my friends in Taiwan during my five years of foreign studying. My thanks also go to my family, to my parents and my sisters for wholeheartedly encouraging me to pursue my own dream.

Finally, I would like to share a poetry that I knew it at Rodolfo's dance class and I recited it at the award of Monaco Dance Forum 2006:

« ... Lorsque mon désespoir me dit: perd confiance car chaque jour n'est que trêve entre deux nuits; la fausse consolation me crie: espère, car chaque nuit n'est qu'une trêve entre deux jours... » ~Stig Dagerman.

Grammar of physically based modeling of dance movements: Use for choreographic composition

Grammaire de mouvements dansés par modélisation physique: Utilisation pour la composition chorégraphique

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IMPERMANENCE (無常)

“The world is continuous flux and impermanent”,
Buddha said that.

“Le monde est continue fluide et non permanent”,
Buddha.

0 Simplicity

“Simplicity is the Ultimate Sophistication” quoted from Leonardo.

The author of this thesis is like a sculptor. At first, the sculptural tool for rough carving is mass-interaction modeling, which is a kind of discrete computing modeling. In order to refine the sculpture, the author ought to choose other sculptural tool. Some toolmakers produce complex tool on purpose because they think the primary sculptural tool is too simple and ill-suited. Most people think different levels of sculpture should be done by suited sculptural tools, e.g. rough carving graver, fine carving graver, etc. Nevertheless, the author decided for only one special means. The thesis wonders whether a refined sculpture depends upon a fine sculptural tool. The author concentrates on understanding the property of materials: both sculpturing tool and sculptured object, and on the carving skills specific to a simpler sculptural tool. Finally, the resulting sculpture is at the same the knowledge of sculpturing tool (mass-interaction modeling), the knowledge of sculptured object (dance), and the knowledge of carving skill (body and movement understanding).

In the thesis, we firstly deconstruct the usual ways to see motion; next, we refine our pure aesthetic to feel or imagine motion; in the end, we construct physically based modeling to do motion. The transition from “to see” through “to do” via “to feel” is very related to artistic judgments (or personal aesthetics).

0.1 Artist and Artisan

“Les découvertes scientifiques les plus brillantes se transformeront avec le temps, et deviendront peut-être obsolètes devant l’émergence de nouvelles révélations de la science. Mais l’art est éternel, car il découvre le paysage intérieur, qui est l’âme de l’homme” quoted from Martha Graham.

A painter is an artisan when he has the ability to produce his wanted pigment. When a painter has the sensibility to create his style, he is an artist. In our process of simplification to seek for the essence of this work, we imagined that “dance is the consequence of energy transmission” as an artistic hypothesis. In order to make this

hypothesis practicable, we did scientific research and developed technology as an artisan does. Physics-based simulation provided the computing means for the elicitation of energy transmission that we assume to be at the basis of human dance movement. By means of physics-based animation, we are able to develop our personal choreographic approach – “dance is the consequence of energy transmission” –, and implement it in virtual dance.

0.1.1 To See & To Do

“Understanding the directions for a free dance performer stems mainly from the qualities and energy of the movement rather from spatial criteria” quoted from François Malkovsky.

A projected parabolic motion can be drawn directly on its explicit motion trajectory by mathematical interpolation or motion capture. An initiating force and the giving gravity can project this motion trajectory as well. We define these two different methods as “to see” for the first and “to do” for the second. In subsection 1.2.1, we discuss the differences in respect of digital representation. In general, “to see” is an objective means related to “analysis”; “to do” is a subjective means related to “synthesis”. Aiming at modeling dancer’s inner space, i.e. properties as quality, energy, etc, this thesis chooses the synthetic method to imitate the process of dance based “to do” paradigm. This approach is noticeably different from copying the results of a dance according to dancer’s external space, i.e. spatial criteria.

0.1.2 To Do & To Feel

“How can we know the dancer from the dance?” quoted from William Butler Yeats.

In dance, a dance repertory interpreted by two dancers could give varying feeling even though the dancers perform the repertory exactly. Sometimes the quality can be thought as resulting from the motion. In this sense, the same motion should maintain the same perceptual quality. We argue this point of view is not exact. A more sharp and closer to reality observation is that the same motion performed by dancer that have different morphologies, e.g. two dancers having different size and volume, can evoke different perceptions. Therefore, we can understand that “motion”, “form”, and “quality” are dependent.

Generally speaking, a fatter dancer should pay more effort to perform given motion

leads to different effects than one performed by a thinner dancer. A fat dancer exhibits two main characteristics: volume in the visual externally-situated function and capability of muscles (or impedance of muscles) in the energy internally-situated function. In the same way, body's functional state is an important distinction between female and male dancer, although it is invisible and usually disregarded. Hence, we copy the term, "to do" movement with "to feel" body's inner state, i.e. to take body's functional state into account in order to improve qualitative control. In conclusion, the three most important elements in the thesis are "motion", "quality", and "invisibles (body's inner states)".

0.2 GO (弈)

As in "Go Game" ("Yi", "Weiqi", board game), based on simpler rules than chess, but delivering a much higher level of complexity, mass-interaction modeling offers complexity in its possibilities through simplicity in its fundamental principles. But, that is also why mass-interaction modeling is generally unsuitable and uncontrollable for human motion implement. The value of our approach stand in the fact that we tried to succeed in integrating complex human motion by simpler mass-interaction modeling. We emphasize that the return to simplicity for both mass-interaction modeling and dance is the most precious (but obscure) element in this thesis. That's Go.

0.2.1 Pyramid Structure

Like pyramid, the thesis has three parts: thinking, modeling and creating.

The part one, which belongs to thinking, shows the way from complication to simplicity in terms of philosophy, in terms of modeling theory, and in terms of dance understanding.

The part two, which belongs to modeling, shows the most sophisticated "modeling methodology" we obtained. We propose innovative dance writing with help of modeling "dance verbs" (chapter 4) and "dance adjectives" (chapter 5). The fundamentals of our dance writing is both conservation and interpretation.

The part three, which belongs to creation, shows the way starting from simplicity to obtain a more complex effect (chapter 6) and relates to the knowledge of acoustics (chapter 7). We organize our thesis on two different perspectives: one focuses on movement representation towards artistic interpretation (chapter 8.1); the other

focuses on modeling signification towards movement understanding (chapter 8.2).

0.2.2 Motivation

The thesis has a structure in three dimensions: thinking (impermanence), modeling (dance writing) and creating (fluxus). It is metaphorical as a pyramid with a triangular base and sloping sides that meet in a point. The meeting point has an essential connecting among philosophy, science, and aesthetics. The motivation of the thesis is to invoke Newton's second law of dynamics, to evoke dance mind as a flow consciousness and to provoke dynamically dance motion that exhibit fineness/beauty or rudeness/sublime.

DANCE WRITING

Is dance like language?

Is dance like graphical symbol?

Dance is writing.

Writing is to be dance.

Writing dance is to forget dance.

Dance writing will do dance... somewhere else.

1 Introduction

“The Dance is a poem of which each movement is a word” quoted from Mata Hari.

Writing dance is indeed an interesting challenge, on which several discussions should be focused. Writing dance is a kind of way to receive, observe, further more a way to analyze. The linguistic-like way for writing dance, i.e. the writing grammar, is a transformation of dance itself. The transformation could have a passive aim of memorization/conservation or an active aim such as interpretation/reproduction. If dance writing can be useful for transfer and communication, it has also the interests for heritage and education.

Nevertheless, there are perhaps some misses while writing from seeing. There are perhaps other misses while reading from writing. There are other misses when doing from reading. In fact, each transformation is followed inevitably with different levels of miss, misunderstanding, and extra-explanation.

Since the destined miss of every transformation, we address ourselves to the perplexing role of dance writing: on the one hand, dance writing, in a passive aspect, is to write down what we see and what we think; on the other hand, dance writing, in an active aspect, is to write for what to do and how to do. That is to say dance writing has two aspects: (i) how to memorize dance? (ii) and then, how to reproduce it?

Two extreme problems about the relation between memorization and reproduction are mentioned here: (1) If all the details are recorded (e.g. photograph, video recording, motion capture), it enlarges higher complexity that is difficult to analyze. It may be useful to reproduce dance; maybe not. Besides, we can restore dancer's external space

such as tempo-spatial motion data but not dancer's inner space. (2) Conversely, writing dance literarily might conserve dancer's inner space in other spirit. If we record some supposed key-points (as drawing sketches, profile, etc), we need to prove whether it is helpful for reproduction. In order to avoid the inconveniences of over subjective judgment or extra-explanation, it is necessary to reproduce it. That is to say we synthesize an unconfirmed hypothesis (i.e. dancer's inner space), and then we should reproduce it for validation. Therefore, we intend to a novel dance writing grammar that focus both on seeing and doing. In other words, memorization (conservation) and reproduction (interpretation) should be always together, one with the other, as the purpose of our work.

1.1 The Memorization of Dance

Writing dance has, at the same time, paradoxical aim to forget dance. The memorization of dance is a fascinating topic. One can conserve choreographies in several ways: (1) Observe it without any analysis, e.g. film record, motion capture; (2) Notate it by dance notation systems such as Laban, Benesh, etc; (3) Criticize it with subjective judgment; Draw it by an artist; (4) Describe it from dancer and choreographer.

Each method represents different degrees of subjectiveness, and has very different properties in accordance with whereon to stress. For instance, in space and time coordinates, motion has explicitly spatiotemporal trajectory, which is observed objectively but exteriorly, focusing more on the form and external gestures. In frequency space, motion can be focused more on its strength and rhythm what is relating to a musical approach. In observer's depiction, motion is inferred often with observer's perception. In dancer's memory, the description is relative to absolute dancer's inner space, e.g. imagination or sensation. Those clues to dancer's inner space are the most profound, but also the most obscure, and the most difficult to conserve. Even though a dancer's memory is a kind of conservation, he has his own subjective way of describing what happens that cannot be understood. One could then hope to find a means that could include those subjective methods and the pure subjective explanations.

The most known dance notations: Benesh notation specifying to symbolic-based ballet positions and Laban notation specifying to general motions, treated well on body's appearance (what we may call "external gestures"). A few notation systems take body's inner space (inner states) into account, even though Laban's Effort-Shape theory based on kinesphere, referred to the relationship between dynamics and

geometric forms. The fact implies that, in order to memorize dance, we should choose suited media whereto attach importance. Hence, the challenge of this topic is how we can memorize the invisibles and by which means. In addition, which kind of invisibles, e.g. respiration, tension of muscles, fatigue, etc, do we want to catch?

1.2 The Reproduction of Dance

Reproducing dance with computers, which is one sort of digital performance, is certainly different with traditional dance. Digital dance improves dance representation in many parts: visual effect, nonhuman dancer, fancying stage, frictionless environment, etc. Digital dance could be concerned with what human can never perform (i.e. non-realistic motion and animation); or digital dance could be concerned with the reality of human behavior (i.e. realistic motion and animation). Nevertheless, there exist some debates on the meaning of digital dance reproduction. For instance, the reason to reuse motion data obtained by motion capture is because its reality and efficiency in respect of movement representation. However, in respect of dance conservation, the original motion data have to be analyzed forward. Conversely, synthetically physics-based animation could provide important cues for movement understanding even though the simulated dance is less realistic and less compelling in respect of movement representation.

1.2.1 Real Dance & Virtual Dance

This subsection discusses the difference between the interpretation by dancers and the reproduction by computers. What are the definitions of real and virtual dance in terms of mental mind, physical body and the environment? We suppose that real dance means true mind and true body in real environment. Virtual dance means a kind of tricks: where mind, body and environment are false mind, artificial body, and the virtual environment. Focusing on movement reproduction, the authors discussed two points as below whereas computers ignore [Hsieh and Luciani 2007]: (1) what are the differences of computational dance, especially in aspect of dance, between figure-based animation and dynamics based animation; (2) how to improve qualitative transition while motion composing occurs?

1. Seeing/Doing vs. Figure based/Dynamics based

Animating characters by computer animation has a significant similarity with making

dance: both create movement. Nevertheless, the developing domain of computer-assisted choreography is still far from profound. Calvert et al. [2005] inferred that: “it reflects the reluctance of dancers and choreographers to let anything get between them and the live kinaesthetic experience”. It also reflects the fact that there is some misleading thinking in the developing technology for computer-assisted choreography. Perhaps the computing thinking is not intuitive and is not in sufficient accord with dance thinking.

From an interesting point of view as below, we compare the real scene with the virtual scene created by computer. Broadly speaking, we appreciate illusively two identical scenes. If we put individually an apple into both the real and virtual scenes, we find out immediately and distinctly the difference between the two scenes. For example, the apple in the real scene falls down and stays finally on the floor due to the gravity and the ground’s resistance force, while the virtual apple has not this natural movement except if it is designed. In the real world, this kind of phenomenon, obeying Newton’s law, exists all the time although we cannot see it. Similarly but more profoundly, human dancer breathes naturally and this is hypothetically due to the interactions inside our material body, even we cannot see them. Conversely, to produce natural scene in virtual environment, these natural interactions have to be considered.

We suppose that the gap is coming from different cognitions in the dancer and the audience. The audience perceives the resulting motion in visual, spatial and temporal ways; that is to say, the motion is composed of “many external gestures”. Dancer concerns his energy within body and his interaction with environment (gravity, floor, partner, etc) to provoke motion. Here, we address roughly the difference between seeing and doing motion. This gap leads to two extreme poles in motion generation: computers produce motion from the result; dancers produce motion from the cause.

It is probably why the usual developed computer-assisted choreography systems focusing on kinematical based gestures are generally less suited for assisting choreography.

2. Motion Composing or Cause Composing

Furthermore, we wonder how to improve motion composing. Considering coherence, “qualitative transition” is relatively ignored in comparison with movement transition. That is to say, people compose two adjoining motion trajectories at position level or even at velocity level, for a smooth transition in kinematics. However, the logic of composing of the two actions at the causal level is disregarded; some important details are also lost during kinematical movement transitions, such as for example, the delicate transfer of gravity center, the preparation for the next action, etc.

Moreover, people disregard whether the qualities of the two adjoining movements are coherent; if not, there should be a “qualitative transition”. While one skilled dancer interprets a dance repertoire, his/her coherent personal quality is injected into movements consciously or unconsciously to retrieve the missing details. Nevertheless, do computers recover the missing details after motion editing and composing? A delicate interrogation is that reuse of motion data is exploited for its primitive quality. It is not only an ideological argument, but indeed, qualitative control is disregarded in comparison with motion control. Instead of motion composing, we focus on “cause composing” referring to physical body states as a cause of motion, precisely in order to improve qualitative control.

To dance is like to poetize; it is not only grammatical composing of words, one must also be fluent in tone/nuance.

1.2.2 What is real & What is virtual?

Through the discussions above, we propose to suppose the following idea: the difference between virtually computing dance and real dance might improve movement understanding. The practical idea, inferring that computing dance is regarded as media to compare with real dance, aims at revealing the invisibles. That is to say, the practice of virtual dance could be a representation of the cause of the motion, aiming at revealing the invisible, and thus maybe closer to the reality of the real dance. The similarities and the differences between real/virtual dances might serve an important experimental tool to reveal the body’s inner space when the dance reproduction (synthetic) can take place as real dance but in the virtual world. In this sense, motion-capture based dance takes place first in the real world, and then it is transferred on the virtual space by mapping on virtual form, virtual character, virtual environment, etc. Whatever, in comparison with traditional dance notations that write down many motionless figures, we argue that there should be an innovative dance writing system, which takes computational reproduction into account and that is different with the visualization (reproduction) of traditional dance notation.

1.3 Novel Dance Writing

“Dance is the hidden language of the soul, of the body” quoted from Martha Graham.

We are interested in searching for something invisible or imaginary, but existing really in dance. The invisibles mean that a great deal of movement takes place inside

the body, where it is usually difficult to be captured by external sensors. Hence, this thesis – synthetic modeling based on physics – implies synthesis of supposed invisibles in order to reproduce movement. The invisibles are thus be conserved by a means more objectively rather than pure literary metaphors.

Furthermore, we anticipate an innovative dance writing: dynamic models as a type of dynamic notation (dynamic figures), to notate invisible part within body's inner space. We intend to an innovative dynamic notation in which masses (particles) present motionless figures, and in which interactions provoke the consequent motions dynamically. In other words, our dynamical figures, at every time step, not only have the present position and velocity, but also anticipate the future state.

In conclusion, our concern in the novel dance writing is with mass-interaction based modeling taking account of “motion”, “quality” and “invisibles”. These three principal concerns are not mutually exclusive but strictly related. The novel dance writing provides an innovative approach: “dynamic notation” (or “dynamic figure”) implies “conservation” and “interpretation” at once.

In the work, at the first level, we create a series of dance verb-dependent models with help of mass-interaction based modeling. These dance verb-dependent models generate dance movements.

At the second level, we create a series of dance adjective-dependent models. These dance adjective-dependent models can be qualitative references.

At the third level, we indicate the invisibles, which are hidden within these models. In other words, during the process of modeling construction, several invisibles are taken into account in order to generate movement and improve qualitative control.

In terms of movement representation, these models are useful for computer-assisted choreography and for character animation. In terms of movement conservation, these models are useful to track the invisibles, which are disregarded. In terms of movement understanding, these models are useful as well through modelling construction and manipulation.

2 Related Works

2.1 Related works in Dance Heritages

2.1.1 Contemporary free dance

The free dance was inspired from Isadora Duncan, and was inherited by Malkovsky. According to the fundamental basic movements of Malkovsky [Bodak 2001; Arnoux 1997], we found out some key points to observe the gesture quality of free dance style. Here we extract some thoughts of free dance classified by Bodak [Bodak 2001]:

1. 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. Secondly, the causality serves itself in a state of “economy of effort”, with the meaning of according to “logic and physics” in the succession and transition. [page 76]
2. Pattern of uniqueness along the movement: The process of dance has a single common formula: “active-passive-neutral” or “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. [page 80]
3. Pattern of alternating laterality: Since the step is triggered 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. [page 100]
4. 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. [page 61]

5. Breathing: The breathing is an essential factor that originates and supports the movement. [page 60]
6. Gaze and orientation: The eyes initiate pivots, change the orientation of turns and always focus on the external as the environment, the partner, etc. [page 60]

The free dance mainly deals with the qualities and energy of movement rather than from spatial criteria. It seemingly implicates a motivation to generate the free dance movement by physically based animation. Laws [Laws 1984; 2002; Laws and Harvey 1994] focused on the physics of dance. He provided some interesting view of physics for observing dance movements: 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 mechanical functionalities that are just necessary to perform the movement, even if the performer is a complex biomechanical system.

2.1.2 Contraction and Release; Fall and Recovery

One could consider two main dance techniques in contemporary dance. One is Martha Graham's technique: "contraction and release"; the other is Doris Humphrey's technique: "fall and recovery".

Graham identified her technique "contraction and release" as a method of breathing and impulse control. The technique stresses the movement originates in the tension of a contracted muscle, and continues in the flow of energy released from the body as the muscle relaxes. The concept of "contraction and release" exists within muscles and as well as within the breath.

Humphrey identified her technique "fall and recovery" as a cycle of the tensions that locate the height or apex of the continuum in the suspension of tension. This technique stresses that all movements fall within the "arc between two deaths", or the range between motionless balance and falling imbalance incapable of recovery. In other words, movement yields and resists to gravity.

The two techniques deal with the relation between quality control and tension change, which exists either within inner body (e.g. muscles, breath, etc) or with environment (e.g. gravity, etc). Dancer's analyses are quite different to scientific analyses, but they are important references for movement qualitative research as well. For the thesis, we are interested in the dance techniques because they take "invisibles" (i.e. the tension within inner body and the attention with gravity) into account and are really helpful to quality progress in practice of physically-based modeling.

2.1.3 Laban, Benesh

In Western culture, the two main dance notation systems are Laban notation and Benesh notation. Griesbec [1996] gave a short introduction about Laban notation. Laban notation is a movement notation system for all kinds of motion, compared to Benesh notation, which is specific to classical Ballet. He introduced Laban notation in three systems of writing: (1) Structural description: a way of writing which tries to record every aspect of motion as precisely as possible; (2) Motif description: a kind of simplified description that writes down the importance; (3) Effort-shape description: used to record the energy content of motion and used in research as well as in physiotherapy and psychotherapy [Griesbec 1996].

Benesh notation system is an abstract symbolic and figure-based system, which has a five-line stave. The five-line stave coincides with the head, shoulder, waist, knees and floor. Some additional signs, e.g. rhythm and phrase information, are notated above the stave. Benesh notation system gives a rich vocabulary for describing structural and positional movement that is in accordance with classical ballet.

Hutchinson-Guest [1989] compares the advantages and disadvantages among historical and present-day dance notation systems. These dance notation systems depending on movement style, on cultural viewpoint, and on the purpose that are very different. Computers have been involved in dance notation. For instance, computers help for communication between symbolic notations to representation. The main applications aim at easily readable and figurative visualization based on an existing notation system. However, there are few researches formulating a new dance notation system, which takes online computing into account. That is to say, in this case computing-based simulation is one part of notation system.

In this work, we intend to introduce an innovative “dynamic notation” aiming at notating body’s inner space, that is to say, by means of physics-based modeling, “dynamic notation” synthesizes body’s inner space.

2.2 Related works in Dance & Computer Graphics

Badler and Smoliar [Badler and Smoliar 1979; Badler 1989] summarized several approaches about digital human motion representations. In the report of Herbison-Evans [Herbison-Evans 1991], he described various uses of computer graphics in dance: dance notation, choreography, live performance, movement

understanding, movement teaching and digital movement representation.

Based on key-framed interpolation, several applications translate the Laban notation scores [Calvert et al. 2005] or Benesh notation [Neagle et al. 2004] into 3D character. With the help of dance notation, these works resolve the labor-intensive problem of keyframing. However, dance notation is recorded manually by notation observer, which might lack the details of interaction with the environment, for example, a little bounce of knee while falling down. For a dancer, this missing can be overcome while for a computer representation, it could have an influence on the movement believability.

Confronted to the difficulty of synthesizing dance motions whether with the symbolic Benesh notation system [Benesh and Benesh 1983], or with the Laban description of body structure at a specific time [Laban 1966; 1971], several approaches focused on adding expressions to the key-framing based motion [Chi et al. 2000; Rose et al. 1998]. Chi et al. [2000] proposed the EMOTE model which gives a good combination between key-pose and the Effort-Shape theory of Laban [Laban and Lawrence 1974] to generate more natural synthetic gestures. Rose et al. [1998] proposed methods of multidimensional motion interpolation.

The web3D Dance composer [Umino et al. 2005] presents dance motions coming from motion capture and connects every motion data based module with help of Laban motif description. Motion data based animation can provide many nuances in the movement, and it is helpful for movement understanding and motion training. However, it is still laborious and costly to modify the data, even though recently some approaches focus on motion editing, transition and synthesizing by algorithm optimization with help of spacetime constraints or kinematics constraints.

2.2.1 Kinematical base animation

For both key-framed and motion data based animation, we should always have a predefined motion, which is less suited for computer-aided choreography. In other words, such methods 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 falling to the floor lightly” or “be as an apple falling to Newton strongly”. It cannot focus more on the style of the motion or on the metaphoric conditions to create it, but it just explicitly describes the motion itself.

Instead of this, dynamic approaches are able to generate realistic or plausible motion. There are two main categories of dynamic approaches: one is direct dynamic when forces generate the resulting motion; the other is inverse dynamic, which means finding the exact forces to generate a desired motion. Recently, several dynamic

researches focus on “dynamic controllers” and “space-time constraints optimization based”.

2.2.2 Physically based animation

Dynamic controllers. Van de Panne [van de Panne and Fiume 1993, van de Panne et al. 1994] 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. “Dynamic controller” belongs to “generative models”, in which the motion is not explicitly defined in itself but is produced by its instinctive forces. That is to say, “dynamic controller” drives the actuator forces based on the current state of the environment. These approaches allow producing various plausible and expressive motions by changing a few of the high-level parameters and they could also exhibit complex evolutions. It enables to take into account the interaction effect with environment. However, “dynamic controller” encounters always the problem of controllability: how to obtain a desired motion?

Space-times constraints. Spacetime constraints were proposed by Witkin and Kass [1988] to obtain high motion control by specifying what to do (from here to there) and how to do, without specifying the explicit motion trajectory. Spacetime constraints optimize the resultant motions underlying physically based objective functions. Therefore it provides more controllability and realism. However, spacetime constraints-based optimization is always time costly and difficult to apply into a complex structure model. Popovic and Witkin [1999] drew some ideas from biomechanical literature and proposed a manual simplification to reduce the complexity of structure. Safonova et al. [2004] propose the similar idea to reduce character’s degrees of freedom automatically. Without doubt, simplifying a complex model reduces the time of computing. Many excellent approaches have proposed algorithmic optimizations to progress this type of problem, but it is still an open problem.

In addition, Gleicher [1997] inferred a concept of other possible objective such as “gracefully” with meaningful attributes in comparison with energy minimization objective. However, for low-dynamic motion and stylized motion, it is not easy to define suited objective function for optimization. In fact, the main interest of our approach is whether the varieties of expression, for example, a comfortable way to move, an exaggeratedly way to move, or a high dynamic way to move, etc, could be achieved by different ways of interaction.

2.3 Related works in Motion Quality

This subsection is related to which kind of motion qualities character animation is intended. There are three rough categories of motion quality according to physical considerations.

1. Cartoon Stylized motion (plausible physics)
2. Excited sportive motion (high dynamics)
3. Graceful sophisticated motion (fine and low dynamics)

Barzel [1997] stated that “fake” dynamics are more favored than purely “real” dynamics for animation because audiences prefer plausible-but-caricatural motion rather than purely physical. His wise statement was convincing, and led us to interrogate ourselves on two aspects.

Firstly, to provide a computational means for our modeling, we encounter confusedly the question whether there exist “real dynamics” in human motion? If not, it seems efficient to produce wave-shaped motion directly [Barzel 1997; Fournier and Reeves 1986]. Liu et al. [2005] mentioned that high-energy motions depend more on physics, whereas low-energy motions toward style are not tightly constrained by physical requirement.

By our analysis, human is like a self-motor system which acts, causing motions that can be complicated and complex. Nevertheless, in a sophisticated and opposing viewpoint, a sensible dancer is conscious of his/her body in low-energy motion and can simplify his/her motor system and make disregard unnecessary control. That is when fine and pure movement arises. Therefore, a dancer has two extreme abilities, one being skilled to interpret excited high-energy motion; the other being fanciful to simplify and refine his/her pure sensation for fineness, our modeling aims to achieve both.

Therefore, a simpler computational system based on mass-interaction is chosen [Luciani 1985; Luciani et al. 1991; Evrard et al. 2006]. Mass-interaction system belonging to discrete algorithms provides powerful computing efficiency and physics-based results. In addition, mass-interaction system has destined uncontrollability to be very complicated if ill-suited parameters are given, and that is in accordance with the human motor system. Unlike previous mass-spring approaches introduced in geometrically based philosophy and leading to an anatomical viewpoint, this work focuses on modeling construction, instead of algorithmic improvement. Our approach starts from simpler interactions (elastic and viscous forces) to implement complicated motions.

Considering the aspect of perception, people perceive quality mainly from energy. Therefore, an exaggerated motion having high dynamics stimulates audience and thus is more attractive. Conversely, sensible appreciators perceive quality with sensation so that a fine low dynamic motion is very precious. “Anticipation, exaggeration, follow-through motion” [Lasseter 1987] has been one of the most important principles for characteristic motion. Several researches [Rose et al. 1998; Bregler et al. 2002; Hsu et al. 2005; Liu et al. 2005] have improved computed expressive or stylized motion. In addition, Laban’s Effort-Shape theory was used for motion qualitative control [Badler 1989; Chi et al. 2000; Camurri et al. 2000; Camurri et al. 2002; Camurri et al. 2004]. However, graceful or sophisticated motions are relatively ignored because they seem hard to encode mathematically. Although several works [Witkin and Kass 1988; Gleicher 1997] proposed to provide users with flexible objective function control, it is still a challenge both for programmers and for skilled animators.

In dance, finesse and elegance are such subtle and delicate qualities that it takes dancers’ fancies all their life. Dancers explore inner sensations by doing it day by day without giving any qualitative definition. We are thus interested in how dancers are conscious of their bodies and movements; it is supposedly the one cue to seek out sophisticated motions.

Due to this reason, we aim to construct our specific modeling to imitate dancers’ consciousness (underlying sensation or imagination). The hypothesis of our modeling, inspired from Laban’s Flow in Effort-Shape theory [Laban 1966; 1971], [Laban and Lawrence 1974] and T. Brown’s Flux in Newark (1987), is that dance can be like flowing, considered in terms of energy. By this shift, abstract qualities become more concrete. For instance, ripple flowing with fine details signifies low dynamic sophisticated motion; stream flowing signifies high dynamic motion; billow flowing signifies exaggerated motion. To sum up, aiming at motion quality control, our original key-concept is that “dance is the consequence of energy transmission”.

2.4 CORDIS-ANIMA & MIMESIS

Above all, the difficulty of dynamic based animation is a delicate problem between motion control, complexity of character structure and computing cost. In this work, we look backward to “physically based particle modeling”, which belongs to “direct dynamic” and has the advantages of an efficiently computing and of a powerful interaction with environment. On account of this, we circumvent the computing problem. The remaining challenge is how to model and control a desired motion.

2.4.1 System Description

The physically-based particle system, called CORDIS-ANIMA [Cadoz et al. 1984, 1989, 1993; Luciani et al. 1991], is a discrete computing formalism that allows to describe and simulate the Newtonian laws of dynamics. 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 law: $F=ma$. The interaction force is generated according to the position and velocity of the masses. In CORDIS-ANIMA, two types of basic modules MAT and LIA are designed (Figure 1), from which any network structure can be created. The MAT module, representing a punctual mass, is made of a single M point and its discrete – time algorithm is calculated from the fundamental relation of dynamics (Equation 1):

$$X_{n+1} = 2X_n - X_{n-1} + \frac{1}{M}F_n \quad \text{Equation 1}$$

where $F_n = f(n \cdot \Delta t)$ is the sum of the forces received by the M point at the time $n \cdot \Delta t$, $X_n = x(n \cdot \Delta t)$ represents its position, f, x are the corresponding continuous measures and $M = m/\Delta t^2$.

The LIA module is composed of two L points sending two opposite forces, according to action-reaction principle from the positions $X_n^{(i)}$ and velocities $V_n^{(i)}$ of the inertial masses connected to it. The visco-elastic link follows the discrete-time algorithm (Equation 2) with K - the stiffness, and B – the viscosity:

$$F_n^{(2)} = -F_n^{(1)} = -K(X_n^{(2)} - X_n^{(1)}) - B(V_n^{(2)} - V_n^{(1)}) \quad \text{Equation 2}$$

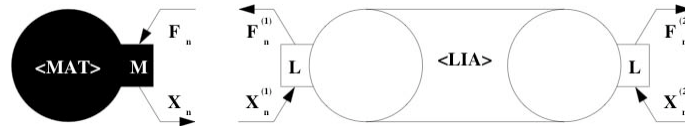


Figure 1: MAT/LIA link with forces and positions.

The assembling of these two elements (MAT, LIA) in network, similar to Kirschoff networks used in Electricity allows to model physical behaviours from very simple to very complex one. By modifying the parameters of each element: mass, stiffness, viscosity, and by defining temporal or spatial non-linearities on them by means of finite state automata formalism, a wide spectrum of real phenomena can be modelled. Thanks to the modularity of the modelling formalism, the facility of building new models in addition to the real-time running are the satisfied conditions for a tool adapted to interactive education.

Next, MIMESIS [Evrard et al. 2006], software based on CORDIS-ANIMA, is used to simulate “direct dynamic” in 3D animation. MIMESIS lets the user operate at the most elementary level of the mass-interaction formalism. In MIMESIS, the modeling process is composed of five stages:

1. The user builds the network of mass-interaction modules, by using an appropriate language mixing graphical and textual representations.
2. Initial conditions (positions, velocities) of the mass elements are given.
3. Specifying the values of the physical parameters for the physical modules.
4. The physical model is computed within one of the simulator producing motions of set of points.
5. The user designs the mapping of previous synthesized point motions to a 2D or 3D set of shapes by a coating process.

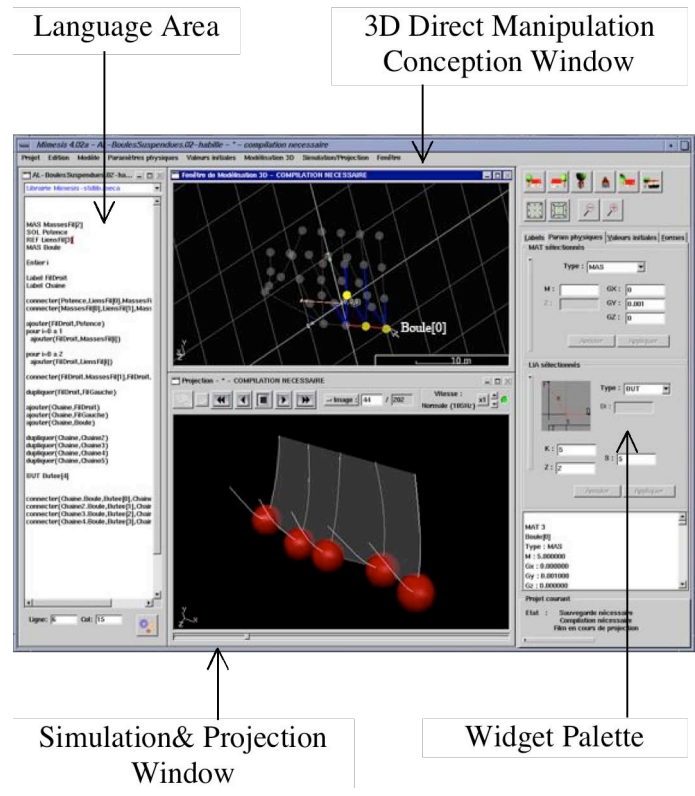


Figure 2: General view of the MIMESIS' interface.

Figure 2 presents a general view of the user space, showing how each of the user stages is given a specific space and ergonomic: language area for scripting the network of modules (left), palette for manipulating through widgets the data (right), and two OpenGL-based windows for respectively working on the network in a direct-manipulation manner and visualizing the resulting movements.

The software MIMESIS is based on two kinds of forces: elasticity and viscosity. Only with elasticity, we are in the case of constructed modeling under energetic consistency that implies an ideal environment. By adding viscosity, we can design a model which consumes its initial energy and which presents exactly a real phenomenon in real world. Broadly speaking, derived from elasticity forces and viscosity forces, MIMESIS provide three principal interaction forces: Elastic-Damping, Collision-Damping and Attraction-Damping. Several complex others can be designed from these basic ones (cohesive, hysteretic, breaking, etc). More details are to be found in [Luciani 1985; Luciani et al. 1991; Evrard et al. 2006].

2.4.2 Interesting point for thesis

Physically based particle models, i.e. mass-interaction based models, are efficient to simulate the dynamical behaviors, in particular for natural phenomenon such as fluid, or deformable solids. However, human motion is a complex biomechanical behavior that seems at a first glance impossible to model with the laws of physics. The originality of our research is that, from mass-interaction based modeling, we generate dance movement only with “the necessary minimized masses” and “the essential interactions”, by means of a fundamental shift: from anatomical approach to a more abstract (functional) physically-based approach.

To solve this challenge of controllability, we propose the idea of “modular design” according to each kind of movement (i.e. dance verbs). Among motion modules, complex character structure and complete motion are simplified and refined by “the just necessary masses” and “the essential interactions”. The driving force could be designed by defining the potential energy (initial position and stiffness parameter) or the kinetic energy (initial velocity and mass). Thanks to the use of the simplification procedure, we could focus more on the interaction and connection through dance movement and take advantage of the simplest computing technique.

Since this simplification procedure can not easily be defined using simple objective functions, and since we have a wide variety of expression, both stylized motion and low-dynamic motion, we decide to derive them directly according to the dance and physics literature [Bishko 1992; Bodak 2001; Laws 1984; 2002; Laws and Harvey 1994].

To sum up, the dynamical simulation system, called CORDIS-ANIMA with MIMESIS interface, is used to treat Newtonian second order motion equations by numerical algorithm on low level. The author, as modeler on high level, will construct virtual dancer and initiate his dynamical capability only with two kinds of data: the initial vectorial position (p) and initial vectorial velocity (v) of mass, and four kinds of physical parameters: the inertia of mass (m), the spring constant (k), the viscosity constant (z) and length rests or thresholds (L or S) for the viscoelastic interaction.

3 The Basic Level of Modeling (Model and Theory)

3.1 The Perplexing Role of Modeling

Modeling has a puzzling role, as it is sometimes said to be purely theoretical. Interrogations about the role and the definition of modeling, as well as its similarities and differences with theory, are the source of many debates in sciences, as well as in philosophy [Frigg and Hartmann 2005].

Omitting its puzzling role, model can be helpful for learning. Model is used to imitate and represent a target system, e.g. natural phenomena or human mental motor, since the target is too complicated to be understood directly. Hughes [1997] stated that learning takes place in three phases: denotation, demonstration, and interpretation. We infer these three phases as (1) “building model” (denotation), (2) “manipulating model” (demonstration), and (3) “representing model” (interpretation). Frigg and Hartmann [2005] explained two notations about learning with models: (1) learning the knowledge about model directly; (2) converting the model knowledge into target knowledge.

In this study, we aim to innovate in the quality control of generated motions, moreover to improve movement understanding. It is so complicated to track the thought in dancing that we have to simplify the movement and then construct models in order to make it more tractable. Taking into account model building and manipulating, the experiments and experiences through models can pioneer an accessible way into a dancer’s consciousness. To track complicated phenomena such as natural movement or human dancing, it is fundamental to model them using fewer hypotheses.

Furthermore, we should avoid poorly understood assumptions and too many additional adjustable parameters, because the more the representation model is simple, the more it is understandable. That is the reason why, in this work, we use “mass” and “spring-based” modeling, even our mass-interaction system can offer a variety of interaction such as elasticity, viscosity, linear, non-linear, etc.

3.2 Model toward Scientific examination or Artistic expression

It could be quite hard to distinguish whether a model belong to scientific examination

or artistic expression. These two notations are not mutually exclusive. In the thesis, we model a dance, which is provoked by energy transmission on imaginary itinerary. In this sense, they are the models toward artistic expression. At the same time, our models explain human dynamic behavior relating to a causal knowledge from movement observation and movement analysis. Our physics-based models become experimental models used in comparison with complicated human behavior. In this sense, they are useful models towards scientific examination. Later, we show a significant example (in subsection 8.2) that a synthetic model could map well with the states of muscles (tension and resistance) and could react logically as human dynamic behavior.

The remark of our models represents the relation between human dynamic behavior and model manipulation. Different with other dynamic simulation based on a figurative anatomical copying and thus that take less this relation into account, our models concern first with the body's inner states, then map coherently into the cause of human behavior, and at the end, evoke the plausible-right movement.

3.3 The concluded role of modeling

The Equation 1 and Equation 2 are the basic algorithms for the computational means of modeling in the thesis. Differently from other approaches, we do not involve in algorithmic improvement, or in interactive multimodal application. The thesis involves in how to simplify and implement complex dance motion by mass-spring modeling, which can take advantage of the efficient algorithm.

In order to construct dynamic models, masses represent motionless figures; springs represent material and functional interactions. The necessary minimized masses and essential interactions are constructed through the principles below:

- A motionless figure is represented by masses' spatial position.
- Level of details of masses could represent, on one hand, the details of figure having lineal/curved form. (Figure 3-a/b).
- Level of details of masses could represent, on the other hand, the details of movement having rude/fine motion. (Figure 3-a/b).
- Spring represent material interaction, e.g. physical body. (Figure 3-c).
- Spring represent functional interaction, e.g. invisible connection between right shoulder and left leg because of symmetrical balance. (Figure 3-d).

Next, the motionless figure comes alive by assigning these physical parameters: the initial vectorial position (p) and initial vectorial velocity (v) of mass, the inertia of mass (m), the spring constant (k) and viscosity constant (z) of viscoelastic interaction. For example:

- Assigning an initial velocity at masses can be regarded as initiating kinetic energy into models. $E_{kinetic} = 0.5 * m * v^2$
- Assigning a compressed/stretched spring can be regarded as initiating potential energy into models. $E_{potential} = 0.5 * k * (\Delta x)^2$

From then on, the dynamical figures, at every micro instant, not only have the present position, but also embody body's inner state and anticipate future state.

The illustrated dynamic figure is extracted in simplicity. As a result, we lose some details of the form, e.g. skeleton, muscle, skin, etc. We will discuss it lately in subsection 8.2.3. But, we concentrate more on the interactions, which could imply the interaction with the environment, the interaction within body's inner states, the coordination of mental control and physical body, the interpersonal co-ordinations. The benefit of our dynamic models hence allows predicting dynamic behavior in where the invisible interactions are taken into account.

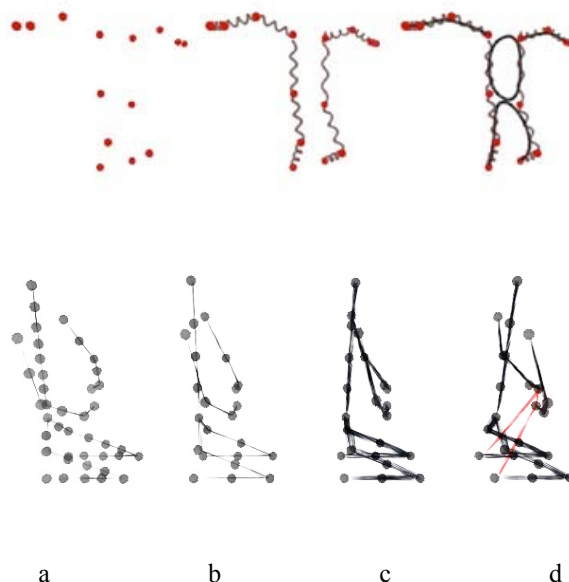


Figure 3: Dynamic Figure is composed of mass and spring. Masses represent figures; springs representing body's inner states provoke movement dynamically.

4 The First Level of Modeling for Movement

In the aim of assisting choreography, the primary principle in this chapter is exactly the interactive (correlative) thought between computer and choreographer.

We suppose choreographers are more interested in “cause propagation” and “energy transmission” during every action. Choreographers always abstract dance movements, i.e. principal actions, reactions, anticipations, etc, and abstract simplified character structures as well. Therefore, if we bring to choreographer an animation system having power algorithms to compute the complex dynamic behaviors, the choreographer is obliged to think in a completely different way, and it will be more complicated for him.

Thus, our approach, according to choreographer’s philosophy, is interested in simplifying dance movements understanding in order to elicit their simplest causal essence instead of constructing complex analogical body computing system. In order to refine dance movement, we need to deconstruct character structure into mass-interaction as well. In view of dance compositing, we extract dance phrases from dance; and we extract dance verbs from dance phrase. Then, we refine a driving cause from every dance verbs (shown in Figure 4). The assisting choreography system we proposed has both the cause and the dance verbs as its origin that is convincingly suitable for choreographer.

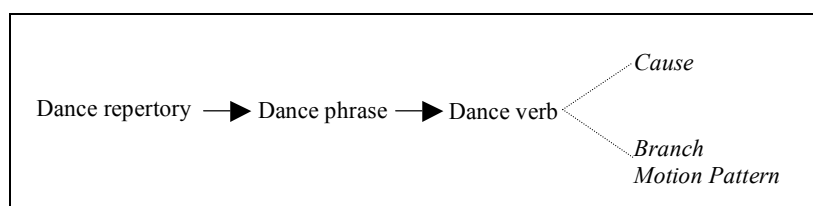


Figure 4: The deconstruction of motion for obtaining its cause and branch (motion pattern) of each dance verb.

4.1 Dance Verbs

The fact that dance can be described as verbal sequences leads to two main questions: (1) How to compose and transit among each dance verbs? (2) Among these dance verbs, do they have some similar properties and qualities? Therefore, we illustrate dance verbs tree as below (Figure 5) with several different branches indicating their relationships. For instance, a jump’s branch includes all the verbs: such as plier,

rebound, jump, leap, flip etc, for which the common link is that they are concerned with contra-gravity. Locomotion's branch includes all the verbs concerned with displacement. Turn's branch means all the verbs concerned about torsion and rotation. Wave's branch means all the verbs related to continuous deformation. Tableau I shows this type of grouping by family characterized by a same action principle. The purpose of the dance verbs tree is not to classify strictly dance verbs. It is probably an impossible task, if we notice that each action can be interpreted and varied toward two extremes: as simple (elementary) and as complex (composed). The illustrated dance verbs tree (Figure 5) is very simplified on purpose to remark the motion patterns for action itself. The movement patterns, namely dance family, are useful for movement transition and composition.

Tableau I: A broad category of “dance family”.

Motion pattern	Cause (pre-movement)	Members
Wave family non-locomotion	propagation	ripple, dolphin, etc
Self-balance family non-locomotion	push and pull	Sway
Turn family spiral and turn	torsion	active pirouette, passive pivot turn, etc
Step family Locomotion	loss-balance & friction	walk, swing step, waltz step, etc
Jump family contra-gravity	gravity	plier, rebound, jump, leap, hop, sissonne, assemblé, etc

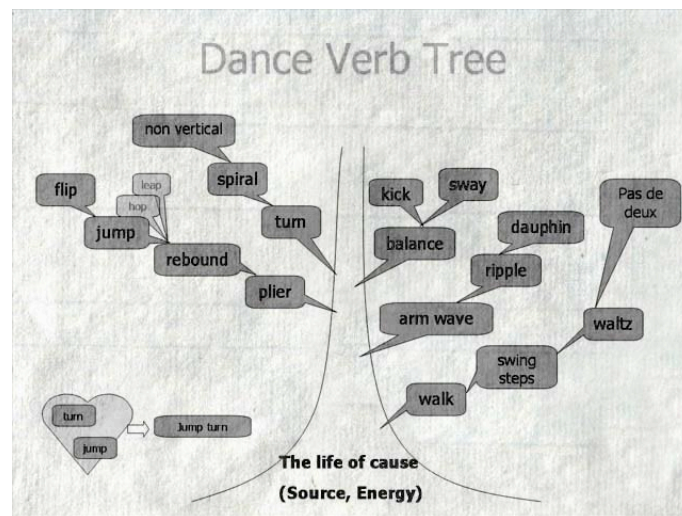


Figure 5: Dance verbs tree composing of branches and the life of cause.

4.1.1 Methodology: Deconstruction I

While a complex character structure is deconstructed in a “mass-interaction” network (shown in Figure 6 and Figure 3), the anatomical skeletons and articulations do not exist anymore. Instead, this reduced number of interacting “masses” represents either materials or functional components. Here, it differs from classical uses of physical modeling to represent exactly the anatomical material properties. Because of this, we are concerned only in the “interactions” through all the actions.

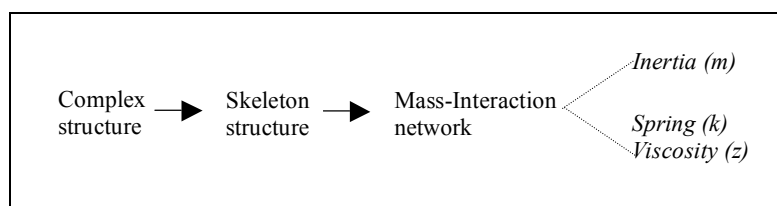


Figure 6: The deconstruction of human structure to alive dynamically.

4.1.2 The Life of Cause

“I was seeking and finally discovered the central spring of all movement, the crater of motor power...” the famous dancer Isadora DUNCAN once said that (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.

In view of dancing’s dynamic, especially for contemporary dance, every action comes from a cause that destroys the initial balance. Then, this cause propagates to trigger the remaining motion. In the end, our body will find another new balance. Consequently, the process of dance has a single common dynamic formula: “a cause trigger, let go and relax, new balance”. This pattern is called “preparation, action, recovery”.

In our approach, in accordance with the process of dynamic, all the dynamic models are created according to the following procedure: (1) finding out the “motor locus” and initiating the energy into this motor (the birth of cause); (2) generating the motions from the “motor” (the growth of cause); (3) decreasing influence of the motor

and finding out another new balance (the death of cause). It is well analogous with, in Chinese calligraphy, a pattern: “drop of stroke - moving brush – closing of stroke”.

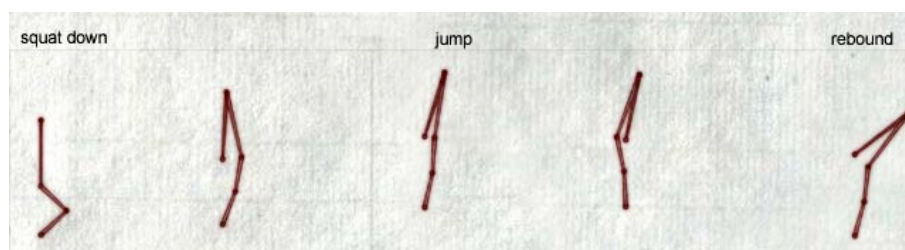


Figure 7: A dynamic life of cause. To squat down is the birth; to jump is the growth; to rebound is the death.

4.1.2.1 The Birth of Cause

For every selected dance verb, we will look for the minimum possible and physically consistent plausible cause – called “motor” - that triggers the movement of this verb. This “motor” is the origin of dancing movement. The process to find out such motor for each 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” [Bodak 2001], 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 weight center, can be considered 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 the weight 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. Once the motor is decided, the subsequent challenge is how to make motor alive, more precisely how to initiate the energy of motor.

Among the twelve Disney studio’s principles of animation [Lasseter 1987], in some action, the technique “anticipation” is required because of physical reasons: for instance, to squat down is an anticipation to rebound. “Anticipation” helps to guide the audience’s eyes to where the action is about to occur; anticipation, including motion holds, is of great importance for “announcing the surprise.” To make the

analogy with the traditional animation principle of “anticipation”, we called our process to initiate the primary energy of motor as “mystic anticipation”. It stresses the mystery of anticipation and implies that even we do not understand how our biomechanical body has its proper energy, we still initiate a plausible energy into motor effects by physics knowledge. We prefer to use this term of “mystic anticipation” even it can be felt strange in a scientific context, as more honest and modest than “intention”, as intention – and above all, the dancer’s intention remains unknown and inaccessible. Dancer imagines and feels an energy transmission through his/her dancing body, but does not care how the motion is provoked by his muscles and by his biomechanical energy.

In our system, driving cause could be designed by defining the potential energy (initial position and stiffness parameter) or the kinetic energy (initial velocity and inertia of mass).

As an example “to rebound”, if we add an initial velocity to the center gravity, causing it to fall down, the driving cause thus has a kinetic energy. If we add a potential energy to the squat state, the driving cause would thus have the ability to jump.

Another example is when a dancer twists his trunk like spiral to have torsion before doing a self-turn. During this mystic anticipation, this dancer generates a potential energy in his driving cause: gravity center. Therefore, the more torsion is, the more turns there will be. Another situation, a lead dancer does a turn because her leading partner pushes her hand. During this mystic anticipation, the lead dancer has a kinetic energy in her driving cause: hand. The more force pushed into her hand, the more turns she does.

Briefly, once the cause have been chosen and the energy initiated, which is the birth of cause, 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.

4.1.2.2 The Growth of Cause

Applying a triggering procedure from the driving cause, then, we could produce all the evolutions of the positional data, namely the trajectories of movement. The process by which causes 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 evolved 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 work.

1. “Inner propagation” principle

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. A good example is the mimic of soft elastic flying with rigid articulated arms. We can model such “inner propagation” by connecting viscous-elastic interaction.

Among the other two animation principles [Lasseter 1987], the technique “follow through” consists of the reactions of the character after an action, and it usually lets audiences know how he feels about what has just happened; the technique “overlapping” describes an action taking place because of another action. To express “follow-through” and “overlapping”, we use always “inner propagation” that assists the main action in provoking a reaction or another action. For example, analyzing walking, the step is an action; the balance of arm is a reaction; the cloth and hair are other actions. We could thus connect them through viscous-elastic interactions, for example the right foot with the left hand, and vice versa, etc.

2. “Virtual momentum exchange” principle

Another typical situation is when movement stops suddenly, without any materially 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 if 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). This skill of the dancer makes it believable that there exists a 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.

4.1.2.3 The Death of Cause

In this dynamic process, we focus on “recovery” that means to re-find a new balance. A driving cause, namely a triggering cause, may remain energetically consistent in the whole dynamic-model; or may be extinguished gradually by the influence of

environment, such as gravity, friction, etc.

After being influenced by the motor’s initial energy and the influence of environment, our body will and should stay at a new balance. With a beautiful ending, the whole effort of every cause is powerful to see and to feel. With a beautiful metaphor, the death of cause is an exhaling breath coming from an inhaling breath and going to another inhaling breath. It is a breathing rhythm for a dancing body and a dancing movement.

Our dynamic system provides an energetic consistence of this environment by elastic interaction and an energy diminution by viscosity interaction. No matter under energetic consistence or energetic diminution situation, our dynamic model always keeps energy succession during all the dynamic process. By the help of viscous damping effort, generating motions have more various nuances.

For example, in “to rebound”, the different ways by which energy is extinguishing affect different feelings of landing. A strong landing with a full rebounding comes from less energy extinguishing. In contrast, a light landing with some vibration of knee comes from diminishing energy.

4.2 Motion Modeling by Mass-Interaction Network

We propose some dance verbs to explain the “inner motor” and “external motor” concepts. Some dance verbs as “to sway” “to squat down” “to turn” are classified as “inner motor” type (in subsection 4.2.1). Other dance verbs “to walk”, “half turns step over step”, “swing steps”, etc are “external motor” type (in subsection 4.2.2).

In subsection 4.2.2.2, we select the dance verb “to work” to explain the “virtual momentum exchange” concept. Tableau II presents the organization of dance verbs in term of “inner motor type” and “external motor” type.

In subsection 4.2.3, we add environment influence, such as gravity, into the new dynamic models. Furthermore, we progress and complete the methodology: the life of the cause. The new results of dynamic models: to rebound, to jump, to flip, are presented below and explain our methodology.

Tableau II: Dance verb library and “A dynamic life of cause.

Dance Verbs	The birth of Cause	The growth of Cause	The death of Cause
Non-locomotion (Balance family)			
Sway	Inner motor: Pelvis	Push and pull	Energy conservation
Squat down (plier)	Inner motor: Pelvis	Push and pull	Energy conservation
Non-locomotion (Wave family)			
Develop (Arm)	Inner motor: Pelvis	Propagation	Energy consumption

Wave (ripple)	Inner motor: Pelvis	Propagation	Energy consumption
Non-locomotion (Turn family)			
Pirouette	Inner motor: Torsion	Push and pull	Energy conservation
Pivot turn	External motor	Propagation	Energy Absorber
Locomotion (Step family)			
Walk	External motor: Foot-take-off	Push and pull	Energy conservation
Half turns step over step	External motor: Foot-take-off	Push and pull	Energy conservation
Swing Steps	External motor: Foot-take-off	Push and pull	Energy conservation
Basic waltz step	External motor: Foot-take-off	Push and pull	Energy conservation
Contra-gravity (Jump family)			
Rebound	Inner motor: compressed leg	Push and pull	Energy consumption
Jump	Inner motor: compressed leg	Push and pull	Energy consumption
Sissonne	Inner motor: compressed leg	Push and pull	Energy consumption
Leap	Inner motor: compressed leg	Push and pull	Energy consumption
Assemblé	Inner motor: compressed leg	Push and pull	Energy consumption
Hop	Inner motor: compressed leg	Push and pull	Energy consumption
Flip	Inner motor: compressed leg	Push and pull	Energy consumption

4.2.1 Non-Locomotion (Pelvis-Triggered Motions)

For many dance verbs, the pelvis can normally be thought as a “motor”. According to the view of free dance, we are interested in finding out how the pelvis motor triggers the body and the arm motions. Some dance verbs that have the pelvis as motor are: (i) to sway, (ii) to squat down, (iii) to wave and 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.

4.2.1.1 To Sway

In “to sway” motion (Figure 8), 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 M_1 and M_2 , 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/elasticity 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 pelvis), and the driven parts (knees, legs and arms), we could obtain different qualities of motions.

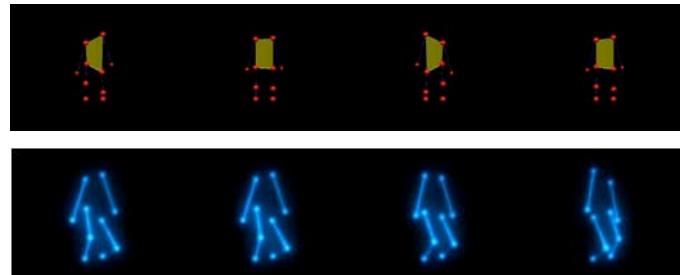


Figure 8: Snapshots of “sway” movement.

4.2.1.2 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 pelvis 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.

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 9). 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 is 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.

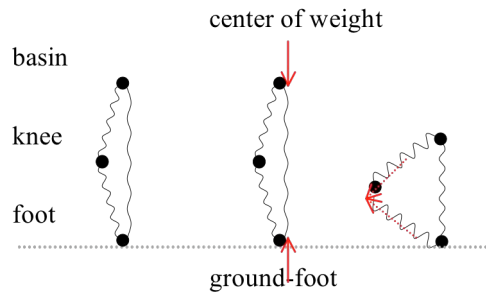


Figure 9: Dynamic model of “to squat down”.

4.2.1.3 To Wave and to develop

The "to develop" movement is a very slow and continuous movement of unfolding an arm or a leg, resulting from pulling the elbow, which in turn induces the motion of the others arm segments (wrist, hand, fingers). The motion along the arm is like a wave propagation 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. The visco-elastic interaction force can produce a jerky/bounded movement (Figure 10-left) or a soft/fluid movement (Figure 10-right), according to the values of masses (m) and of visco-elasticity (k, z) between the elbow, the hand, and the fingers. The driving force could be an external motor, which impact on the mass-elbow for provoking wave propagation (Figure 11). While this dynamic model “to develop” connects with other dynamic model hierarchically, a driven mass from other dynamic model may be designed as the driving motor into “to develop”.

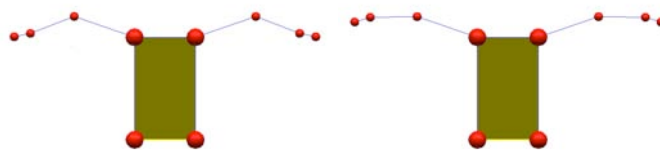


Figure 10: Snapshots of “to develop”.

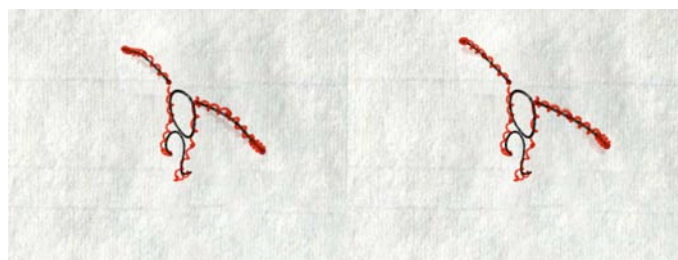


Figure 11: An impulse of arm wave motion.

Next, we propose a dynamic model for the verb “to ripple” that has an expression of wave propagation under material spine. When the dynamic model of “to ripple” stays in the static balance, it produces a breathing motion as a real human. After an external driving force sets the spine into action, an influence propagates from spine until the end of limbs. Through this dynamic model, we obtain a sustained and continuing movement with breathing. It is so naturally soft in comparison with a mechanical movement from a robot or usual articulated virtual body. This kind of movement is a suited presentation for contemporary dance.

“Dolphin” is a similar movement to ripple. The difference is that the dolphin motion starts wave motion from a head; ripple motion starts wave motion from the basin. From this model “to ripple”, by modifying the parameters, several varieties of wave motion, i.e. swimming, could be obtained (Figure 12).

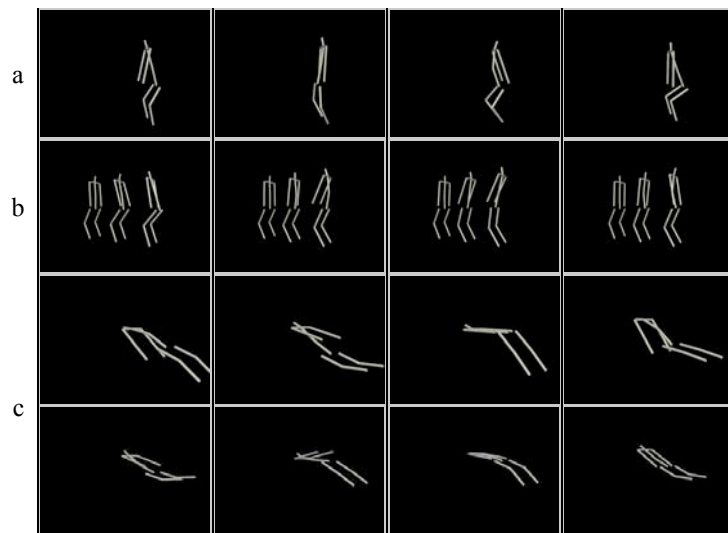


Figure 12: (a) “ripple” movement; (b) the different degree of driving force; (c) a variety of wave movement: swimming.

In brief, these verbs, “to develop”, “to ripple”, and “to dolphin”, have the common pattern: “wave propagation”, this pattern being able to be simulated easily and suitably by our methodology of “inner propagation”. Furthermore, because of hierarchical modularity propriety, it is possible to compose these dance verbs (Figure 13), for example, wave propagation from basin to fingers. It shows not only the possibility of composition but also the property of energy succession under the same rhythm and the same original motor.

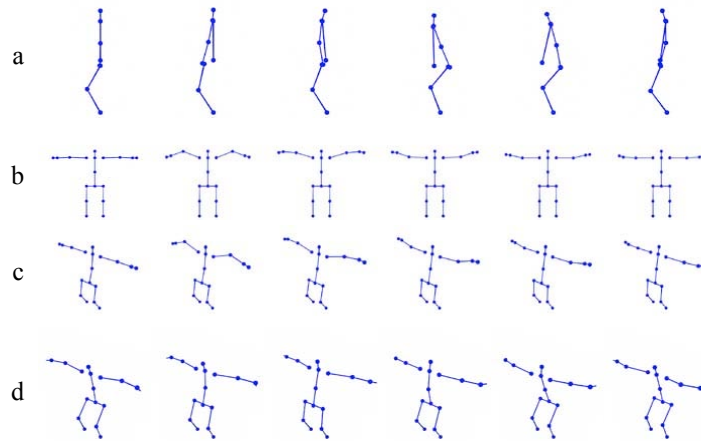


Figure 13: (a) “ripple” movement; (b) “arm wave movement”; (c) “arm wave movement” is added to “ripple movement” without interaction; (d) “spine wave movement” connects with “arm wave movement” with interaction.

4.2.1.4 To Turn

“To turn” is an essential movement of dance and includes some styles of turn, e.g. “pirouette”, “spin turn”, “pivot turn”, 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 pelvis 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 (Figure 14). After a little change in the initial positions of the masses representing the hip, a torsion force appears immediately between the pelvis and the feet, trying to return to the rest state. 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 14: Snapshots of four instant of the physically based model for the verb “To turn”. The two sides (right and left) are represented by two different colors.

Figure 15 and Figure 16 present snapshots of a film produced 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 15: Snapshots of pirouette.

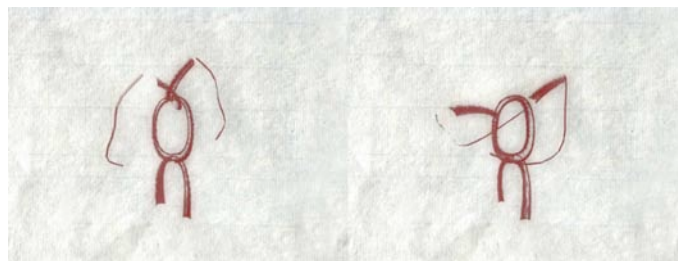


Figure 16: An expressive visualization of pirouette.

4.2.2 Locomotion (Foot-Take-of 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 pelvis 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 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.

4.2.2.1 One foot locomotion model

In the direction of the displacement, when the foot stops, all it happens as if the foot loses 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 D_a (resp. D_r). When thresholds are reached, there is a complete motion quantity transfer from one mass (from $v_1=v$ to $v_1=0$) to the other (from $v_2=0$ to $v_2=v$). The foot-mass is starting its motion by means of an initial velocity (Figure 17-a). The initial distance between the foot-mass and the medium-mass is less than D_a . Since D_r is reached, the foot-mass and the medium-mass are colliding (Figure 17-b) by a conservative hit. The foot-mass stops and the medium-mass starts to move. Since D_a is reached, the foot-mass starts to be attracted by the medium-mass (Figure 17-c), 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.

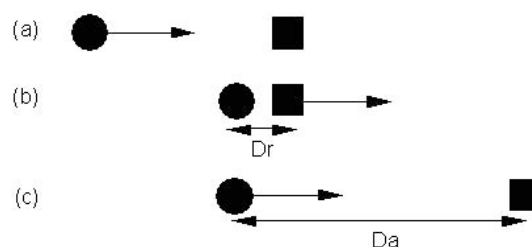


Figure 17: Physically based model of “virtual momentum transfer”. The foot-mass is the circle and the medium-mass is the square.

4.2.2.2 Two feet locomotion 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 pelvis. The pelvis 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 pelvis, 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 pelvis.

Biomechanics 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 D_a) and only one foot (the right foot on Figure 18-a) has an initial velocity. When the right-foot is at D_r of medium-mass, it stops and the medium-mass starts to move (Figure 18-b). The first mass that will be at D_a of the medium-mass is the left-foot. Thus, the medium-mass stops and left-foot starts to move (Figure 18-c). Thus, the medium-mass gives alternatively its energy to the left-foot (Figure 18-c) and to the right-foot (Figure 18-e) after having received its energy alternatively from the right-foot (Figure 18-b) and from the left-foot (Figure Figure 18-d).

By applying different values of the parameters for each foot (D_a and D_r , initial velocity, initial positions), we obtained various types of walking: symmetric, non-symmetric, fast, slow, etc.

Figure 37 shows a walking from right side to left side. Each snapshot presents “virtual momentum exchange” between the right foot (a red sphere) and the virtual mass (the circle) or between the left foot (another red sphere) and the virtual mass.

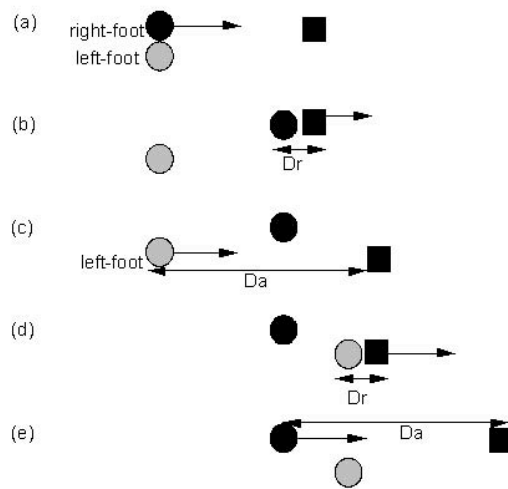


Figure 18: Improvement of the physically based model for the two feet walking. The right foot-mass is the black circle and the left foot-mass is the grey circle.

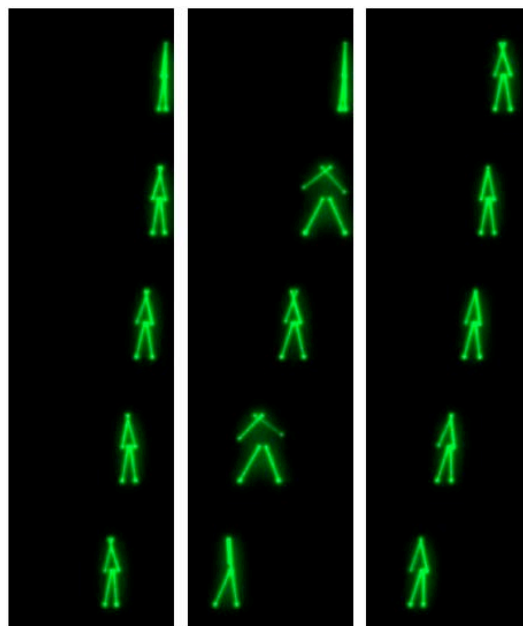


Figure 19: (a) Regular symmetric walking; (b) asymmetric walking; (c) composed walking of two different walking velocities.

4.2.2.3 Half turns step over step: “to débouler”

“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 20-(a) shows the spatial trajectories of both feet for this movement.

Figure 20-(b) 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 20-(c). 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:

$$V_{xi} = (Dx / Pi) * \text{sqrt} (k/m)$$

$$V_{yi} = (Pi / 2) * V_{xi}$$

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

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 21 shows an expressive visualization of the simulation of “half turns step over step”.

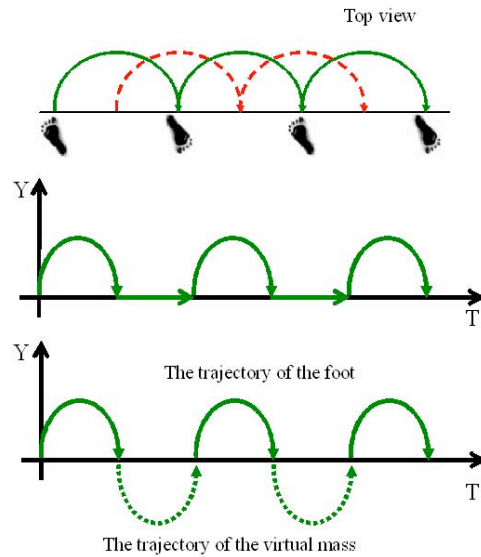


Figure 20: (a) Spatial trajectory of feet; (b) Y-directional space and time of one foot; (c) trajectory of virtual medium.



Figure 21: Visualization of "half turns step over step".

4.2.2.4 Swing 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 22-a). 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.

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 V_x 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 22-a. By adding similar motion in the Y direction, we obtain the 2D waltz footsteps, as drawn in Figure 22-b.

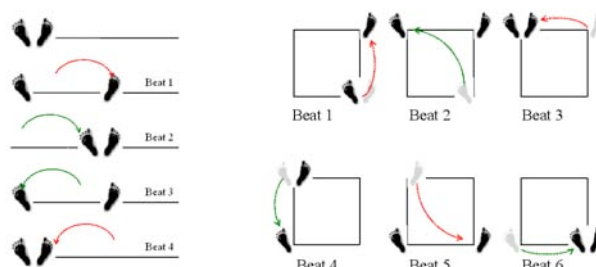


Figure 22: (a) Swinging steps; (b) the primary waltz steps.

4.2.3 Contra-Gravity

In this subsection, we interplay with the kind of jumping verbs with an environment influence such as gravity. The interesting point here is that one simple model can derive a variety of jumps as “jump, leap, hop, sissonne, assemblé”, moreover generates other mutations as “flip”, etc.

4.2.3.1 To Rebound

Analyzing a simple vertical rebounding, there are some phenomena during this action: The gravity center comes down and leads the knee to squat. The knee stretches lead the body to rise up. Finally, the feet and knees bounce and vibrate. By dynamic view, we suppose this action also has 3 periods: (1) The gravity center has a kinetic energy that leads the knee to squat down; (2) Having a potential energy, the leg pushes the floor to compensate the gravity and rebounds; (3) The gravity centre has small vibrations and try to find out his new balance. There are exactly three sections according to our methodology: (1) Mystic Anticipation; (2) Inner propagation; (3) New balance (cause frustrating or cause extinguishing).

In our model “to rebound”, such movement is modeled with four masses, one for the basin, one for the foot, one for the knee and one for a virtual-symmetric knee. The virtual-symmetric knee is designed to keep the knee in the right transversal translation direction, because the knee is limited in its rotate degree of freedom in anatomy. Each

of them are linked by only six viscous-elastic interactions (Figure 23).

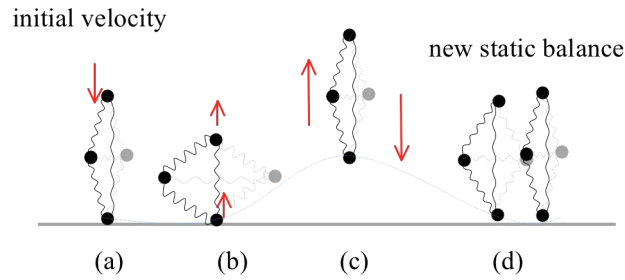


Figure 23: Dynamic model of “to rebound”

Because the dancer squats down without a conscious thinking of what the explicit gesture of knee should be, we put the weights of mass-knee and mass-virtual knee relatively lighter than the weights of mass-basin and mass-foot. It means exactly that the mass-knee is the reaction to the mass-basin and mass-foot. Because of the physically solid leg, we set the elastic interactions stronger between them (basin and knee, foot and knee, basin and virtual-symmetric knee, foot and virtual-symmetric knee). The viscous-elastic interaction between knee and virtual-symmetric knee causes a small the vibration of the knee. The viscous-elastic interaction between basin and foot is the main factor deciding the highness of jump and the vertical bounce.

Once the viscous-elastic interactions have been set up, that is to say our simplified character model has the ability to react by a driving force into motor, the user could easily and intuitively control the movement “to rebound” by giving an initial vertical velocity into mass-basin. The higher driving force leads to a deeper squat down and a higher rebound (Figure 24). It reflects well the thinking of dance: to jump higher, dancer needs to squat down more and pushes the floor more. Besides, the user could change the degree of gravity that implies the influence between environment and human action. Thus, this model of “to rebound” can generate different rebounding under the same condition (the same character, the same driving force) in different environments, for example on the earth or on the moon.

When a driving force with velocity (V_0) is applied onto the mass representing the basin (m_{basin}) as shown in Figure 23-a, it exists a kinetic energy for the entire model. Then, the kinetic energy is transferred to potential energy by the function of spring. Figure 23-b shows that the entire model stays at the maximum amplitude of squat without any velocity, so there exists only potential energy. Figure 23-c shows the rebounding provoked by potential energy and it finds out another dynamic balance at the highest level. Figure 24-a shows that an initial force $V_0=15$ leads a little rebounding; Figure 24-b shows $V_0=30$ leads a higher rebounding; Figure 24-c shows $V_0=45$ has the highest rebounding; Figure 24-d shows $V_0=45$ with more vibration of

knee.

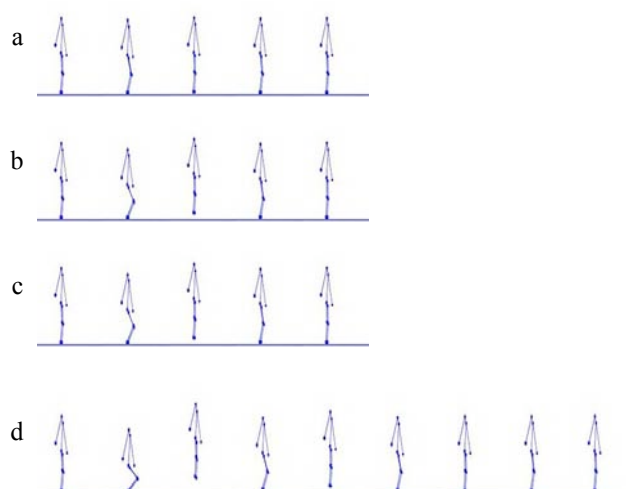


Figure 24: (a) $V_0=15$ leads a little rebounding; (b) $V_0=30$ leads a higher rebounding; (c) $V_0=45$ has the highest rebounding; (d) $V_0=45$ with more vibration of knee.

Through this model of “to rebound”, these parameters are well suited for the thinking of dance: the mass is in accordance with body weight; the viscous-elastic interaction is in accordance with our muscle and it is chosen to fit our way to dance. By adjusting these parameters, we could have a high/low rebounding, rigid/soft landing, sustained/sudden vibration before stopping (arriving to a new balance). Moreover, all the movement is provoked by an initial energy (a driving force applied onto the mass of the basin) and all the process is in well accordance with energy transmission, which is treated by “inner propagation” in our approach. It is thus an ideal interactive way to assist choreography and includes the philosophy of dance dynamics into science technology.

4.2.3.2 To Jump

Jump is a so beautiful movement that expresses the dream of flying and the courage to resist to our physical world. No doubt that jump is a very important action, and that dancers have interpreted many varieties of jump by composing with two legs' take-off, flying and landing. In Tableau III, we list five basic forms of jumps: **Jump** from both feet to both feet; **Leap** from one foot to the other foot; **Hop** from one foot to the same foot; **Assemblé** from one foot to both feet; **Sissonne** from both feet to one foot.

Jump consists in a horizontal motion such as the “grand jeté” and a vertical motion such as “a free falling object”. When the body is thrown in the air, the gravity center's trajectory is a parabolic curve. In physics, the parabolic trajectory of a projectile is decided by: the initial velocity composed of horizontal and vertical components, the

weight and the gravity. Kinetically, the projectile motion could be seen as the abstraction of a jump movement while flying.

Further more, in view of dynamics, for a jump action, both take-off feet receive their momentum because of pushing together the ground. For leap action, the take-off foot receives its momentum because the other foot squats down and pushes the ground. In our live experience, to leap from one leg to the other leg, we always care about the support-leg pushing the floor to provoke the other leg to take off. However, what happened indeed between the support leg and take-off leg is complex and the complete mechanism could not be virtually implemented. In fact, human body is a self-driving motor so complex in biomechanics that we do not know how human anticipates the exact quantity of energy necessary to act. In our approach, it is exactly “mystic anticipation”.

Tableau III: Five types of “to jump”.

	Form	Modeling
Jump	from both feet to both feet	two identity strong legs; two take off driving force
Leap	from one foot to the other foot	two identity strong legs; one take off driving force
Assemblé	from one foot to both feet	two identity strong legs; one take off driving force; quickly inner propagation
Hop	one foot to the same foot	two different strong legs; one take off driving force
Sissonne	from both feet to one foot	two different strong legs; two take off driving force

In this “mystic anticipation”, instead of looking for how the take-off foot has its momentum, we are looking on how its momentum acts physically on the remaining action. We simplify the problem of getting the primary energy with an intuitive and plausible designing (motor initiating). So, the take-off foot is initiated with a kinetic energy that implies an explosion immediately of this fly leg. Then the fly leg will trigger the support leg to fly. In the same way, jump action occurring on both take-off feet, we thus initiate kinetic energy into both feet. Briefly, our approach focuses on plausible dynamic anticipation instead of pose anticipation. For instance, “squat down” is a “pre-movement” to anticipate a “jump”; however, the most important is not to design the “pose of squat down” but to initiate energy into “the state of squat down”. This “mystic anticipation” generates jump action physically and variously.

To model the series of “to jump” action, we derive each leg motion from the prototype of “to rebound” model. We connect the right and left legs with a viscous-elastic interaction between both mass-basins. In addition, we can also connect both mass-feet to achieve certain various jumps. Thus, the energy could be

transmitted between two legs due to “inner propagation” (Figure 25). Figure 25-a shows “mystic anticipation” of dynamic model “to leap”. In the first step of “mystic anticipation”, this dynamic model is under “squat down” state, which means it has potential energy to rebound vertically. In the second step of “mystic anticipation”, we initiate kinetic energy to provoke a horizontal locomotion by two forward horizontal driving forces. One is given into basin and leads to the advancement of the whole body; another is given into take-off foot and leads to a “fly forward” movement for the take-off foot. Then, Figure 25-b shows the “inner propagation” during which the advance momentum is transferred from take-off leg to support leg with the help of basin’s viscous-elastic interaction. In the end, Figure 25-c shows the dynamic model, which finds out its new balance under the environment influence.

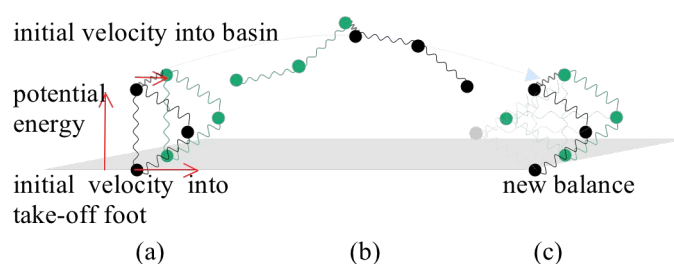


Figure 25: Dynamic model of “to leap”.

As mentioned, by initiating a kinetic energy into one foot or two feet, we decide to take off with one foot (leap) or two feet (jump) and also the distance of flying. By designing the parameters of legs’ viscous-elastic interactions between basin and foot, the two legs will have different strong muscles, which means that the two legs have different potential energy. Thus, it leads the difference about fly time and highness of jump (hop and sissonne). In case of “assemblé”, it acts in the same way: to take off with “leap”; then, the interaction between two legs (inner propagation) regulates the transfer of advance momentum, so it causes if two legs land together (assemblé) or not (leap).

To sum up, all the varieties of jump action are based on a typical action that consists in “to be opposed” to the gravity. We have provided the powerful way of generating such varieties of jumps just by initiating “mystic anticipation”. Therefore, we believe that such dynamic generation is more intuitive and physically plausible than kinematics based animation or anatomically-based physical models.



Figure 26: (a) jump, (b) leap, (c) assemblé, (d) hop, (e) sissonne, (f) a bound jump, (g) a free jump.

4.2.3.3 To Flip

Flip is a jump action combined with an added self-rotation (Figure 27). Derived from “to jump”, we could have another dance verb “to flip” by initiating “mystic anticipation” differently. In the “mystic anticipation”, we design a horizontal velocity V_1 into take-off foot, and another horizontal velocity V_2 into take-off basin.

Because mass-knee is relatively lighter than mass-basin and mass-foot, we simplify the leg model as

Figure 28. By playing these parameters, the difference of velocity ($V_1 - V_2$) decides the forward or backward direction. Using the difference of angular velocity ($\omega_1 - \omega_2$) expression, one decides the direction of rotation. Figure 29-a shows backward flip to back; Figure 29-b shows backward flip stay; Figure 29-c shows forward flip stay; Figure 29-d shows forward advance. We illustrate, thus, a simplification of one leg’s flip. In a similar way with “to jump by two legs or one leg”, we can derive wide varieties of flip action.

To sum up, this “to flip” model presents the powerful way of “mystic anticipation” that allows to obtain such wonderful results only by modifying some parameters. It

means a high-level and intuitive motion control. Besides, from “rebound” through “variety of jump” to “variety of flip”, one has the possibility to develop the existing dynamic models and to combine them into a more complex model. It shows the advantage of modular motion design by physically based particle modeling. Moreover, even though the “to flip” is a highly dynamic and complex motion in the whole character structure, in the frame of dynamic model, “to flip” is refined as two principal masses with one principal interaction (Figure 28). Thus, the velocity of rotation can be designed easily by this simplest pattern: driving V_1 and driving V_2 . However, the most important thing in this model is how to perform the rotation movements rather than the velocity value.

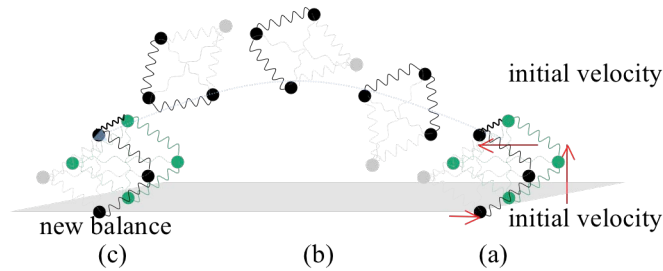


Figure 27: Dynamic model “flip backward”.

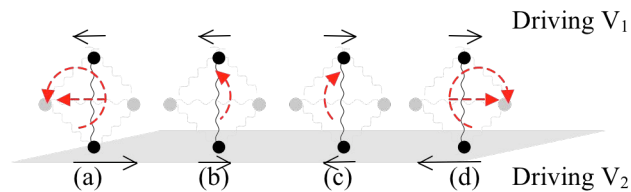


Figure 28: The simplest pattern of “flip”.

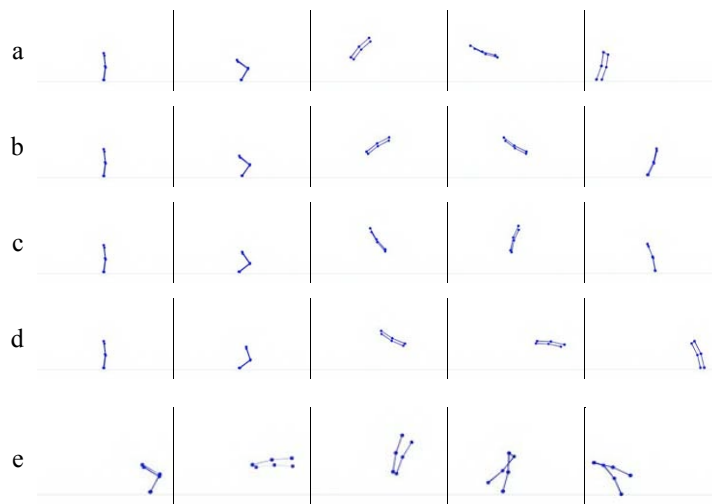


Figure 29: (a) backward flip to back, (b) backward flip stay, (c) forward flip stay, (d) forward flip advance, (e) a variety of backward flip.

5 The Second Level of Modeling for Quality

Usually, computing system is developed to have more complexity and offer user more the functions. Therefore, mathematic algorithms try to solve more complex equations and to improve efficiency. We pioneer another direction in the thesis. In this chapter, following up our process of thinking about simplicity, first we abandon (suspend) the modeling method by mass-interaction network, which is presented in the chapter above. More precisely, we abandon (1) the network topology to the benefit of more simple structure made only with string topology and (2) we come down to more simple interaction – spring with damping, abandoning with collision, attraction, etc, to reduce the interaction forces to linear elastic ones.

We assume that if we can simulate natural phenomena by simpler rules, we will have more the chance to approach the reality. By this way, we encounter the most difficult and the most profound challenges, because, to simulate complex phenomena by a simpler way should understand really the cause-effect of the phenomena.

In terms of dance writing, we argue that choreography should not composing dance verbs in the first step. It is easier to compose a series of movements (dance verbs). But, how can we keep quality coherent after composition. We orientate thus our direction to qualitative research, i.e. dance adjectives. From then on, we can choreograph fluently in terms of quality towards emotion, not just in terms of motion trajectory.

To sum up, this chapter is the evolution of the chapter above. It progresses successfully on simplicity on two aspects: one is the shift of the modeling method from mass-interaction network topology to mass-spring-damper based string topology; the other is concerning on quality from motion.

5.1 Dance Adjectives

In section 4.1, we extract “the life of cause” from dance verb tree. The life of cause, implying the “cause” of movement and the whole effect of the “cause”, aims at constructing a dynamic coherence within every dance verb. In this section, we move forward for “quality”, namely dance adjective. Based on the life of cause, we intend to search for qualitative control more generally. Hence, we orient our aim toward “the way of energy transmission”. Different with the section above that action occurs dynamically but not precisely enough, we aim to control energy transmission strictly to obtain quality precisely.

5.1.1 Methodology: Deconstruction II

From movement to quality... It is a great evolution in terms of thinking and physical based modeling as well. In terms of thinking, we must imagine fantastic phenomena to reflect and embody the qualities. In terms of modeling, we need to treat carefully micro interaction during dynamic processes.

In section 4.1, human body interacting with the environment has been simplified as mass-interaction network (set of viscoelastic, collision and attraction forces networking a minimal set of masses). The strength was to figure out the initial cause, which sounded like pre-action of movement understanding knowledge, and then to provoke certain dance actions physically. The minimal and essential masses presenting human structure was a very interesting cue. Although giving the quantity of initial energy controls the motion's qualities, it did not mention the key factor of inner body states. Nor did it take care of the coherent quality after composition.

Compared with the work above, a new modeling – Flowing Dance Modeling (FDM) – is based on mass-spring based string without energy loss. FDM assigns wanted masses for different levels of detail that makes motion more fluid/fine in comparison with their excited/rude quality. FDM takes care of the body's inner state and coherent quality and keeps the conservation of energy.

5.1.2 Energy Transmission & Flowing Itinerary

After extracting the first concept, “a dynamic life of cause” within dance verbs, we move forward to qualitative control. Aiming at dance adjectives, we address the relation between “energy transmission” and human hierarchic structure. Thus, we orient our aim toward “the way of energy transmission” instead of “the occurring cause”. The second concept, “energy transmission on imaginary itinerary”, infers the essential connection between physically energy transmission and artistically flowing itinerary.

Because “energy transmission” is formless and theoretical, we should track motion by its “plausible logic” in dynamics. We pose some reasons why it is difficult to perceive “flowing itinerary” with “source” and “energy transmission” behind human motion. While there are double or multi “sources” that influence each other on the itineraries, it is thus difficult to recognize their “energy transmission”. While “energy transmission” circulates, it is difficult to perceive where the “itinerary” starts to and end in. We might perceive the “energy transmission” but not the “source”. While

“energy transmission” jumps within limbs, it is less intuitive for brain expectation to perceive it. When “energy transmission” is too fast, we see the whole motion without perceiving the details of “energy transmission”.

For these reasons, the new modeling – Flowing Dance Modeling (FDM) – is asked to be flexible for the user, to create “imaginary itinerary”. In fact, the sequencing of masses is the key to construct the flowing itineraries. The number of masses on flowing itineraries implies the levels of detail for finesse. Flowing itineraries of FDM can be very creative depending on the animator’s imagination. Then, FDM can implement single dancer and a group of dancers as well.

Figure 30 shows that the sequence of masses is decided according to selected dance verbs and choreographic movement.

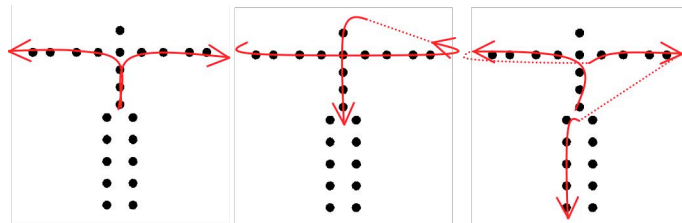


Figure 30: Creating flowing pathway for different dance verbs.

5.2 Quality Modeling by Mass-Spring String

Inspired from Gerstner’s model, that particles of water describe circular stationary orbits, we imitate string for continuous wave by discrete masses. Nevertheless, we do not draw wave-shape but we simulate its dynamics with “source” and “energy transmission”.

We simplify FDM in uni-dimension and illustrate its motor schema. For better comprehension, we illustrate transverse wave instead of longitudinal wave to present this uni-dimension schema (Figure 31-a). We intend to model that a driving force (initiated by m_0) put strings ($m_1 \sim m_n$) in vibration. Mass 0 is a part of oscillator system that is regarded as a driving force. The others masses (Mass $m_1 \sim m_n$) are connected in sequence by linear springs (stiffness $k_1 \sim k_n$).

Subsection 5.2.1 describes how to imitate an ideal string by mass-spring. Subsection 5.2.2 shows string’s reflection and refraction effect. Subsection 5.2.3 describes how to compose strings in parallel and in series. Subsection 5.2.4 describes how to compose driving motors for motion composition.

5.2.1 Traveling Wave

In the first step, we link the primary mass (inertia m_0) with a spring interaction (spring constant k_0) in a frictionless environment. The primary mass hence has a simple harmonic oscillation. The angular frequency (w_0) depends on the square root of k_0/m_0 . According to Newton's second law, the motion of primary mass can be illustrated by the Equation 3, where ψ_0 is the displacement, A_0 is the amplitude and φ_d is the phase.

In the second step, we consider the primary mass as a driving motor. We set other masses as driven masses, which are much slighter than the primary mass ($m_0 \gg m_1, m_2, m_3, \text{ etc}$), to diminish the feedback force towards the driving motor. The first driven mass (m_1) is connected to the driving motor (m_0) with a spring force (spring constant k_1) without friction. Then, the motion of m_1 can be illustrated as the Equation 4, where ψ_1 is the displacement, A_1 is the amplitude, φ is the phase.

$$F_0 = m_0 (d^2\psi_0/dt^2) = -k_0 \psi_0$$

$$\psi_0(t) = A_0 \exp[i(w_0 t + \varphi)] = A_0 \cos(w_0 t + \varphi_d) \quad \text{Equation 3}$$

$$m_1 (d^2\psi_1/dt^2) + (k_1 \psi_1) = F_0 \cos(w_0 t + \varphi_d)$$

$$\psi_1(t) = \psi_{transient} + \psi_{steady\ state}$$

$$= A_h e^{-\gamma t} \sin(w't + \varphi_h) + A_1 \cos(w_{oscillator} t + \varphi)$$

$$\cong A_1 \cos(w_{oscillator} t + \varphi) \quad \text{Equation 4}$$

Thirdly, we connect the other driven masses in series. We suppose that all the driven masses have equal inertias and spring constants to simplify the complexity, but later on, we can modify the inertia and stiffness. A special case here is to construct an ideal string by a series of discrete masses and springs. To imitate a traveling wave on an ideal string, we encounter a serious challenge: all the masses have the different frequencies, amplitudes, and phases. In other words, the modeling will be uncontrollable because all occurs under dynamic processing. Since the driving energy goes through finite driven masses and then comes back, it (motion equation of every mass) becomes more and more complex after every superposition. The wise idea is to do as if we had an infinity of driven masses, therefore, the energy generated by oscillation moves forward without ever returning. However, it is not convincing to design a huge number of masses and springs because of ill efficiency.

The proposed trick is to give a special force on the last driven mass to balance the

force from the last spring. Comparing a mechanical harmonic oscillator with an RLC circuit, the impedance, which can keep the energy within a circuit without loss, is exactly the solution. Therefore, we design a viscosity force equating the square root of $k_n \cdot m_n$. The equation is deduced as below:

$$\begin{aligned}
 F_n^+ &= m_n (d^2 \psi_n / dt^2) + k_n \psi_n \\
 F_n^- &= Z_n (d\psi_n / dt) \\
 F_n^+ &= F_n^-
 \end{aligned}
 \tag{Equation 5}$$

To satisfy the Equation 5, Z_n , which is called characteristic impedance, is equal to the square root of $k_n \cdot m_n$. If the given viscosity is under the characteristic impedance, the propagating energy reflects back; if the viscosity is over the characteristic impedance, the propagating energy diminishes gradually along driven masses.

Fourthly, we compare the obtained traveling wave with wave equation. Since wave motion can be interpreted as a manifestation of Newton's second law on a microscopic level, what we do when connecting masses only by spring interactions is to consider that, like waves, they can propagate.

Because all driven masses and springs are equal, they can be regarded as an ideal string, which has its natural frequency of material oscillation (w_{nature}) and its material impedance (Z_n). We denote w_0 as $w_{\text{oscillator}}$ meaning the frequency of oscillated force. Then, our basic travelling model can be written as Equation 6, where ψ_n is displacement of nth mass, A_{force} is amplitude of driving motor, φ is phase between two adjacent masses, $V_{\text{propagation}}$ is propagation velocity.

$$\psi_n (n, t) = A_{\text{force}} \cos (w_{\text{oscillator}} t + \varphi_n)
 \tag{Equation 6}$$

The phase and the propagation velocity depend on $w_{\text{oscillator}}$ and w_{nature} (square root of k_n/m_n). The amplitude depends on A_{force} and Z_{nature} (square root of $k_n m_n$). Thus, we can tune the flowing mode for different qualities by controlling these parameters: A_{force} , $w_{\text{oscillator}}$ (square root of k_0/m_0), k_n and m_n . If $w_{\text{oscillator}}$ is lower than w_{nature} , the vibration of string is below resonance; if $w_{\text{oscillator}}$ is higher than w_{nature} , the vibration of string is above resonance; if $w_{\text{oscillator}}$ is equal to w_{nature} , the vibration of string is on resonance.

In the aspect of qualitative control, we master resulting wave-shape comparing to Laban's effort-shape theory by these parameters: 1) amplitude for strong/light, 2) phase for direct/indirect, 3) frequency for sudden/sustained. For each quality, we have

our proper explanation, which corresponds to energy propagation. For example, according to Laban, a direct movement has less curvature in motion trajectory. We think that a direct movement signifies that energy propagates more directly between media to cause smaller phases between masses. That way, there is less curvature in result. Another example, strong movement has more amplitude, apparently; however, we are interested in the signification of “strong”: the oscillator’s given energy is relatively higher than the string’s impedance. Thus, stronger energy causes higher effects.

To sum up, we model a traveling wave based on discrete mass-interaction strings. A series of masses-springs is an ideal string with two material properties: material frequency (w_{nature}) and material impedance (Z_{nature}). In consequence, we resolve the uncontrollable difficulty of mass-interaction model. Later, we can combine strings in series or in parallel for complex strings.

Furthermore, we can assign wanted masses and springs to present energy transmission in different levels of detail.

5.2.2 Reflecting and Standing Wave

Before combining strings, we must carefully deal with the reflection and refraction effects on the boundary of two individual strings. Considering the basic modes of a reflecting wave, we design a fixed end-point and a flexible end-point, as below.

In the mode of fixed end-points, we assign the last mass as the ground, which has infinite inertia ($m_n = \infty$) and immobility. Due to the infinite inertia and immobility, the forces at the last mass (m_n) equal zero ($\Sigma F_n = 0$). Therefore, there is a spring force feedback from m_n to m_{n-1} , and that models exactly the force effect at fixed end-points. Then, according to our dynamic process only with mass-spring interaction, this feedback force can be regarded as a reflecting wave that occurs at fixed boundaries.

In the mode of flexible end-points, we do nothing on the last mass. Because spring between m_n and m_{n-1} can provide interaction all the time, it is exactly the ideal state and is similar to flexible end-points. In other words, the last spring (k_n) receives and transforms the external force into potential energy. Then, it (the last spring) releases kinetic energy as a reflecting wave.

After modeling the reflecting wave at end-point, naturally and automatically, we have the phenomenon of standing wave, but only if the harmonic oscillator keeps working under the same puissance (strength or force) and frequency. The important point is that the phenomenon (obeying at natural law) can be implemented (be modeled) without mathematical explanation. That is to say, even if we cannot resolve a complex exponential or differential equation of harmonic motion, the physical phenomenon

can still be reproduced, but only if all the microscopic interactive forces obey Newton's law during the entire process.

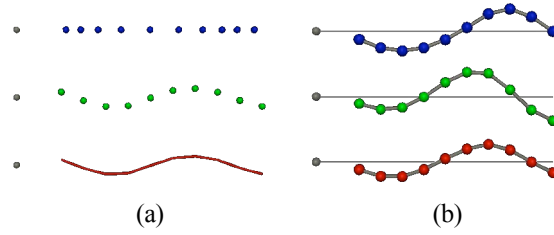


Figure 31: (a) A sequence of masses-springs presents an ideal string; (b) from up to down are fixed end-point, flexible end-point, and null end-point (characteristic impedance).

Figure 31-(b) shows three special cases on the boundary: Fixed end-point (up) means the perfect reflecting wave with inverse phase ($\varphi=\pi$); Flexible end-point (middle) means the perfect reflecting wave with the same phase ($\varphi=0$); Coincidence with characteristic impedance (down) means no reflecting wave. Furthermore, we must treat general boundary effect for string combination. As described in subsection 5.2.1, each ideal string based on mass-spring has its natural frequency (square root of k/m) and impedance (square root of $k*m$). Such material impedance is the exact factor determining the distribution of energy. While two strings adjoin in series, the dispersion of energy can be illustrated as Equation 7, where Z_1 is the first string's impedance, Z_2 is the sequent string's impedance, $E_{\text{reflection}}$ is the energy of reflection, and $E_{\text{transmission}}$ is the energy of transmission.

$$E_{\text{reflection}} = E_{\text{incidence}} [(Z_1 - Z_2) / (Z_1 + Z_2)]$$

$$E_{\text{transmission}} = E_{\text{incidence}} [(2*Z_1) / (Z_1 + Z_2)]$$

$$E_{\text{incidence}} = E_{\text{transmission}} + E_{\text{reflection}}$$

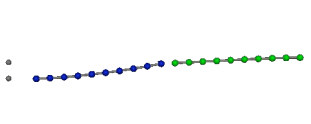
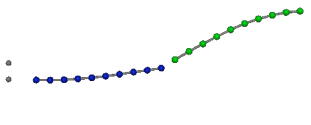
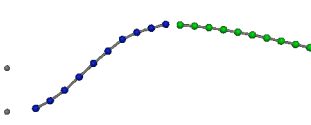
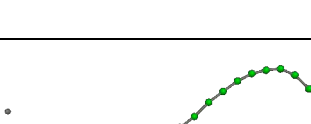
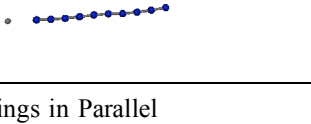
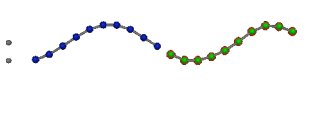
Equation 7

To sum up, we model traveling waves encountering fixed or flexible end-points, and indicate how energy dispersion relates to the material impedances (Equation 7). We state that our mass-spring based string could react on physical phenomena logically according to Newton's second law. However, it is important that we make progress with the fundamental challenge of controllability, which has always been left unanswered by such direct dynamic processes. In the next subsection, we propose precisely how our flowing modeling benefits by Equation 7.

5.2.3 Variety of Driven Propagating Wave

In this subsection, we introduce some possibilities to vary driven propagating waves. In order to take into account of energy conservation and traveling fluency, we must avoid the interruption from reflecting waves to maintain a fluent flow. Thus, we propose to take care of the constancy of impedance on the boundary ($Z_1=Z_2$, $E_{\text{reflection}}=0$), unless a disturbance phenomenon is wanted. In Tableau IV, we list several transitional examples: amplitudes ranging from large to small, or small to large, propagation velocity ranging from fast to slow, or slow to fast.

Tableau IV: Propagating Waves in Series and in Parallel.

Composing Strings in Series	
Amplitude Large to Small Thin to Thick $Z_1(k, m) < Z_2(2k, 2m)$	
Amplitude Small to Large Thick to Thin $Z_1(k, m) > Z_2(0.5k, 0.5m)$	
Propagating velocity Slow to Fast Sparse to Dense $w_1(k, 2m) < w_2(2k, m)$	
Propagating velocity Fast to Slow Dense to Sparse $w_1(2k, m) > w_2(k, 2m)$	
Composing Strings in Parallel	
Composing, in parallel, the same material but thin/thick strings results in the same amplitude	
Transition of propagating velocity; composing strings by different materials.	

To sum up, when composing strings, we take into account how waves propagate along mass-spring based strings. It can be a flow starting slowly, flowing quickly, vanishing slowly; or it can be a small wave translating to a big wave, etc. It implies

quality changes in space. We focus here not only on composing various wave propagations, but also on treating every transition perfectly on the boundary. Such perfect transitions might not exist in reality, but they exist ideally. Later, we aim to control dance dynamically by such perfect transition without any interruption in flowing.

5.2.4 Variety of Driving Oscillator

5.2.4.1 Single Linear Oscillator

In analogy to playing a musical instrument, we can “pluck” to oscillate our mass-spring based strings in order to generate wave motion. Firstly, we assign the driving motor doing simple harmonic oscillations without energy loss ($Z_0=0$). Then, giving damper into the driving motor, we have under-damped ($Z_0 < 2 \cdot \text{square root of } k_0 m_0$), critical damped ($Z_0 = 2 \cdot \text{square root of } k_0 m_0$) or over-damped ($Z_0 > 2 \cdot \text{square root of } k_0 m_0$) vibration of driving motor. Percussion can be modeled as a critical or an over-damped oscillation. However, the way to attain a better performance of percussion is to give a slight under-damping, e.g. half of the critical damping ($Z_0 = \text{square root of } k_0 m_0$), because the system can react more quickly under acceptable slight bouncing. By way of percussion, we can generate motion towards excited effects in comparison with simple harmonic oscillations.

5.2.4.2 Single Planar Oscillator

Then, we extend oscillator composing to two directions: X and Y for planar motion, similarly for spatial motion. According to Lissajous’ curves [Cundy and Rollett 1989], the variety of trajectories depends on the square root of w_x/w_y and on the difference of phase. Therefore, we can assign planar oscillation trajectories as a line, a circle, an ellipse, a parabola, an eight-twist curve, etc. Then, these planar patterns generated by the oscillator propagate along the path of mass-spring based string. The provoked motions on strings are thus the same as the mutation or the evolution from the oscillator.

5.2.4.3 Coupled Oscillators

At this point, we can compose, as time goes on, one oscillator having several

characteristics: damped, non-damped, lineal, planar, spatial motion, etc. Moreover, we go forward on the particular case of coupled oscillators: two oscillators (m_0^α and m_0^β) are fixed separately by two springs (k_0^α , k_0^β) and are coupled by one spring (k_0^γ). The motion function of these coupled oscillators can be illustrated as Equation 8.

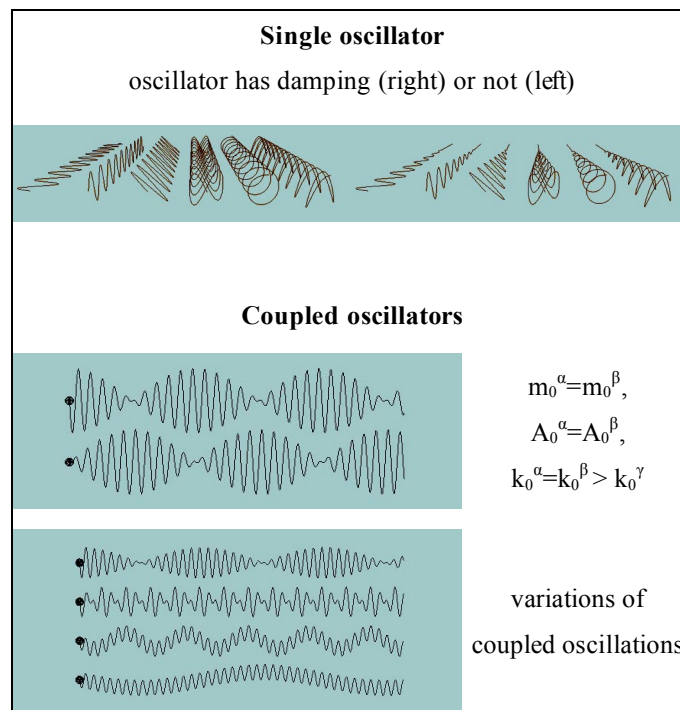
$$\psi^\alpha(t) = A_1 \cos(w_1 t + \varphi_1) + A_2 \cos(w_2 t + \varphi_2)$$

$$\psi^\beta(t) = A_1 \cos(w_1 t + \varphi_1) - A_2 \cos(w_2 t + \varphi_2) \quad \text{Equation 8}$$

$$\psi(t) = [2 * A_1 \cos 0.5(w_1 - w_2)t] * \cos 0.5(w_1 + w_2)t \quad \text{Equation 9}$$

Considering special cases where $m_0^\alpha = m_0^\beta = m$, $k_0^\alpha = k_0^\beta = k$, and $A_0^\alpha = A_0^\beta = A$, the motion equation can be simplified as Equation 9. By Equation 9, we can have a beating oscillation where the frequency is half of the difference between w_1 (square root of k/m) and w_2 (square root of $(k_0^\gamma + 2k)/m$). Later, these coupled oscillators are involved more deeply in their relation of energy (subsection 6.2), and are then used to the benefit of “paradoxical fluid-bound” (subsection 7.3).

Tableau V: The Composition of Oscillator.



6 The Composing Level of Modeling

6.1 Motion Composing

Inherited from chapter 4, the section 6.1 aims to compose dance verbs. In this paragraph, we illustrate the modularity of such modeling approach, which allows to combine simple models to design more complex models and motions, without re-designing them.

In the Figure 32-up, the pelvis 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 pelvis relatively heavy comparing to the knee mass. The pelvis 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 32-down). The movement of the arm is based on “to develop” motion (Figure 32-middle) that has its own motor locus and its rhythm, different from that of "to sway movement" (Figure 32-up). This is an example of movement composition by the superposition of two dynamic models representing the movements of parts of the body.

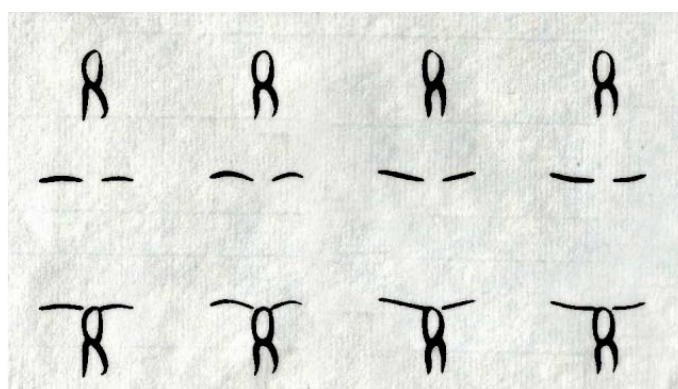


Figure 32: An example of composition.

Until now, we describe two possibilities of combining a complex dance figure. One is

the interacting connection (e.g. Figure 13-c) when the movement accords the same rhythm ($w_{oscillator}$); the other is spatial adding without interaction (e.g. Figure 13-d) that leads to different rhythms ($w_{oscillator1}$ and $w_{oscillator2}$) and different motors for the parts of body.

Another example is the basic footstep of waltz, derived from the « swing step » model, by developing it on a plane as shown in Figure 22-b. Then, these basic waltz steps as external mobile motor trigger the pelvis and the body alive due to the dynamic interactions. Figure 33 shows four instants of the basic waltz movement.

Taking advantage of the minimal dynamic modeling, we are able to develop a duo waltz where a dancer is led by her partner. In Figure 34, even though this is the simplest basic waltz step, we show the possibilities of combining complex dance movements. Two independent models (2 characters) have the same waltz steps as their own motors. With the interacting connection between the two characters, we could simulate the leading ship between 2 characters. For example, Figure 34-right shows the interaction more softly comparing to the left.



Figure 33: Four instants of a basic waltz step.

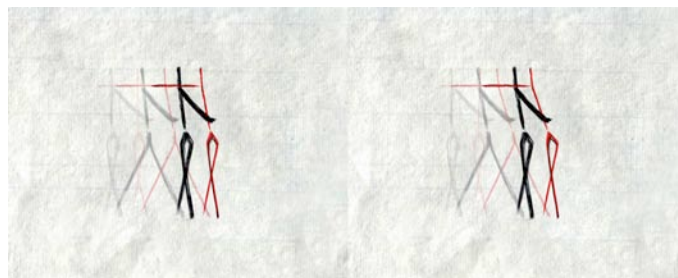


Figure 34: Duo characters show a more complex movement by the necessary minimized interaction.

Inherited from “a dynamic life of cause”, our methodology is progressing on bringing the death of one cause into the birth of another cause. In other words, we attempt to compose “cause” and take care of its “body state” at the same time.

For instance, we choose a series of jumping verbs such as: jump, leap, hop, sissonne and assemblé. By initiating a kinetic energy into one foot or two feet, we decide to take off with one foot or two feet. By designing the parameters of legs’ viscous-elastic interactions between pelvis and foot, the two legs will have muscles with different

strength, which means that the two legs have different potentials. Thus, it can lead two legs to land together or not. By composing with two leg take-offs and landings, five basic jumping models can be achieved: jump from both feet to both feet; leap from one foot to the other foot; hop from one foot to the same foot; assemblé from one foot to both feet; sissonne from both feet to one foot.

All of these jumping models are provoked by their squat states (the birth of cause). Then, they achieve their movement at the rebound states (the death of cause) that can provoke another jumping motion dynamically as shown in Figure 35. In such special case, it is logical to compose the jumping models because all the varieties of jumping action are based on a typical motion pattern opposing to gravity. In addition, these jumping models, which have the same structure and the same inertia, can maintain, in part, the quality coherently. To sum up, focusing on “a dynamic life of cause” pioneers another way to think of “cause composing” instead of “movement composing”.

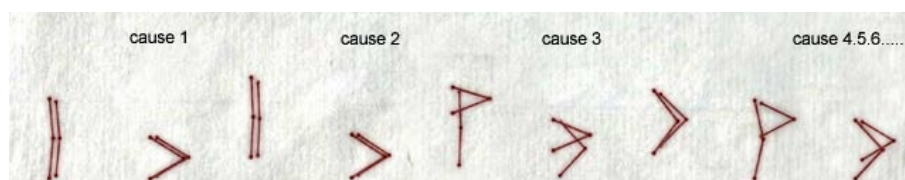


Figure 35: Composing of dynamic causes. Cause 1 leads to jump; cause 2 leads to sissonne; cause 3 leads to leap; then cause 4, 5, 6, etc.

6.2 Coherent Quality: instrumental body with motor control

Nevertheless, in a usual case, we need to find out the logic in dynamics to compose sequential dance verbs. Generally speaking, dance repertory is composed of a series of movement, i.e. dance verbs. Dancer interprets dance repertory by his/her physical body as analogous to that a musician interprets musical notation by an acoustic instrument. Musician has his personal emotion and style to interpret; acoustic instrument has its timbre to embody quality coherently. Our proposed method is very particular because we are attempting to compose oscillations in the motor (the cause). That is to say, in analogy to musical playing, we compose different ways to “oscillate” an “instrument”. In such a case, the physical body is regarded as an acoustic instrument that can keep the quality coherent.

In this section 6.2, inherited from chapter 5, we take account of “mental motor” and “physical body” for improving coherently quality composition. The proposed

composing method for quality control is listed as below:

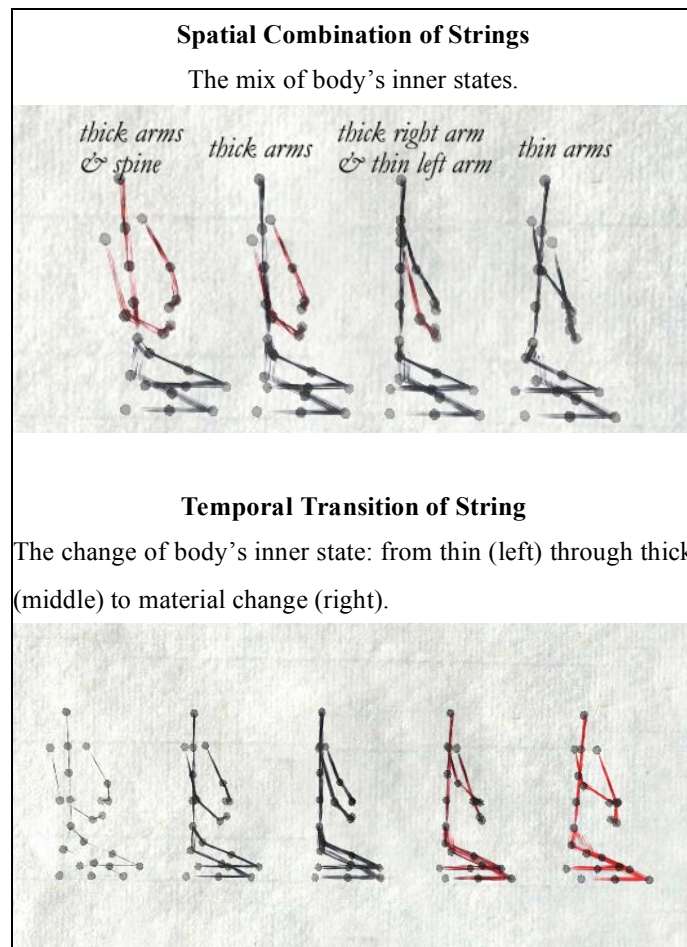
1. Spatial combination of springs in series and in parallel.
2. Temporal transitions of spring like the changes of body's inner state.
3. Temporal composition of driving oscillator.

6.2.1 Instrumental body

Spatial combination implies body's inner states are different at the same instant, e.g. right rigid body and left soft body or weak upper trunk with muscular lower trunk. Tableau VI-up shows complex springs, namely strings, which are combined in series or in parallel.

Temporal transition implies the changes of body's inner state, e.g. contracted muscles become relaxing. Tableau VI-down shows temporal transition of a spring, which is at different states.

Tableau VI: The spatial combination and temporal transition.



6.2.2 Motor Control

The composition of driving oscillator provides a wide variety of complex human motion. As mentioned in subsection 5.2.4, it refers to four types of oscillation: (1) no damping without energy loss; (2) under-damping; (3) critical damping; (4) over-damping. Then, we extend oscillator composing to two directions: x and y for planar motion, similarly for spatial motion. Therefore, we can assign planar oscillation trajectories, shown in Tableau V, as a line, a circle, an ellipse, a parabola, an eight-twist curve, etc. Until now, we indicate how to achieve complex motion in aspect of movement reproduction by means of the composition of oscillation(s).

More advanced, controlling human behavior by “oscillator(s)” is a very interesting topic in aspect of movement understanding. Therefore, we intend to orientate ourselves from complex human motion to human behavior. Our synthetic modeling with help of coupling driving oscillators allows to imitate/implement the phenomena of co-ordinations with intention or not. In subsection 8.1.3, we choreograph duo dance implying the interpersonal co-ordinations. In subsection 7.3, we infer the self-interchange inside solo mental decision that leads to a free/bound resulting motion. In addition, the frequency and the strength of driving oscillator could have many applications towards musical-based motor control.

Issartel et al. [2006] stated a concept about intrinsic individual dynamic (motor signature) after their experiment on improvisatory behavior among subjects: professional dancers, amateur dancers and non-dancers. We are interested in application the concept of motor signature as our driving oscillator as well. Inspired by William James', psychologist and philosopher, viewpoint on habit, a repetitive frequency, an envelope pattern, and a range of amplitude can be designed into our motor control to reproduce dance, moreover to experiment on human behavior in the future.

7 The According Level of Modeling

Considering that the physical body is represented as an instrumental string, we use acoustic properties as the main influence aiming for motion quality. Timbre is a sound quality that distinguishes two different musical instruments whose sounds have the same loudness and pitch. It is worth it to explore the timbre of motion while different dancers (or the same dancer with different body states) interpret the same repertoire. In analogy with spectrum and envelope, which are recognized as the physical characteristics of sound, we look into the interrelation between the oscillator's properties (such as intensity, frequency, phase, envelope, decay, etc) and string's properties (W_{nature} and Z_{nature}).

However, we must be careful with the abstract and multi-sense definition of acoustic properties, and be careful not to map rudely from music to motion. With the help of FDM, experimental modeling can allow trial and exploration from acoustics into dance.

7.1 Rhythm & Harmonic

Rhythm. With the oscillator's frequency, we can control the rhythm as 2, 3 or 4 beats every measure. We do not perform a movement strictly in the limited time or on beats to stress its rhythm. From author's perspective, there are two different levels of rhythmic control: one is to accentuate the key posture in accordance with beats; the other is to concentrate on the entire transitional period. Our generated movement does not emphasize on key postures where we would concentrate on a measure's beginning and end, but lets spectator perceive the movement's instinctive rhythm after repetitive circulation. Due to this characteristic, we do not need to synchronize our movement with the local beats ($\varphi \neq 0$), but we do harmonize the oscillator's frequency with musical rhythm ($W_{\text{oscillator}} = W_{\text{music}}$). This kind of rhythm control can have a more profound impact on the spectator's perception. In other words, our motion rhythm aims towards the circular rhythm of respiration. Furthermore, giving a higher frequency of material oscillation (W_{nature}) can accelerate the velocity of flowing to perform movements on beat. However, it should be understood that the result signifies a more direct and rigid motion (φ decrease), which creates an excited effect.

Harmonic. With FDM, we seek a harmonic movement in two ways: one is harmonic in rhythm; the other is harmonic in topological form (spatial topological symmetry),

such as repetition or reflection. By assigning integer times of $W_{\text{oscillator}}$, a series of oscillators has harmonic rhythm. By designing different phases of oscillators, each one with its own flowing path, we can control, for example, right body and left body having the same rhythm but inverse phase ($\varphi=\pi$) for reflecting movement, conversely the same phase ($\varphi=0$) for symmetric movement.

A subtle experimental harmonic movement is proposed here (Figure 36-a). We design a two branch flowing path coming from the same oscillator (the same rhythm) to present half right/left body. With our qualitative control: direct flowing path (smaller φ) for rigid right body and indirect flowing path (larger φ) for soft left body, we obtain two different qualities in the body. In still image, we perceive clearly the difference of rigid/soft in the geometric form. In motion, we lose the appearance of conflict and perceive harmony between rigid/soft due to the same original oscillator. It is a subtle qualitative control that creates an harmonious or graceful feeling. We suppose that dancers are concerned about harmonious motion arise from their pure source. Doing movements in accordance with respiration is the trick for a harmonious movement. That is the essence of FDM, which is composed of “simple harmonic oscillators” and a “propagation underlain conservation of energy”.

We demonstrate the result without a perceptive validation explanation yet. That is to say, we choreograph according to harmonic frequencies theoretically, but we do not yet validate whether the result can give harmonious perception in movement. There is maybe a gap between acoustic and motion perception. Indeed, even if it is possible to define precisely harmonization in sound and music, it is quite difficult to define harmonization between several spatial motions. We intuitively feel that there is a possible and powerful analogy, but that question remains open for now. This refers probably to a way analyze the body motion more in terms of signal processing techniques (as the wavelet and cross-wavelet transform proposed by [Issartel 2006]) than in terms of solid kinematics. Nevertheless, our flowing modeling can be a useful experimental tool for this kind of perception research.

7.2 Resonance & Silence

Resonance. If the oscillator’s frequency equals the natural frequency of material oscillation ($W_{\text{oscillator}} = W_{\text{nature}}$), resonance theoretically occurs. We can thus implement a movement which is provoked by minimized energy and which is growing due to energy accumulation. In the same time, we should be careful of the resonant phenomenon because energy accumulation might destroy the expectative movement.

Immobility. As silence is also a musical pattern, immobility in dance is not a stop,

but it is an artistic pattern... a balance, an equilibrium! In classic physics, the vector sum of forces should be zero to maintain unchanged immobility. In FDM, we include this balance concept in several points, for instance: 1) A perfect transition on the boundary results from the constancy of impedance of complex strings; 2) The variation of the oscillator's driving energy is in tune with that of the driven string's impedance, and vice versa, to maintain the same effort. 3) Two identical opposing oscillators create vibrations on the same string to have a silent effort.

FDM stresses the conservation of energy in order to be a reference for the driving energy and the resulting effort, and furthermore, to be a reference for kinetic and potential energy. Thanks to such a modeling way, FDM makes micro-movements within the interior body states visible.

7.3 Noise & Trembling (Paradoxical Fluid-Bound)

Fluent flow results from “a harmonic oscillator” and its “ideal mass-spring string”. If we combine several strings without taking care of W_{nature} and Z_{nature} , or if we give an inharmonic oscillator, it is no longer a free flowing and it causes bound effects.

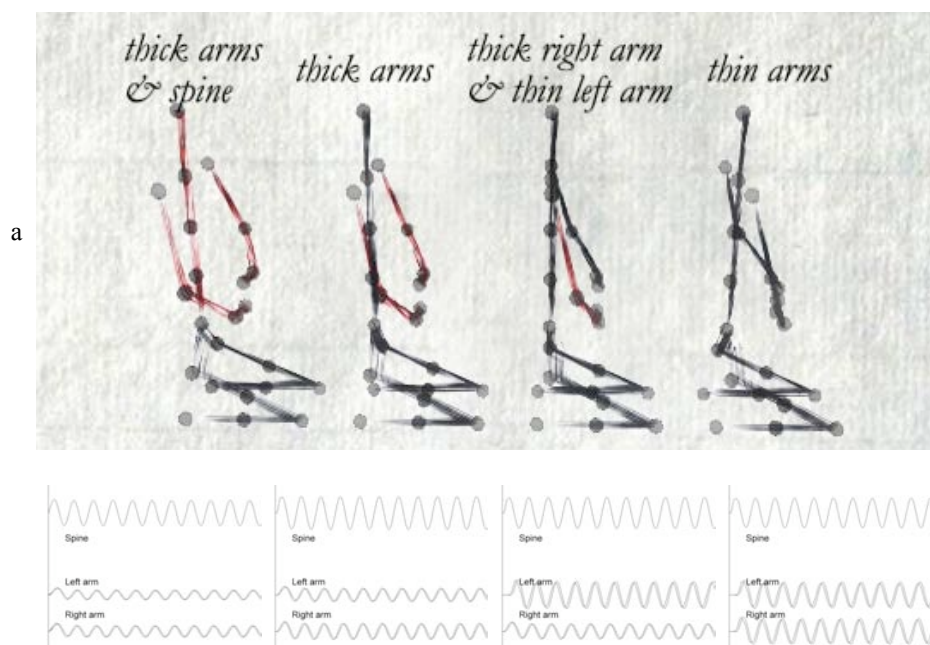
With mass-interaction modeling, it is easy to have bound motion because the property of mass-interaction modeling is exactly its uncontrollability. However, let's imagine a fantastic, highly trained dancer who does bound motion with a fluid illusion. We intend to model this paradoxical fluid-bound effect.

How can bound motion give fluid perception? We define it as geometrically discontinuous motion trajectory coming from continuous flowing in dynamics. As we turn off the tap, the flowing water is reduced to drops. To implement this transition between flowing and dripping, we use coupled oscillators. By Equation 10, the augmentative effort of $(E_{\text{potential}})_{\alpha\beta}$ leads energy exchange between oscillators quickly enough to such discontinuous (bound/zigzag) movements. Nevertheless, the whole system (center of oscillators) keeps the same continuous movement (harmonic oscillation). The particular phenomenon creates a paradoxical fluid-bound perception for the spectator.

Since paradoxical fluid-bound is subtle, we list several variations in Figure 36-b to compare these effects. When coupling (k_0^γ) is smaller than (k_0^α, k_0^β) , there is perfect momentum exchange. When k_0^γ is slightly bigger than k_0^α and k_0^β , the free oscillator becomes bound. When k_0^γ gets largely bigger than k_0^α and k_0^β , the oscillator becomes zigzag that leads to trembling of fingers. When k_0^γ is critically strong, the coupled oscillators are combined strictly, that lead a small, fast, and subtle trembling in the central oscillators. It is not easy to perceive this delicate trembling in the center,

which is enveloped in high dynamic appearance. However, such delicate vibration brings more details and nuances, subtly perceptible in the global motion as well.

1. Figure 36-a shows free oscillator with bound body from thick body (left) to thin body (right). When body has mixed thin/thick states, the form is less continuous, but a free oscillator results in a continuous motion. Thus, the perception is paradoxical.
2. Figure 36-b shows free body with bound oscillator from thin coupling (left) to thick coupling (right). Form is continuous, but motion is discontinuous. The perception is paradoxical and subtle.



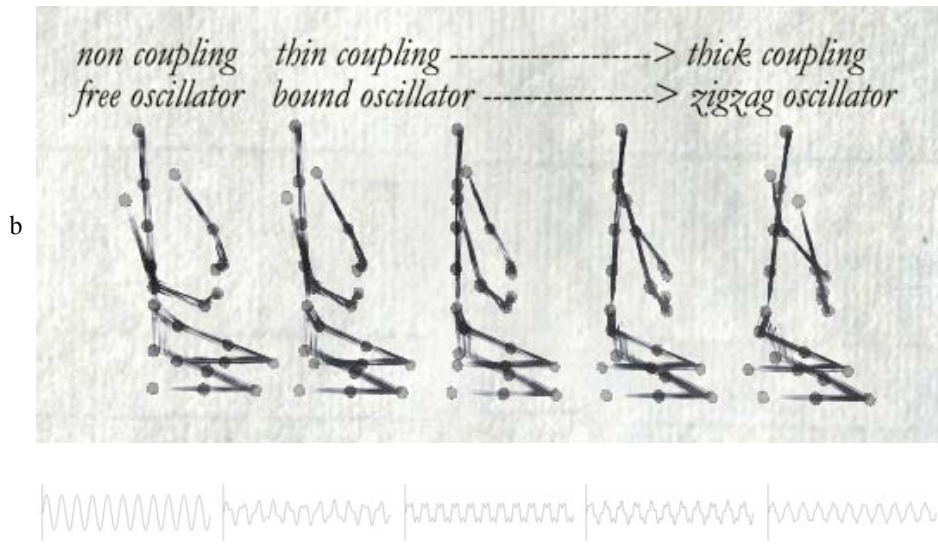


Figure 36: (a) Free oscillator with bound body; (b) Free body with bound oscillator.

8 Modeling Application

The chapter indicates two directions of our modeling application: (1) one is for movement generation in terms of artistic creation; (2) the other is for movement understanding in terms of scientific experiment.

8.1 Movement Creation: The conservation of energy

8.1.1 Mystic Exchange: Perfect Momentum Exchange (行)

Walk. Here we choose a typical locomotion: walk, to explain the “virtual momentum exchange” concept in our methodology. In the direction of the displacement, when the foot stops, all it happens like the foot loses 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, “virtual momentum exchange”, able to stop the motion and to restart it under an energy conservation condition.

Figure 37 shows a walking form right side to left side. Each snapshot presents “virtual momentum exchange” between the right foot (a red sphere) and the virtual mass (the circle) or between the left foot (another red sphere) and the virtual mass.

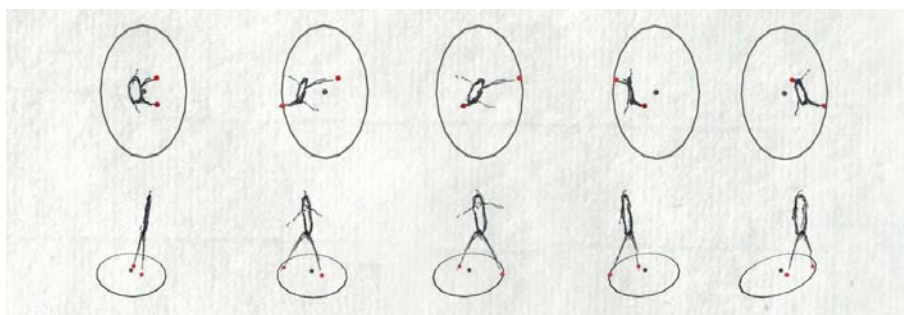


Figure 37: A walk example of perfect momentum exchange.

8.1.2 Mystic Exchange: Dynamic Absorber (旋)

Turn. After “perfect momentum exchange”, we involve in another fashion that

energy transmit and exchange continuously. It is different with the perfect momentum exchange that occurs discretely by each collision.

When we integrate Den Hartog's [1956] dynamic absorber into our modeling, so that a specific mass-interaction is created to absorb energy, this results in immobility underlying energy transmission. For instance, if we implement this ideal vibration phenomenon into a dancing turn, the supporting-pivot foot absorbs all the energy to balance spiral rotational forms and to immobilize the pivot itself. Figure 38 shows a rigid puppet's pivot turn. Figure 39 shows a soft puppet's pivot turn.

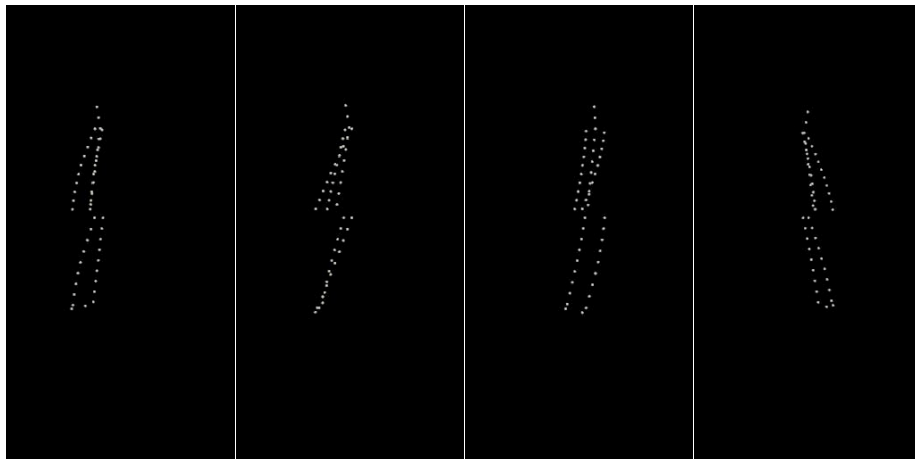


Figure 38: A rigid puppet pivot turn.

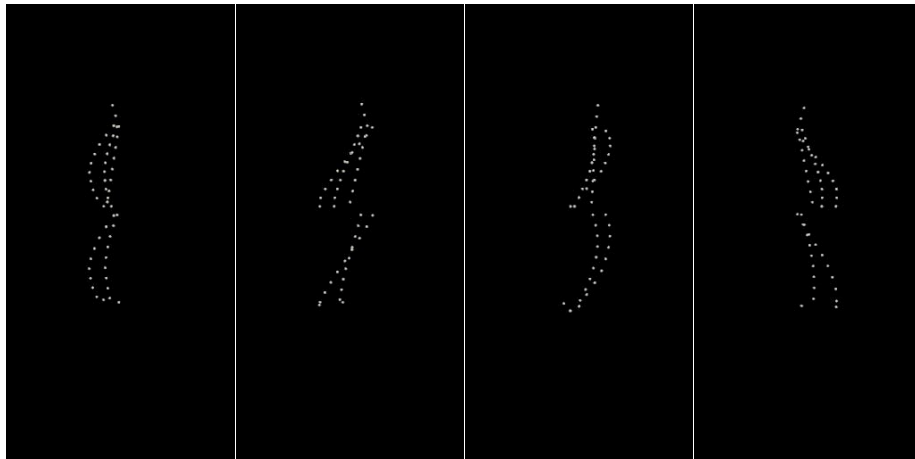


Figure 39: A soft puppet pivot turn.

8.1.3 Mystic Exchange: Coupling Duo (流)

Flow. To apply FDM to dance, we begin by specifying our direction. We must distinguish the difference of energy propagation in biomechanics and in “imagination”. Because our approach is concentrated on human motion in dynamics,

it is often confused or associated with direct dynamic based on biomechanics. In neuroscience, a movement, no matter if voluntary or reflex, is provoked in the spine and follows a neurological path. Generally speaking, such dynamic motions look more natural and correspond well with contemporary free dance. However, a skilled dancer can control his body finely by his inner sensations. A dancer can do wave motions starting from his finger through his arm, to his other arm, or to his body, or to both legs, etc. There are limitless possibilities of flowing path being independent of “neurological path”, and all of them can give fluent perception (or illusion) when performed by a skilled dancer. Such kinds of movement are in accordance with contemporary free dance as well. It seems contradictory, because the perception results from “sensation in momentum”. Therefore, previous direct and inverse dynamic techniques are not useful in this case because they depend too much on hierarchical articulation.

The dynamic procedure proposed in this work is neither limited to a character’s form nor to his hierarchical skeleton. The masses exist for interpreting motion, not for presenting the body’s hierarchical structure (articulation, skeleton). More precisely, since a dancer can perform a perfect flow with his “imagination” or his “sensation of momentum”, FDM is flexible for users who want to create flowing itineraries as well.

Our mass-spring based string approach is based on sequencing connections (including series and parallel). The choreographer or dancer designs the sequence of masses depending on which movement he wants. That is how our flowing modeling can be a bridge to realizing fluxing motions through the dancer’s sensation or imagination of momentum.

Duo Dance. The physical interaction between duo dancers is marvelous and precious according to the author’s experience. In this paragraph, we are involved in duos in two aspects: one is their physical reaction; the other is their abstract communication, be it a physical connection or a mental connection.

In the first case, we think that duo dancers can become one flowing path because of interaction in motion. It is the extension of a single dancer and they (duo dancers, who are interpreted by two different strings to present two different qualities.) are under the same oscillator, the same source, the same rhythm, and the same quantity of energy. In this sense, duo dancers mingle together perfectly and keep their personal qualities.

In the second case, since communication is very abstract, we need a more convincing reference to bridge duo dancers. Coupling oscillations obeying conservation of energy is our proposed reference. Equation 10, derived from Equation 9, illustrates energy

relation of identical coupled oscillators. $(E_{\text{potential}})_{\alpha\beta}$ represents the exchange of energy between coupled oscillators. Without coupling, each oscillator is an independent system having its constant energy. After coupling, the entire system has constant energy, although each oscillator does not keep constant energy. This phenomenon signifies that duo dancers are communicating and that there is energy flowing from one to the other. We notice how energy exchanges continuously and gradually in comparison with perfect momentum collisions. They always share one unit quantity of energy. Using this phenomenon, we can choreograph as following: in the beginning, one moves and another stands still; in the middle, both move; in the end, one stands still and another moves (Figure 40-a). Here is another example: in the beginning, one does an up-down movement and another does a right-left movement; in the middle, both do a planar movement; in the end, they exchange their movements (Figure 40-b).

$$\begin{aligned}
 E_{\text{total}} &= E_{\text{kinetic}} + E_{\text{potential}} \\
 &= [0.5 * m_1 v_1^2 + 0.5 * (k_1 + k) x_1^2] + [0.5 * m_2 v_2^2 + 0.5 * (k_2 + k) x_2^2] - [k x_1 x_2] \\
 &= (E_{\text{kinetic}} + E_{\text{potential}})_{\alpha} + (E_{\text{kinetic}} + E_{\text{potential}})_{\beta} + (E_{\text{potential}})_{\alpha\beta}
 \end{aligned}
 \tag{Equation 10}$$

To sum up, the dynamic interaction of duo dance is treated under one oscillator or coupled oscillators. One oscillator signifies a physical connection by a flow of energy characterized by the same source, rhythm and quantity of energy. Coupled oscillators signify mental response by energy flowing including momentum exchange and motion trajectory exchange.

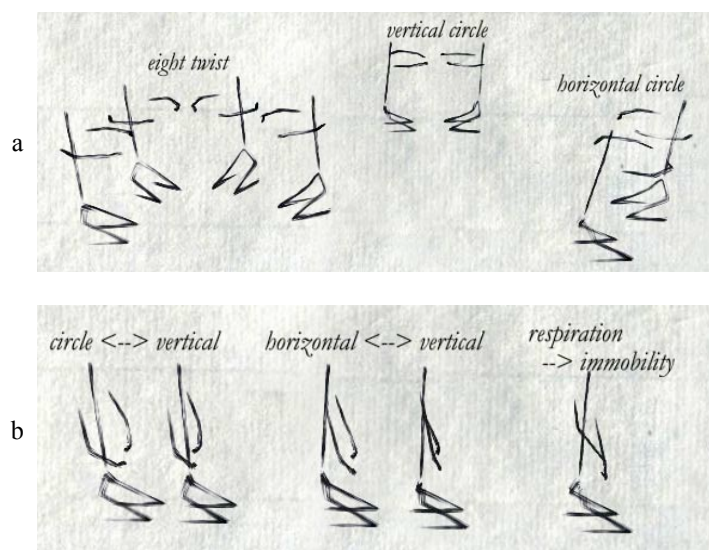


Figure 40: (a) Momentum exchange; (b) Spatial motion trajectory exchange.

Among Dancers. Metaphorically, a choreographer (an orchestra conductor) is as a motor system in our flow modeling. Every dancer is now regarded as a driven mass. Every mass can interpret every individual dancer's momentum. From then on, a main flowing path connects the dancers' oscillators, and every dancer has his/her flowing path branch.

Due to "energy transmission", dancers start to move in sequence, one by one like a domino effect, or a crowded wave, etc. It is interesting to take this propagation phenomenon and to imply energy transmitting among dancers. One unit of energy is shared and played by duo, trio, or plural dancers on stage.

Integrating coupling oscillation into FDM, we can model (achieve) different degrees of interpersonal co-ordinations. These models are used for duo dance in aspect of movement interpretation as shown in Figure 41 and could be useful for human behavior understanding as well. In conclusion, mass can be presented as a whole dancer or a part of dancer, FDM provide a flexible and concrete concept for our creativity and imagination.

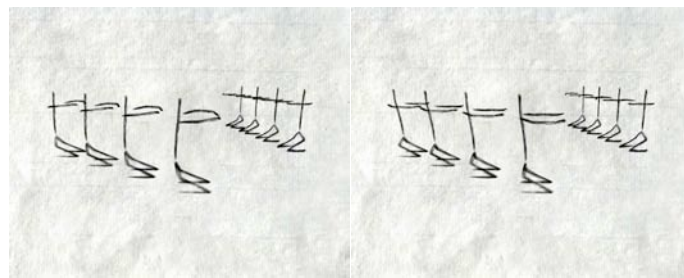


Figure 41: Coupling oscillations for duo dance.

8.2 Movement Understanding

8.2.1 Invisibles vs. Spring's functions vs. Qualitative Controls

Analyses are related to kinetic appearance; synthetics could be related to implicit invisibles. It is the fundamental distinction between movement analysis and movement synthetics. The two methods are not mutually exclusive but can benefit each other. In fact, our proposed synthetic models are based coherently on the knowledge of movement analysis. Hence, we propose the physical functions of mass-spring to bridge between invisible body's inner state and Laban's effort-shape, one theory of movement analysis.

We propose to map dancer's inner body state by the functions of driven spring such as thin/thick spring and soft/rigid material. We also propose to map dancer's breath rhythm by a driving oscillator with a constant frequency. For instance:

- Thin spring of soft material (k, m)
- Thick spring of soft material ($2k, 2m$)
- Thin spring of rigid material ($2k, 0.5*m$)
- Thick spring of rigid material ($4k, m$)
- Slow frequency of driving oscillator ($w_{oscillator}$)
- Fast frequency of driving oscillator ($2 * w_{oscillator}$)

The driving oscillator represents the mental motor in the dancer's mind. Driven spring has two factors: impedance and natural frequency, which signifies the body's inner. A materially soft/rigid spring represents the ability of resistance of muscles. A compressed/stretched spring represents an instantly potential state of muscles. A specific damping represents the fatigue state of muscles. Tableau VII shows the mapping from the physical parameters of mass-interaction modeling into body's inner state.

Next, we indicate how to improve qualitative control with help of body's inner state and driving oscillator. Tableau VIII shows the qualitative control relating to Laban's effort-shape analysis. The advantages of our qualitative control comparing to effort-shape are (1) good relation with the invisibles (body's inner state and mental motor); (2) intuitive controlling parameters; (3) direct energy control (on the cause not

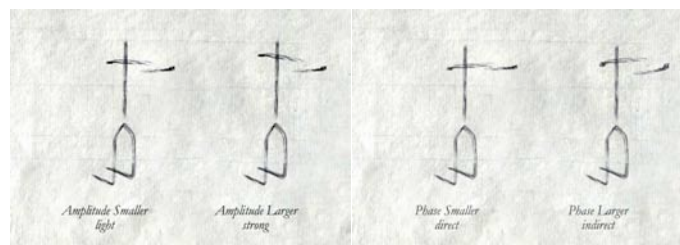
on the results). Figure 42 shows the results of our proposed qualitative controls.

Tableau VII: Mapping from mass-interaction modeling to body's inner states.

driven spring& driving oscillator		body's inner state	
Natural frequency root (k/m)	soft material (k, m)	muscle material	sparse female
	rigid material (2k, 0.5m)		dense male
Impedance root (k*m)	thin spring (k, m)	muscle strength	slight
	thick spring (2k, 2m)		heavy
Oscillator's Frequency	fast $w_{oscillator}$	mental motor rhythm	fast rhythm
	slow $w_{oscillator}$		slow rhythm
Oscillator's Amplitude	small A	mental motor strength	light
	large A		strong

Tableau VIII: Mapping from qualitative control to Laban effort-shape analysis.

Qualitative control		Effort-shape	
Amplitude	big A	Weight	strong
	small A		light
Phase	small ϕ	Space	direct
	big ϕ		indirect
Frequency	fast $w_{oscillator}$	Time	sudden
	slow $w_{oscillator}$		sustained
Coupling oscillation	non-coupling	Flow	free
	coupling		bound



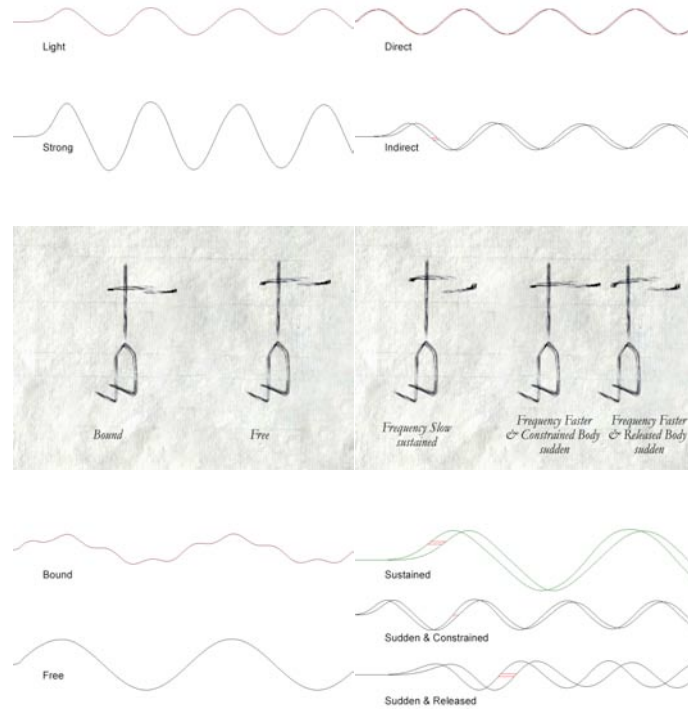


Figure 42: The results of qualitative controls.

8.2.2 Signification between human motion and motor control

Based on mass-interaction paradigm, we can choreograph by way of energy transmission inside a single dancer or among groups. It sounds utopian but we make it real. A serious discussion here is whether spectators appreciate this kind of motion, that is strictly based on dynamics and on the conservation of energy. Since we concentrate on energy's transmission and conservation, it is valuable to seek the signification between human motion and model control.

In this subsection, we analyze and explain the reasons that while a human accelerates his movements, it is difficult to keep the same motion trajectory. It is supposed to be the effect of the relation between driving oscillator (mental control) and driven spring, these two factors should to be treated synchronously. It signifies that the dancer accelerates the movement in his mind and should modulate his muscles at the same time to keep the same motion trajectory. Our synthetic models explain this phenomenon as below:

1. $w_{oscillator}$ with spring w_{nature} (k, m) in Figure 43-a.
2. $2^* w_{oscillator}$ with another material spring $2^* w_{nature}$ ($2k, 0.5m$) in Figure 43-b.
3. $2^* w_{oscillator}$ with spring w_{nature} (k, m) in Figure 43-c.

The results in Figure 43 explain that playing/lecturing the same motion trajectory by twice faster velocity will maintain the same difference (phase) between two adjoining observation-points, i.e. two adjoining masses or two articulation-points. However, in our modeling, twice frequency leads to the change of phase that cannot maintain the same resulting motion trajectory. The change of phase leads a delay that implies the body is not at a suited state when acceleration occurs. This phenomenon in our models is less suitable for movement control rather than in reusing motion data at first. Nevertheless, it points out the difference between non-human movement control (e.g. robotic) and human movement control. It is important for movement understanding, especially in dance referring to the release dance-technique.

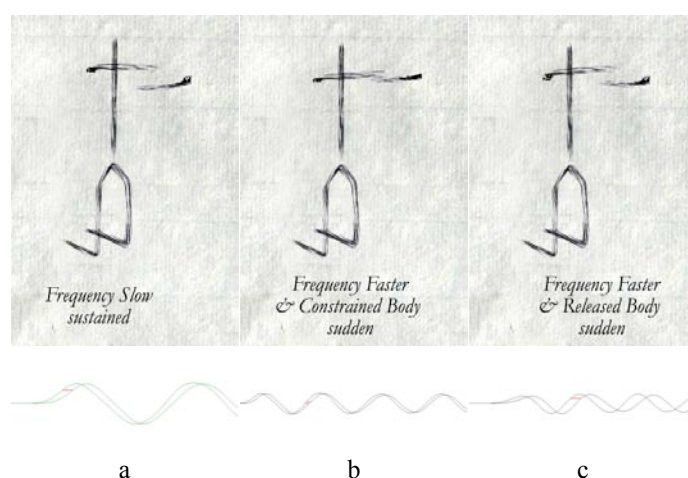


Figure 43: A comparison about oscillator control and driven body.

After that, how do we model that motion changes unconsciously while the dancer does it repetitively? If it is the effect from the fatigue of muscles, the muscle-bound tension is represented that a string becomes thick under the repetitive motor oscillation. How does a dancer perform a higher dynamic motion? One possibility: he trains himself in order to gain more strength. This means, in modeling terms, to assign more energy into driving oscillator. Another possibility: the dancer relaxes his muscles as much as possible to perform such higher dynamic motions. In modeling, this shifts into replacing “thick string” with “thin string” without changing the strength of oscillator. To conclude, through modeling construction and manipulation, it improves the explanation of human movement behavior relating to model control.

8.2.3 Discussion: form and motion

In our “mass-interaction” network, the methodology to coat the motion in order to

render it visible – e.g. through a visualization process – is another stage of modeling. This coating may be simple, as it is usually done in motion-capture philosophy. It could also be understood in a more general way as clothing of a point-based structure. There is a wide variety of visualization (e.g. some examples shown in Figure 44 and Figure 45).

Because of this dynamic procedure in accordance with contemporary dance, we concentrate on energy and quality within dance movements. We are concerned less with visual form than with motion quality. It is exactly the core in our approach, as well as the dancer's. Nevertheless, spectators may not perceive the quality inside a refined and subtle movement if the dancer has an ill-suited costume (for example, a subtle movement under a huge costume). We therefore face a trick question: some movements are suited to be represented by an abstract form (e.g. point-based or curve-based); some movements need to be represented by a more complete form (e.g. a complete 3D character). This kind of problem is probably referred to the area of recognizable Gestalt [Johansson 1973]. Because we can control two extreme kinds of qualities: rude and fine, then we apply these two qualities to two different forms, e.g. (1) fine motion with thin form; (2) fine motion with thick form; (3) rude motion with thin form; (4) rude motion with thick form. These specially designed models could be useful for perceptual experiment. We pose this open discussion and stress that our dynamic models can be treated as perceptual/predictive models that are helpful for movement understanding.

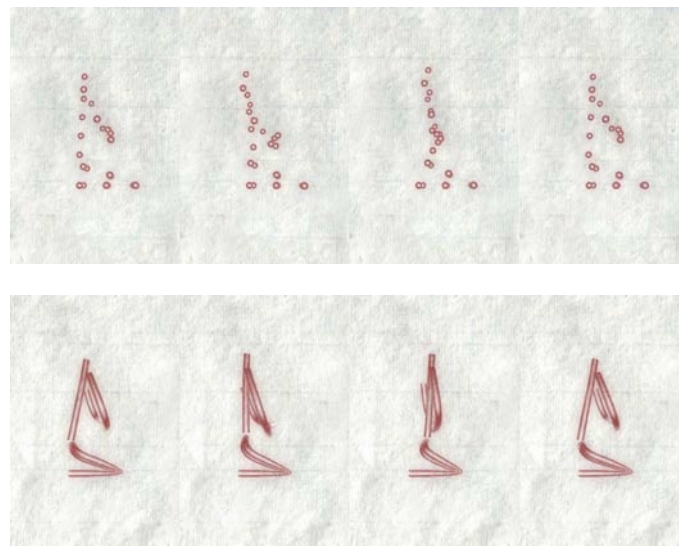


Figure 44: Mass figure (up) and Solid figure (down).

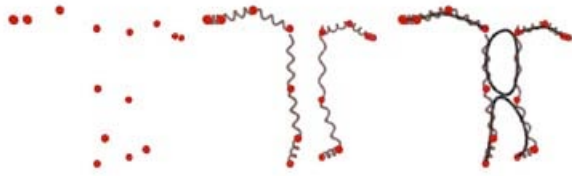


Figure 45: 1D point-base figure, 2D line-based figure; 3D form-based figure.

9 Conclusion and Prospect

In terms of movement representation, we have now at our disposal a dance verb library within five movement patterns and dance adjective controls: amplitude, phase, frequency, coupling oscillators.

In terms of movement understanding, we have now at our disposal several special models toward invisibles (pre-movement, functional interaction, mental motor, body's inner states) and perceptual synthetics (paradoxical fluid-bound). In addition, we discussed the signification between motor control and human behavior.

In terms of artistic work, we designed a virtual choreography (FLUENTE) based on the concept of mystic exchange concerning energy conservation (perfect momentum exchange, dynamic absorber, coupling duo).

Our modeling based dance writing can take movement conservation (seeing) and movement representation (doing) into account. Therefore, we can write down “motions”, “qualities” and “invisibles” in respect of conservation; we can write for creative style including quality and energy in respect of interpretation. We remind and conclude the research works in two parts: dance verb (motion) and dance adjectives (quality).

1. Dance Verbs (motion)

As mentioned before, the two different ways to implement computer-choreographer communication are the ways to produce desired motions, one from the result, and one from the cause. We indicate another interesting view starting with the question: does human consciously think of how much force he should have to perform a desired motion? Computer is passive and needs to be told the exact forces or the rule to obey (i.e. constrained optimization). Conversely, human is sensible to the force change, and concerns always himself with all the interactions. In our research, we argue the instinctively different capabilities of computer and human. We hypothesize dancer has a good sensibility to feel the interactions and to be influenced by these interactions. Because of this, we constructed interacting network instead of developing algorithms.

In this step, to find out the minimum but sufficient number of interactions, we deconstructed character structure as “mass-interaction” network keeping always the essential interactions; and we extracted dance verbs to be used for modular motion

design. Then, we proposed the methodology for energy processing of every dance verbs, the life of the cause. All mentioned above aims to bridge the gap between computer and choreographer and to assist choreographer, computer has to produces motions from the cause not from the results, and has to consider the interactions inside the body and with environment.

The proposed methodology is well adapted to the philosophy of contemporary dance, in which the movements of body parts are not explicitly dirigible in a prescriptive way but provoked by the dynamic status. In these dynamic models, they provide not only an intuitively high-level motion control, but more important, it is possible to modify the quality of movement such as light/strong, free/bound, sudden/sustained. Without doubt, to produce digital dance motion and have its own style and quality as well, is a wonderful aim in our research.

Briefly, these 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. More profoundly, the aims in our methodology could focus on bringing a death of cause into the birth of another cause, namely “cause composing” instead.

2. Dance Adjectives (quality)

The sentence "simplicity is ultimate sophistication", quoted from Leonardo, is the core of the second step aiming at qualitative control. Flowing Dance Modeling (FDM) is a simpler model with strict deduction, which can provide fantastic implementations and inmost signification.

The value of our modeling is of course its resulting presentations, but also the process leading up to it, including objective and assumptive theory, as well as the cause-effect inference. Let us resume our contributions to modeling. Firstly, we integrate natural frequency and impedance as references to determine inertia and stiffness. FDM innovates by allowing a more direct and intuitive quality tuning, due to its strictly energetic motor control and driven strings. Secondly, we implement some musical properties to dance movements, such as “rhythm, harmonic, silence, resonance”. This allows us to actualize conceptual ideas using dynamic processing according to acoustics knowledge. Thirdly, our work improves motion controllability as well in other fashions because we control qualities coherently, by referring to inner body states and mental motor, instead of motion control.

Finally, we seek graceful/sophisticated qualities by caring for delicate vibration

enveloped in high dynamic appearance, by caring for near silent-balance, by caring for conservation of energy with its potential, and by caring for high levels of detail through wanted masses. According to philosopher Kant's aesthetic judgment between the beautiful and the sublime, a beautiful/graceful movement rises because the actual movement coincides with brain expectation delivering harmonious pleasure inside our mind; a sublime arises because of unexpected surprise [Hagendoorn 2003]. We hence address ourselves to, in motion qualitative terms, subtle and finesse qualitative research instead of explicit kinetic stimuli (exaggerated or expressive style).

We cannot overemphasize that our modeling method is not as user friendly as pose composing; at first, it is unusual for users to compose using oscillators and strings. Our motion control is designed with the very particular purpose of attaining better qualitative control. In the future, we will combine our qualitative control modeling with data-driven based animation. Optimization will be one of the possibilities, but by doing this, we wonder whether our modeling method will lose its properties of energy transmission after transition. That is an open question relegated to future works.

Prospect. The prospect will turn toward returning the knowledge of models to the knowledge of target system. The choreographic code – energy transmission on imaginary itinerary –, which has been inferred within models, will return to real dance. As well as the invisibles, which are synthesized in models, will appear on real dancer.

10 Annex

. Impermanence

Impermanence (Tibetan: mi rtag pa; Chinese: 無常 wúcháng; Japanese: 無常 mujō) is one of the essential doctrines or three marks of Buddhism. The term expresses the Buddhist notion that everything, without exception, is constantly in flux, even planets, stars and gods. Human life embodies this flux in the ageing process, the cycle of birth and rebirth (samsara), and in any experience of loss. Because things are impermanent, attachment to them is futile, and leads to suffering. The only true end of impermanence is nirvana, the one reality that knows no change, decay or death. In the Mahayana Mahaparinirvana Sutra, all compounded and constructed things and states are said to be impermanent - but to say the same of nirvana and the Buddha (who is the personalisation of nirvana) is to commit a gross error in understanding and to fall into a harmful misperception of truth (as discussed in the Mahaparinirvana Sutra). Impermanence is intimately associated with the doctrine of anatta, according to which things have no fixed nature, essence, or self. [from Wikipedia]

. TAO

“The Tao that can be told is not the eternal Tao.
The name that can be named is not eternal name”.

. Qi

In the Eastern philosophy, “Qi”, i.e. vital breath, flows through the body with respiration and keeps its perpetual circulation. By the imaginary flowing “Qi”, all motion occurs naturally and simply.

. Fuente

味

Abstract:

«The world is continuous flux and impermanent», Buddha said that.

In this project, "FLUENTE", the human material body is no more solid as we see, but is fluid as we imagine. We can see motion flows through the material body, because all the fluid motions are consequent on the energy transmission. Furthermore, the energy transmission does not only exist on one individual, but also exist among groups gradually and continually underlain the energetic conservation. Dancers exercise their body everyday in the aim to discover and rehearse how the motion of the whole is duly evolved from their motor locus. The process by which motors provoke the whole motion is as mysterious as beautiful; therefore, we realize it in the virtual choreography. "FLUENTE" does not aim to present the fluid motion of human body but to explore the "inner propagation" existing within the real material bones, muscles, and our imagination as well. It comes from the center source with the vital breathe to flow and to propagate perpetually.

Résumé:

«Le monde est continu fluide et non permanent», Buddha disait.

Dans le projet, "FLUENTE", le corps humain n'est plus solide comme nous le voyons, mais fluide comme en imagination. Nous percevons le mouvement qui s'écoule partout dans le corps matériel parce que toute la fluidité du mouvement vient de la propagation d'énergie. En outre, la transmission d'énergie, qui existe dans un individu, se communique également dans le groupe, s'échangeant de l'un à l'autre. Tout se passe doucement et continuellement en conservant l'énergie. Comme les danseurs qui s'exercent, jour après jour, sans arrêt pour trouver leur source d'énergie et provoquent les mouvements à partir de leur propre source, ce projet a le but d'explorer cette histoire mystérieuse par cette chorégraphie virtuelle: "FLUENTE". "FLUENTE" ne veut pas représenter le résultat du mouvement fluide, mais cherche à explorer "la propagation intérieure" qui vient de la source centrale et qui s'écoule perpétuellement en accord avec la respiration.

摘要:

«这个世界是连续非静止非永恒», 佛陀说。

在这个项目中,“流”,人类的身体不再像我们看到的那样是固体,而是像我们想象的那样是流体,因为我们看到运动通过物质身体流动,因为所有的流体运动都是能量传递的结果。此外,能量传递不仅存在于个体之间,而且存在于群体之间,并随着能量守恒而逐渐和持续地传播。舞者们每天都在练习,旨在发现和排练整个身体如何从其运动中心适当地演变。这个过程是神秘而美丽的;因此,我们在虚拟编舞中实现它。"流"并不旨在呈现人体的流体运动,而是探索存在于真实骨骼、肌肉和我们的想象力中的"内在传播"。它来自中心源,以呼吸为动力并不断传播。

FLUENTE

The nature is moving.

Wind blows, cloud floats, river flows.

«The world is continuous flux and impermanent», Buddha said that.

The Concept

In this project, the human material body is no more solid as we see, but is fluid as we imagine. We question paradoxically that how to distinguish between solid and fluid if there is no motion. Conversely, how do we feel the flux behind the material body in dance? Two philosophies concerning the project were selected below.

As quoted in the philosophy of contemporary 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” by body and energy.

In the Eastern philosophy, «Qì», i.e. vital breath, flows through the body with respiration and keeps its perpetual circulation. Conceivably, we desire to see, moreover to feel that a dancer explores his pure «Qì», and then immerses in the fluidness of «Qì». As the movements of nature, e.g. flowing, flying, floating, are full of fluidity, the dance motion behind material body is full of fluidness as well.

The Object

In this project, we propose a virtual choreography, “FLUENTE”, supported by the innovative technique, which is described in the next session. In “FLUENTE”, we could see the fluid motion flows through the body, from the center mass to the hands, from the hands return to the navel, etc. We would like to emphasize that all the fluid motions are consequent on the energy transmission behind the material body to cause these beautiful results. Due to different ways of energy transmission, we have different qualities of fluidity by implication, as flowing in the river, flowing in the stream, or the billow in the sea.

Furthermore, the energy transmission does not only exist on one individual, but also exist between dance partners, and between the groups. In "FLUENTE", we also implement the mysterious energy exchange gradually and continually underlain the energetic conservation between the partners and between the groups. Another secret in "FLUENTE", even though we see a bound motion in extrinsic result, it keeps its intrinsic fluidity in the aspect of energy.

The Technical Innovation

To support the project that focuses on generating dance movements by energy transmission and keeps respecting the dynamic during all the process, there must be a profound research and a novel technique invented. In our approach, complex character structure and complete motion are simplified and refined by "the just necessary masses" and "the essential interactions". Thanks to the use of the simplification procedure, we could focus more on the interaction and connection through dance movement and take advantage of the simplest computing technique. Then, we propose a methodology, focusing on the birth, the growth and the death of cause, which include energetic propagation and virtual momentum exchange. The dynamic procedure is as below: (1) finding out the "motor locus" and initiating the energy into this motor (the birth of cause); (2) generating the motions from the "motor" (the growth of cause); (3) decreasing influence of the motor and finding out another new balance (the death of cause).

To sum up, human motion is a complex biomechanical behavior, rather than a pure behavior obeying law of physics. The originality of our research is that, based on dynamic modeling, we generate dance movement only with the necessary minimized masses and interaction. Our methodology exhibits energetic succession and connects well the dance, physics and computer. All mentioned above aims to bridge the gap between computer and choreographer and to assist choreographer, computer has to produce motions from the cause not from the results, and has to consider the interactions inside the body and with environment.

More details about the technique research are to be found in the references [1, 2]. This research and the thesis are going on.

Discussion

The energy transmission or the propagation of «Qi» under human dance movement is concerned with sensation, perception and cognition of movement. It is difficult neither to provide directly nor to simulate by scientific way. As quoted from David Hume (1757), "Experience only teaches us, how one event constantly follow another; without instructing us in the secret connection, which binds them together, and renders them inseparable". The secret connection is considered reflectively to induce the distinct identities of motion style. We argue that even though we capture

directly a beautiful fluid motion of human body with help of technology such as motion capture, could we conserve the essential connections behind the beautiful fluid motion. More profoundly, how do we define a perfect fluid motion? A motion is composed of a series of geometrically curvaceous gesture? A motion has high degree continuity in velocity or acceleration? Alternatively, a motion can be fluidized by "imagination" and then flow through the material skeleton.

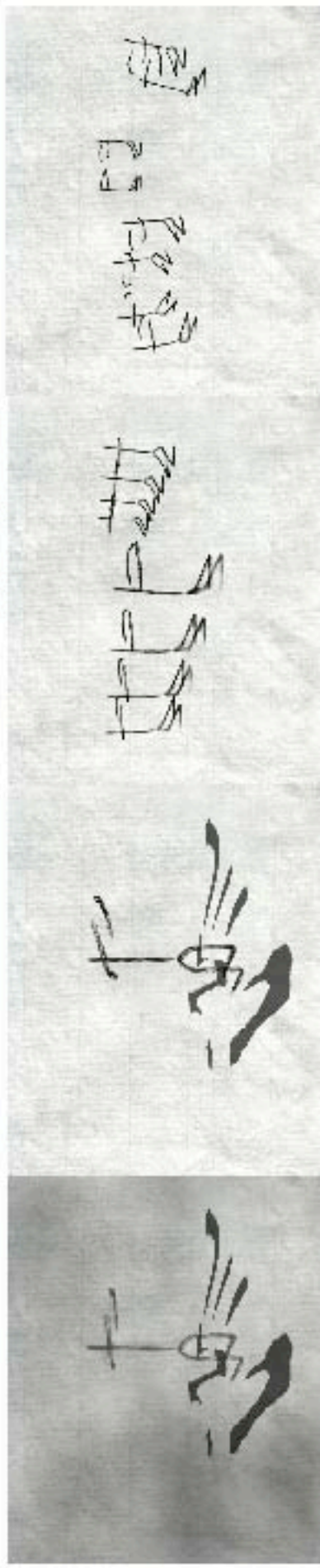
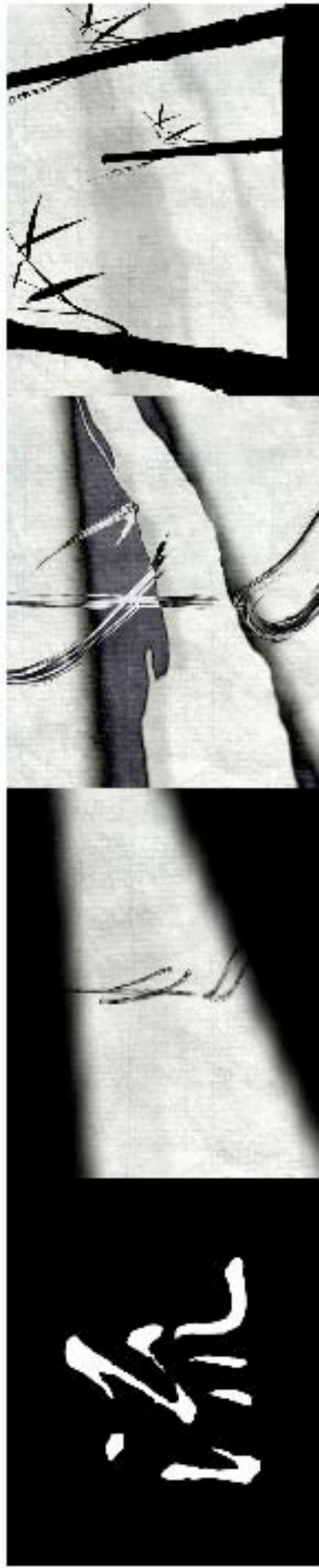
The fundamental thesis we proposed is to hypostatize (hypostatize) the fluidness (the energy or the momentum) flowing from the origin to somewhere by the essential connections and keeping perpetual conservation of energy. Once a fluid motion is predictably obtained according to the hypothetical essential connections, we pioneer a way to model and to conserve the essential connections. Debatable, since we never find out the truth of such human fluid motion, based on imitation of river flowing or based on imagination of cloud going, our thesis illustrates a beautiful vision to simulate the naturally fluid motion. More advanced, we could have thousands fine qualities by turning the essential connections. For example in "FLUENTE", it demonstrates a series of qualities in fluidity: light/strong, free/bound, direct/indirect, sudden/sustained, etc.

Conclusion

Dancers exercise their body everyday in the aim to discover and rehearse how the motion of the whole is duly evolved from their motor locus. The process by which motors provoke the whole motion is as mysterious as beautiful; therefore, we realize it in the virtual choreography. "FLUENTE" does not aim to present the fluid motion of human body but to explore the "inner propagation" existing within the real material bones, muscles, and also our imagination while we are dancing. "FLUENTE" comes from the center source with the vital breathe to flow and to propagate perpetually.

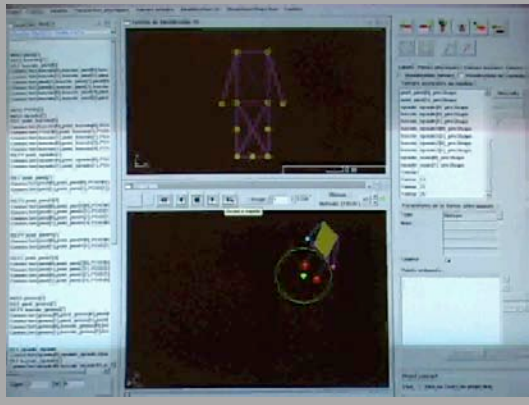
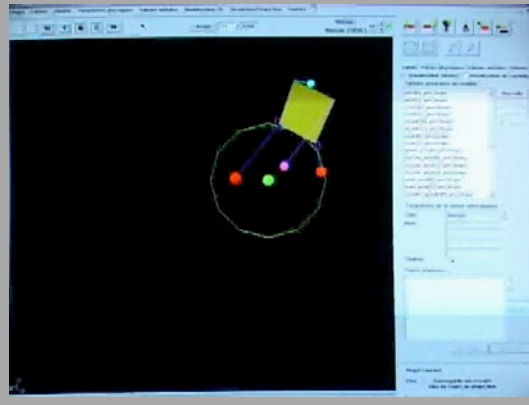
Reference

- [1] Chi-Min HSIEH, Annie Luciani: Generating Dance Verbs and Assisting Computer Choreography. In *Proc. of ACM Multimedia 2005*, page 774-782, Singapore, November 2005.
- [2] Chi-Min HSIEH, Annie Luciani: Minimal Dynamic Modeling for Dance Verbs. In *Journal Computer Animation & Virtual Worlds*, vol. 17, nos. 3-4, page 359-369, July 2006.



This page shows some snapshots from FLUENTE which shows fluidly within dance motion, a variety of qualities in fluidly and mysterious energy exchange between the groups.

. Physical parameters of selected examples

Walk			
			
MASS			
Mass	Inertia (M)	Gravity (g)	Initial velocity (v)
Right foot	1E+07	0	$V_z = 30^{(i)}$
Left foot	1E+07	0	0
Virtual foot-mass	1E+07	0	0
Right basin	1E+02	0	0
Left basin	1E+02	0	0
Right shoulder	1E-06	0	0
Left shoulder	1E-06	0	0
Right hand	1E-08	0	0
Left hand	1E-08	0	0
SPRING			
Spring	Stiffness (k)	Damping (z)	Initial deformation (ΔL)
Virtual mass-Right foot collision (BUT)	1E+03	0	Threshold = 0.5
Virtual mass-Right foot attraction (BUL)	1E+03	0	Threshold = $30^{(ii)}$
Virtual mass-Left foot collision (BUT)	1E+03	0	Threshold = 0.5
Virtual mass-Left foot attraction (BUL)	1E+03	0	Threshold = $30^{(iii)}$
Right foot-basin	1	0	0
Left foot-basin	1	0	0
Right basin-shoulder	5E-07	5E-07	0
Left basin-shoulder	5E-07	5E-07	0
Right shoulder-hand	5E-09	5E-09	0
Left shoulder-hand	5E-09	5E-09	0
Right foot-Left hand	0	$5E-11^{(iv)}$	0
Left foot-Right hand	0	$5E-11^{(v)}$	0
Remarks:			

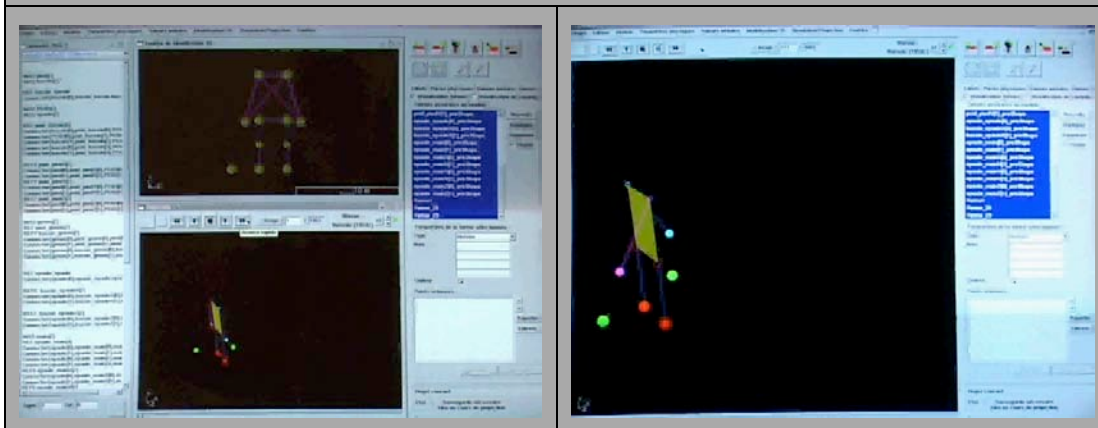
The velocity of step depends on parameters (i).

The lengths of feet's steps depend on parameters (i) (ii) (iii).

The parameters (iv) (v) tune the symmetric balance between right and left body.


The difficulty of the walk model, in dynamic procedure, is how to stop the feet and then re-start the steps. The proposed trick is to create a virtual mass identifying with foot in order to transfer kinetic energy by perfect momentum collision (attraction).

Half turns step over step (Débouler)



MASS			
Mass	Inertia (M)	Gravity (g)	Initial velocity (v)
Right foot	1E+07 ⁽ⁱⁱⁱ⁾	0	$V_z \approx 41.8$ ⁽ⁱ⁾
Left foot	1E+07	0	0
Right virtual medium	1E+07	0	0
Left virtual medium	1E+07 ^(iv)	0	$V_z \approx 41.8$ ⁽ⁱⁱ⁾
Right basin	1E+02	0	0
Left basin	1E+02	0	0
Right shoulder	1E-06	0	0
Left shoulder	1E-06	0	0
Right hand	1E-08	0	0
Left hand	1E-08	0	0
SPRING			
Spring	Stiffness (k)	Damping (z)	Initial deformation (ΔL)
Right foot-virtual medium collision (BUT)	1E+05	0	Threshold = 0.5
Right foot-virtual medium attraction (BUL)	1E+05	0	Threshold = 40 ^(vii)
Left foot-virtual medium collision (BUT)	1E+05	0	Threshold = 0.5
Left foot-virtual medium attraction (BUL)	1E+05	0	Threshold = 40 ^(viii)
Right foot (only in X axis)	1E+02 ^(v)	0	20 ^(ix)
Right virtual medium (only in X-axis)	1E+02	0	0
Left foot (only in X-axis)	1E+02	0	0
Left virtual medium (only in X-axis)	1E+02 ^(vi)	0	20 ^(x)
Right foot-basin	1E+01	0	0

Left foot-basin	1E+01	0	0
Right basin-shoulder	5E-07	5E-07	0
Left basin-shoulder	5E-07	5E-07	0
Right shoulder-hand	5E-09	5E-09	0
Left shoulder-hand	5E-09	5E-09	0
Remarks:			
Right/Left virtual medium and Right/Left mass have identical movement behavior.			
The parameter (i) depends on the parameters (iii) (v).			
The parameter (ii) depends on the parameters (iv) (vi).			
The parameters (vii) (viii) (ix) (x) decide the rotational length.			

Rebound			
			
MASS			
Mass	Inertia (M)	Gravity (g)	Initial velocity (v)
Basin (right leg)	10	-1E-05	$V_y = -45^{(i)}$
Knee (right leg)	0.1	0	0
Virtual knee (right leg)	0.1	0	0
Foot (right leg)	10	3E-05	0
Basin (left leg)	10	-1E-05	$V_y = -45^{(ii)}$
Knee (left leg)	0.1	0	0
Virtual knee (left leg)	0.1	0	0
Foot (left leg)	10	3E-05	0
SPRING			
Spring	Stiffness (k)	Damping (z)	Initial deformation (ΔL)
Basin-Knee	0.005 ^(vii)	0.001 ^(viii)	0
Knee-Foot	0.005 ^(vii)	0.001 ^(vii)	0
Basin-Virtual knee	0.005	0.001	0
Virtual knee-Foot	0.005	0.001	0
Basin-Foot	4E-05 ⁽ⁱⁱⁱ⁾	1E-05 ^(iv)	0
Knee-Virtual knee	1E-05 ^(v)	0.002 ^(vi)	0
Ground-Right foot (BUT)	0.01	0.05	The resistance force from the Ground (BUT collision) Threshold = 0.5
Ground-Left foot (BUT)	0.01	0.05	
Remarks:			
The parameters (i) (ii) decide the initial kinetic energy in the preparation.			

The rebound state (oscillation and decay) of leg depends on the parameters (iii) (iv).

The vibration state of knee depends on the parameters (v) (vi).

The length of leg is represented and tuned by the strength and initial length of parameters (vii) (viii).

Vertical Jump



MASS			
Mass	Inertia (M)	Gravity (g)	Initial velocity (v)
Basin (right leg)	10	-1E-05 ^(iv)	0
Knee (right leg)	0.1	0	0
Virtual knee (right leg)	0.1	0	0
Foot (right leg)	10	3E-05 ^(v)	0
Basin (left leg)	10	-1E-05 ^(iv)	0
Knee (left leg)	0.1	0	0
Virtual knee (left leg)	0.1	0	0
Foot (left leg)	10	3E-05 ^(v)	0
SPRING			
Spring	Stiffness (k)	Damping (z)	Initial deformation (ΔL)
Basin-Knee	0.005	0.001	0
Knee-Foot	0.005	0.001	0
Basin-Virtual knee	0.005	0.001	0
Virtual knee-Foot	0.005	0.001	0
Basin-Foot	4E-05 ⁽ⁱⁱⁱ⁾	1E-05 ^(viii)	~ 22.5 ⁽ⁱ⁾
Knee-Virtual knee	1E-05 ^(vi)	0.002 ^(vii)	~ 32.1 ⁽ⁱⁱ⁾
Ground-Right foot (BUT)	0.01	0.05	The resistance force from the Ground (BUT collision) Threshold = 0.5
Ground-Left foot (BUT)	0.01	0.05	
<p>Remarks:</p> <p>The parameters (i) (ii) decide the initial potential energy into the preparation.</p> <p>The jump height depends mainly on the parameters of leg (i) (iii) and the parameters of gravity (iv) (v).</p> <p>The vibration of knee depends on the parameters (vi) (vii).</p> <p>The rebound state after jump depends on the parameters (iii) (viii).</p>			

Flip backward



MASS			
Mass	Inertia (M)	Gravity (g)	Initial velocity (v)
Basin (right leg)	10	1.7E-06 ⁽ⁱⁱⁱ⁾	$V_y = -73$ ⁽ⁱ⁾ ; $V_z = -15$ ⁽ⁱⁱ⁾
Knee (right leg)	0.1	0	0
Virtual knee (right leg)	0.1	0	0
Foot (right leg)	10	1.7E-06 ⁽ⁱⁱⁱ⁾	0
Basin (left leg)	10	1.7E-06 ⁽ⁱⁱⁱ⁾	$V_y = -73$ ⁽ⁱ⁾ ; $V_z = -15$ ⁽ⁱⁱ⁾
Knee (left leg)	0.1	0	0
Virtual knee (left leg)	0.1	0	0
Foot (left leg)	10	1.7E-06 ⁽ⁱⁱⁱ⁾	0
SPRING			
Spring	Stiffness (k)	Damping (z)	Initial deformation (ΔL)
Basin-Knee	0.005	0.001	0
Knee-Foot	0.005	0.001	0
Basin-Virtual knee	0.005	0.001	0
Virtual knee-Foot	0.005	0.001	0
Basin-Foot	8E-05 ^(iv)	1E-05 ^(v)	0
Knee-Virtual knee	1E-05 ^(vi)	0.005 ^(vii)	0
Ground-Right foot (BUT) ^(viii)	0.01	0.05	The resistance force from the Ground (BUT collision) Threshold = 0.5
Ground-Left foot (BUT) ^(viii)	0.01	0.05	
<p>Remarks:</p> <p>The parameters (i) decide the jump in vertical axis.</p> <p>The parameters (ii) decide the jump in horizontal axis that lead to flip backward.</p> <p>The jump height depends mainly on the parameters of leg (i) (iv) and the parameters of gravity (iii).</p> <p>The vibration of knee depends on the parameters (vi) (vii).</p> <p>The rebound state after jump depends on the parameters (iv) (v).</p> <p>In these jump-pattern models, the friction of the Ground was not taken into account. It can be achieved by varying the type of interaction (viii).</p>			

Qualitative Controls (Flowing Dance Model)



MASS

Mass	Inertia (M)	Gravity (g)	Initial velocity (v)
Origin	∞	0	0
Driving oscillator	1E+08 ⁽ⁱ⁾	0	0 ⁽ⁱⁱⁱ⁾
Virtual oscillator	1E+08	0	0
Spine _{0, 1, 2, ...N}	1 ^(v)	0	0
Right Arm _{0, 1, 2, ...N}	1 ^(vii)	0	0
Left Arm _{0, 1, 2, ...N}	1 ^(vii)	0	0

SPRING

Spring	Stiffness (k)	Damping (z)	Initial deformation (ΔL)
Origin-Driving oscillator	1E+04 ⁽ⁱⁱ⁾	0	10 ^(iv)
Origin-Virtual oscillator	1E+04	0	0
Driving oscillator-Spine ₀	1E-04 ^(vi)	0	0
Spine ₀ -Spine ₁	1E-04 ^(vi)	0	0
Spine ₁ -Spine ₂ Spine _n	1E-04 ^(vi)	0	0
Spine _n -Right Arm ₀	1E-04 ^(viii)	0	0
Right Arm ₀ -Right Arm ₁ Right Arm _n	1E-04 ^(viii)	0	0
Right Arm _n – Origin	0	1E-02 ^(ix)	0
Spine _n – Left Arm ₀	1E-04 ^(viii)	0	0
Left Arm ₀ -Left Arm ₁ Left Arm _n	1E-04 ^(viii)	0	0
Left Arm _n – Origin	0	1E-02 ^(ix)	0
Coupling virtual oscillator-driving oscillator ^(x)	0	0	0

Remarks:

The frequency of driving oscillator depends on the parameters (i) (ii).

The amplitude of driving oscillator depends on the parameters (iii) (iv).

The phase depends on the parameters (i) (ii) (v) (vi) (vii) (viii).

The functional state of spine is represented by the parameters (v) (vi).

The functional state of arm is represented by the parameters (vii) (viii).

The parameter (ix) is characteristic impedance depending on the parameters (vii) (viii).

The parameters of coupling (x) are the key-trick to perform the fluid-bound effect.

. Overview

The first level: Motion (towards movement representation and computer-assisted choreography)		
Models:	A dance verb Library	17 dance verbs.
	[Hsieh and Luciani 2005] [Hsieh and Luciani 2006]	Five motion patterns: (1) wave family, (2) balance family, (3) turn family, (4) step family, (5) jump family.
Concept: see vs. do	<i>A dynamic life of Cause</i> [Hsieh and Luciani 2007]	<i>The birth of cause, the growth of cause, the death of cause.</i>
Complexity	Composition	Cause composition instead of gesture/motion-data composition.
Invisibles:	Pre-movement	Each dance verb's cause (which is related to its motion pattern)
	Functional interaction	For example: (1) with environment, (2) between partners, (3) self body
The second level: Quality (towards movement representation and computer-assisted choreography)		
Models:	Dance adjective controls	Flowing Dance Modeling (FDM): mass-spring based string
		Light/strong amplitude, fast/slow frequency, phase, continuity.
Concept: do & feel	<i>Energy transmission on imaginary itinerary</i>	<i>Energy transmission & the propagation of "Qi".</i>
Complexity	Composition	Spatial combination of strings in series and in parallel
		Temporal transition of string
		Temporal compositions of oscillation(s)
Invisibles:	Mental motor	Oscillator's rhythm, strength.
	Body's inner state	Thin/thick spring with soft/rigid material.
The third level: Invisible (towards movement understanding and conservation)		
Extraction	Could be	Cause (pre-movement), functional interaction. Mental motor, body's inner states.
Mapping	Invisibles vs. Spring's physical functions	Spring's natural frequency map to soft/rigid material representing sparse/dense muscle.
		Spring's impedance map to thin/thick spring representing muscle strength.
		Oscillator's frequency map to mental motor representing rhythm.
		Oscillator's amplitude map to mental motor representing strength.
	Qualitative controls vs. Laban effort-shape	Amplitude map to Weight of Laban's effort-shape.
		Phase map to Space of Laban's effort-shape.
		Frequency map to Time of Laban's effort-shape.
		Coupling oscillations map to Flow of Laban's effort-shape.
Significant Examples	The relation between human behavior and model control	Conclusion1: In order to improve movement understanding, we take two factors: driving motor and driven body, into account. Hence, minimal energy means not only minimal quantity but also resonant frequency,
	Paradoxical fluid-bound	Conclusion 1: co-ordination between duo. Conclusion 2: different levels of details (rude/fine movement) controlled by

		different degrees of coupling.
Applications & Prospects		
New Dance writing	Dynamic Notation (dynamic figure)	The “dynamical” concept in two parts: (1) The dynamics-based simulation. (2) The implication of dynamically body’s inner state.
	Grammar	The above composition methods (from simplicity to complexity).
Creating dance	A virtual choreography	Fluente
	Real performance	M. Dance
Means	Modeling construction and manipulation	Towards predictive models or perceptual experimental models.

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Résumé Significatif en Français

Intitulée :

Grammaire de Mouvements Dansés par Modélisation Physique : Utilisation pour la Composition Chorégraphique

Spécialité :

Art, Science et Technologies

Thèse de Doctorat de l'Institut National Polytechnique de Grenoble

Laboratoire :

Thèse préparée dans le laboratoire ACROE & ICA-INPG, sous la direction conjointe de Mme. Annie Luciani et M. Claude Cadoz.

I. Introduction

« La danse est un poème dont chaque mouvement est un mot. » Mata Hari.

L'écriture de la danse est un défi vraiment intéressant, qui oblige se pencher sur plusieurs problématiques. Ecrire de la danse est un moyen de recevoir, d'observer, plus qu'un moyen d'analyse. Le moyen d'écrire de la danse, par exemple l'écriture grammaticale est une transformation de la danse elle-même. Cette transformation peut avoir un but passif de mémorisation/conservation ou un but actif tel que l'interprétation/la reproduction. Si l'écriture de la danse peut être utile pour transmettre et communiquer, elle peut ensuite être utilisée pour l'héritage et l'éducation. Néanmoins, il y a des pertes de la vue à l'écriture, et de la lecture à la reproduction. En effet, chaque transformation est inévitablement suivie de différents niveaux de perte, d'incompréhension et d'information ajoutée.

En raison de la perte causée par chaque transformation, nous remarquons le rôle troublant de l'écriture de la danse : d'une part, la réception passive consiste à écrire ce que nous voyons et ce que nous pensons de la danse ; d'autre part la réception active consiste à écrire une nouvelle chorégraphie. De plus, l'écriture de la danse a, en même temps, un but paradoxal de faire oublier la danse. Nous introduisons dorénavant un concept d'écriture de la danse qui comporte deux aspects : (1) Comment mémoriser la danse ? (2) et après, comment la reproduire ?

Deux problèmes extrêmes et conséquents sont mentionnés ici : (1) Si la plupart des détails d'origine sont enregistrés (comme des photographies), cela augmente considérablement la complexité à reproduire la danse. (2) Quand un point précis est affiné (comme avec une esquisse), nous avons besoin de vérifier s'il est précieux ou non pour reproduire la danse. Par exemple, l'écriture littérale de la danse devrait conserver, par quelque façon que ce soit, des « invisibles » agissant dans la mémoire du danseur ou dans l'état intérieur du corps. Afin d'éviter les inconvénients d'un jugement subjectif ou d'« informations ajoutées », il est nécessaire de reproduire l'écriture dans le but de la comparer avant et après la reproduction. Par conséquent, nous avons l'intention de créer une nouvelle écriture de la danse qui se concentre à la fois à voir et à reproduire. En d'autres mots, la mémorisation (la conservation) et la représentation (l'interprétation) devraient toujours fonctionner ensemble, l'une avec l'autre, ce qui est une caractéristique de cette nouvelle écriture.

II.I. Mémorisation

La mémorisation de la danse est un sujet fascinant. Chacun peut conserver des chorégraphies à l'aide de différents moyens : (1) En les observant sans aucune analyse, par exemple avec l'enregistrement filmique ou la capture du mouvement ; (2) En les notant au moyen des systèmes de notation de la danse, tels que les méthodes Laban, Benesh, etc ; (3) En les critiquant avec un jugement subjectif ; (4) En les dessinant par un artiste ; (5) En les décrivant par des danseurs et des chorégraphes. Chaque méthode possède différents degrés de subjectivité ainsi que des propriétés différentes, selon ce qu'elle souligne. Par exemple, dans des coordonnées d'espace et de temps, le mouvement a une trajectoire spatiotemporelle explicite, qui est observée objectivement mais extérieurement, soulignant plus la forme et les gestes. Dans la coordonnée de fréquence, le mouvement peut se concentrer plus sur la force (amplitude) et sur le rythme relevant de la musique. Dans la description de l'observateur, le mouvement est souvent dépendant de sa perception et rattaché à des perspectives critiques. La mémoire du danseur est comme est un espace intérieur personnel, relevant par exemple de l'imagination et de la sensation, où la danse est inscrite le plus profondément, le plus obscurément, et où elle est le plus difficile à conserver. Même si la mémoire du danseur est une sorte de conservation, la lisibilité a besoin d'être améliorée dans une intention d'héritage.

Les notations de la danse les plus connues sont la méthode Benesh, qui note la danse classique à l'aide de symboles, et la notation Laban, créée pour le mouvement général, qui traite l'apparence du corps (gestes extérieurs). Quelques systèmes de notation prennent en compte l'espace intérieur du corps (les états intérieurs), même si la théorie « Effort-shape » de Laban, basée sur la kinésphère, s'attache à la relation entre les dynamiques et les formes géométriques. Cet état de fait implique que, pour mémoriser la danse, nous devrions choisir un média approprié auquel attacher quelque chose d'important. Dorénavant, le défi de ce sujet est de savoir comment nous pouvons mémoriser les invisibles et avec quels moyens. De plus quelles sortes d'invisibles, par exemple la respiration, la tension musculaire, la fatigue, etc, voulons-nous saisir?

II.II. Reproduction

Reproduire la danse par ordinateur, ce qui est une sorte de performance numérique, est sans aucun doute différent de la représentation traditionnelle de la danse. La danse numérique améliore cette représentation de plusieurs façons : effet visuel, danseur irréel, scène imaginaire, environnement sans frottement, etc. Elle pourrait concerner ce que l'homme ne pourra jamais réaliser lui-même ; ou la réalité du comportement humain. Cependant, il existe des débats sur l'intérêt de la reproduction de la danse numérique. Par exemple, pour sa réalité et son efficacité au niveau de la représentation du mouvement, nous réutilisons la donnée du mouvement obtenu par capture. Cependant, au niveau de la conservation de la danse, la donnée du mouvement d'origine doit être analysée. Inversement, la méthode de synthèse du mouvement pourrait offrir des clés importantes pour comprendre le mouvement, même si la danse par simulation est moins réaliste et moins fidèle à la représentation du mouvement. En se concentrant sur la reproduction du mouvement, les auteurs ont souligné deux éléments que l'ordinateur ignore : (1) Quelles sont les relations entre la danse par ordinateur, partant du résultat ou de la cause, et l'animation basée soit sur des figures, soit sur des dynamiques ? (2) Comment améliorer la qualité du passage d'un mouvement à un autre lors de l'enchaînement du mouvement [Hsieh and Luciani 2007].

A travers les éléments exposés ci-dessus, nous proposons comme nouvelle idée que la différence entre la danse virtuelle par ordinateur et la danse réelle pourrait améliorer la compréhension du mouvement. L'idée selon laquelle la danse par ordinateur est un média de comparaison à la danse réelle prend une tout autre signification à la mise en évidence et à la conservation des invisibles. Les similarités et les différences entre danse réelle et danse virtuelle pourraient être un important outil expérimental pour distinguer, dans l'espace intérieur du corps, si la reproduction de la danse peut se passer comme la danse réelle mais virtuellement. Dans ce sens, la capture du mouvement basée sur la danse « se passe » réellement (analytiquement) et est ensuite transformée en une forme, un personnage, un environnement, etc, virtuels. Quoi qu'il en soit, en comparaison avec les notations traditionnelles de la danse qui enregistrent des figures sans mouvement, notre argument est qu'il pourrait exister un système innovant d'écriture de la danse qui prendrait en compte la reproduction par ordinateur, ce qui est absolument différent de la visualisation (reproduction) de la notation traditionnelle de la danse.

Pour résumer, nous nous sommes intéressés à la recherche de quelque chose d'invisible ou d'imaginaire, mais qui existe réellement dans la danse. L'existence des invisibles signifie que beaucoup de mouvement se passe dans le corps, lieu où il est habituellement difficile à capturer. Désormais, cette thèse – une modélisation physique – implique de synthétiser les invisibles supposés dans le but de reproduire le mouvement. Les invisibles sont ainsi conservés par un moyen plus objectif que critique.

III. La Nouvelle Ecriture de la Danse

Notre intérêt dans cette nouvelle écriture de la danse est une modélisation basée sur « masse-interaction » prenant en compte le « mouvement », la « qualité » et les « invisibles ». Ces trois principes ne sont pas exclusifs mais réellement apparentés. La nouvelle écriture de la danse stipule un concept innovant : une « notation dynamique » (ou une « figure dynamique ») impliquant à la fois le « voir » et le « faire ».

A la première étape, nous créons une série de modèles de verbes de la danse, à l'aide de la modélisation basée sur « masse-interaction ». Ces modèles de verbes peuvent générer des mouvements dansés. A la deuxième étape, nous créons une série de modèles concernant les adjectifs de la danse. Ces modèles peuvent être des références qualitatives. A la troisième étape, nous nous attachons aux invisibles, qui sont cachés dans ces modèles. En d'autres mots, durant le processus de construction de la modélisation, plusieurs invisibles sont pris en compte afin de générer du mouvement et améliorer le contrôle sur la qualité.

III.I. Moyen et Sens de la Modélisation

La méthode de synthèse proposée est basée sur une masse et un ressort. La modélisation par masse-interaction est efficace pour simuler le comportement dynamique, en particulier pour des phénomènes naturels comme le fluide et les solides déformables. Cependant, le mouvement humain est un comportement biomécanique complexe, plus qu'un comportement « pur » obéissant aux lois de la physique. L'originalité de notre recherche est que, grâce à la modélisation par masse-interaction, nous générons du mouvement dansé uniquement avec « les masses minimum nécessaires » et « les interactions essentielles ».

Le système de simulation dynamique, appelé Cordis-Anima [Cadoz et al. 1984, 1989, 1993] avec une interface MIMESIS [Luciani 1985; Luciani et al. 1991; Evrard et al. 2006], est utilisé pour traiter l'équation de mouvement de second ordre de Newton par un algorithme numérique (équation 1). L'auteur, en modéleur, va construire un danseur virtuel et initier sa capacité dynamique avec seulement deux types de données : la position vectorielle initiale (p) et la vitesse initiale (v) de la masse; et quatre types de paramètres : l'inertie de la masse (m), la constante du ressort (k) et la constante de viscosité (z) de l'interaction viscoélastique, la longueur initiale et le seuil de ressort (l et s).

Par exemple, nous avons l'intention de modéliser un oscillateur à vibrations amorties dont l'équation de mouvement est l'équation 2. Cette équation ayant deux parties, une partie transitoire et une partie stable, la solution générale est décrite dans l'équation 3. Pour une meilleure compréhension, nous ignorons la partie transitoire et simplifions dans l'équation 4, qui a pour paramètres : la fréquence angulaire (w), l'amplitude (A) et la phase (φ). En pensant à la modélisation physique, nous pourrions modéliser la fréquence angulaire (w) par la racine carrée de (k/m) ; modifier l'amplitude (A) et la phase (φ) par l'ensemble de la position initiale (p) et la vitesse initiale (v).

$$X_{n+1} = 2X_n - X_{n-1} + \frac{1}{M}F_n$$

$$F_n^{(2)} = -F_n^{(1)} = -K(X_n^{(2)} - X_n^{(1)}) - B(V_n^{(2)} - V_n^{(1)}) \quad (eq. 1)$$

$$m \cdot dx^2/dt^2 + c \cdot dx/dtx + kx = F_{oscillator} * \cos(w_{oscillator}t) \quad (eq. 2)$$

$$\psi(t) = \psi_{transient} + \psi_{steady state}$$

$$= A_h e^{-\gamma t} \sin(\omega' t + \varphi_h) + A \cos(\omega_{oscillator} t + \varphi) \quad (eq. 3)$$

$$\psi(t) \cong A * \cos(\omega_{oscillator} t + \varphi) \quad (eq. 4)$$

III.II. Nouvelle Notation Dynamique (Figures Dynamiques)

Les systèmes traditionnels de notation se concentrent sur des figures inanimées basées sur des symboles et sur l'espace-temps. Nous innovons une nouvelle notation dynamique, c'est-à-dire des figures dynamiques, basée sur la modélisation par masse-interaction pour restaurer l'information cachée telle que l'énergie et la dynamique. Dans notre notation dynamique, les masses représentent des gestes inanimés ; les ressorts représentent les interactions matérielles et fonctionnelles. Les masses minimum nécessaires et les interactions essentielles sont construites à travers les principes suivants :

- Un geste sans mouvement est représenté par la position spatiale des masses.
- Le niveau de détail des masses pourrait représenter, d'un côté, les détails du mouvement qui ont des formes linéaires/courbes (figure 1-a/b).
- Le niveau de détail des masses pourrait représenter, d'un autre côté, les détails du mouvement qui ont un mouvement brut/fin (figure 1-c).
- Le ressort représente l'interaction matérielle, par exemple le corps physique.
- Le ressort représente l'interaction fondamentale, par exemple la connexion invisible entre l'épaule droite et la jambe gauche, causée par l'équilibre.

En d'autres mots, les figures dynamiques n'ont pas seulement, à chaque micro instant, la position présente, mais incarnent aussi l'état intérieur du corps et anticipent l'état futur. La figure dynamique illustrée, c'est-à-dire la notation dynamique, est créée pour simplifier le corps humain. Par ce moyen, nous perdons des détails de la forme : squelette, muscle, peau...Cependant, nous gagnons plus sur les interactions : sur la fonction des muscles (par exemple la contraction et le relâchement), sur l'interaction avec l'environnement (par exemple la chute et le rétablissement), et sur l'effet du système moteur mental (par exemple le principe de la causalité dans le pré-mouvement).

Nous distinguons deux possibilités selon lesquelles la figure immobile donne l'impression de mobilité. La première est de dessiner un geste en déséquilibre, par exemple lorsque le centre de gravité est loin du pivot support, ce qui donne une

perception visuelle menant à l'anticipation du mouvement. Le tableau de Toulouse Lautrec, *La Goulue au Moulin Rouge*, est un exemple typique : le manque d'équilibre qui arrive pendant le mouvement peut donner l'impression de mobilité. Herbison-Evans a catalogué ce type de figure de transition en vélocité « non-zéro » et en accélération « non-zéro ». A l'égard de la statique en mécanique, le déséquilibre pourrait rendre la gravité visible. La seconde possibilité est d'anticiper le mouvement en restaurant la force. Un ressort idéal qui conserverait l'énergie entre l'énergie cinétique et l'énergie potentielle est un exemple de ces possibilités. Notre notation dynamique innovatrice, qui appartient au second type, est utile pour instaurer la raison (une cause, une force restaurée, de l'énergie potentielle) qui fait qu'une figure en déséquilibre peut bouger. A partir de maintenant, notre modélisation synthétique et dynamique va mettre en avant le pré-mouvement et prendre en compte les invisibles. En bref, les masses représentent des figures inanimées et les ressorts l'état intérieur du corps en dynamique.

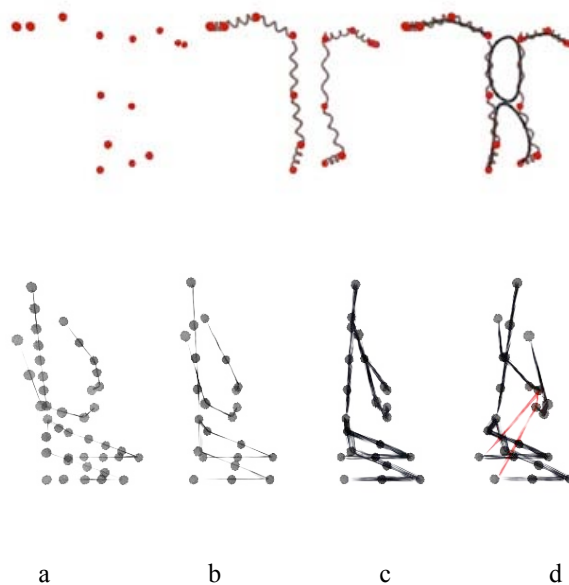


Figure I: Figures dynamiques construites par masse-interaction. Les masses représentent des gestes inanimés; les ressorts représentent les interactions matérielles et fonctionnelles.

III.III. Mouvement, Invisibles & Qualité

L'existence des invisibles signifie qu'une grande quantité de mouvement a lieu à l'intérieur du corps. Les invisibles pourraient être, par exemple, le pré-mouvement, l'interaction fondamentale, le rythme respiratoire, la tension des muscles, etc. Dans la littérature de la danse, ces invisibles sont souvent mentionnés (état intérieur du corps). Selon ces littératures, nous voyons comment l'énergie affecte le mouvement humain aussi bien que les interrelations entre la qualité du mouvement et l'énergie. Nous considérons que la qualité du mouvement dépend du mouvement dynamique explicite (énergie cinétique) et de l'état implicite du corps (énergie potentielle), qui est négligemment ignorée. De nombreux domaines, tels que l'animation par ordinateur, font usage d'un stimulus cinétique apparent (exagération, caricature, etc) ; mais peu incluent une recherche de finesse et de qualité subtile, on est donc loin du mouvement gracieux. Notre argument est que, pour suivre à la trace la qualité du mouvement, nous devrions considérer les états intérieurs du corps, sinon la compréhension du mouvement est moins profonde car nous observons seulement la cinétique apparente.

La relation entre les invisibles (états intérieurs du corps), le mouvement et la qualité est certainement obscure. Un simple mouvement harmonieux peut être écrit ainsi : « $\psi(t)=A * \cos(\omega t+\varphi)$ », ce qui peut être le résultat d'un ressort ayant un paramètre de rigidité (k) et une inertie (m) en supposant que ω est égal à la racine carrée de (k/m). Un autre ressort ayant ($2k$) et ($2m$) pourrait réussir le même mouvement. Si nous analysons seulement les mouvements résultant de ces deux ressorts, nous ne pouvons malheureusement pas distinguer de différence. Dans ce cas, le fait de percevoir la qualité seulement avec son mouvement cinétique pose problème. Cependant, dans les deux cas la quantité d'énergie initiatrice est différente : le second ressort a deux fois plus d'énergie que le premier. Afin de définir la différence de qualité, nous avons pris en compte l'inertie et la rigidité. C'est pourquoi nous insistons sur le contrôle de la qualité avec l'état intérieur du corps (les invisibles).

IV. Mouvement : verbes de la danse

Nous proposons l'idée de construire à l'aide de « modules » selon chaque type de mouvement, c'est-à-dire selon chaque verbe de la danse, pour résoudre le défi de la contrôlabilité et de la complexité de la simulation physique. Parmi ces modèles de verbes de la danse, la structure complexe du personnage et le mouvement complet sont simplifiés et affinés grâce aux « masses nécessaires » et aux « interactions essentielles ». Grâce à l'utilisation de la procédure de simplification, nous pouvons nous concentrer sur l'interaction et la connexion à travers le mouvement dansé et tirer avantage à une méthode numérique efficace.

Alors que la structure complexe du personnage est déconstruite en une « modélisation basée sur masse-interaction », la matière du squelette et des articulations n'existe plus. A la place, le nombre réduit de masses interagissant représente ou les composants matériels (par exemple le squelette et les membres invisibles) ou les composants fonctionnels (par exemple l'interaction invisible, due à l'équilibre, connectant la main droite et la jambe gauche). A ce niveau-là, ce procédé diffère des utilisations classiques de la modélisation physique (par exemple l'utilisation de la modélisation du masse-ressort pour représenter la déformation de la surface de la peau) : nous représentons exactement les propriétés de la matière. De ce fait, nous nous intéressons seulement à l' « interaction » pendant la durée de l'action.

IV.1. Concept

Du point de vue du danseur sur la dynamique, spécialement pour la danse contemporaine, chaque action provient d'une cause qui détruit l'équilibre initial. Pour la plupart des danseurs, il doit y exister une cause, qui peut être un changement du centre de gravité ou une perte de l'équilibre, qui provoque tous les mouvements. Ensuite, cette cause déclenche le mouvement qui à venir. A la fin, le corps va trouver un nouvel équilibre. Par conséquent, le processus de la danse a une unique formule dynamique : « préparation – action – récupération ». Malkovsky appelait ce modèle « provoquer – laisser aller et relâcher – nouvel équilibre » et le rattachait au principe de causalité, qui se sert dans un état d'« économie de l'effort ».

Dans notre approche, tous les modèles physiques et de verbes de la danse sont créés selon la procédure suivante :

1. Découvrir « l'emplacement moteur » et initier l'énergie dans ce moteur (naissance de la cause).
2. Générer les mouvements depuis le « moteur » (croissance de la cause).
3. Diminuer l'influence de moteur et trouver un nouvel équilibre (mort de la cause).

Pour résumer, les danseurs entraînent leur corps chaque jour afin de découvrir et de répéter comment le mouvement complet est justement développé depuis l'emplacement moteur. Comme Isadora Duncan qui disait : « Je recherchais et finalement j'ai découvert le ressort central, le cratère du pouvoir moteur », l'auteur recherche la cause, c'est-à-dire le ressort central, pour générer des mouvements dansés et continuer à respecter la dynamique durant le processus. Le concept des modèles dynamiques s'appuyant sur la causalité peut se trouver dans l'article [Hsieh and Luciani 2007].

IV.II. Modèles

Une bibliothèque des modèles basés sur masse-interaction et sur les verbes de la danse est inscrite ci-dessous. Les modèles sont catalogués en cinq branches selon leur type de mouvement. Chaque branche représente une variation de ce type. Plus de détails sur les modèles sont disponibles dans les articles [Hsieh and Luciani 2005; 2006].

Table I. La bibliothèque des modèles basés sur les verbes de la danse

Motion pattern	Cause (pre-movement)	Members
Wave family non-locomotion	propagation	ripple, dolphin, etc
Self-balance family non-locomotion	push and pull	Sway
Turn family non-locomotion	torsion	pirouette, etc
Step family locomotion	loss-balance & friction	walk, swing step, waltz step, etc
Jump family contra-gravity	gravity	plier, rebound, jump, leap, hop, sissonne, assemblé, etc

L'auteur a été amené à générer des mouvements dansés par ordinateur qui peuvent être considérés au premier abord comme une représentation numérique du mouvement. La bibliothèque de modèles basés sur masse-interaction, suivant les verbes de la danse, a été développée dans le but de créer une chorégraphie assistée par ordinateur. Les précédentes approches des auteurs sur ce sujet concernaient l'interprétation de la danse.

Notre étude porte sur la « conservation de la danse » qui garderait des parties invisibles. On pourrait comprendre que l'analyse est moins appropriée à ce genre de recherche, à cause de la définition de l'invisible, dont la capture est par exemple impossible. La méthode proposée - la modélisation du mouvement invisible – a pour but de valider l'hypothèse de l'existence des invisibles au moyen de la synthèse. C'est différent de la méthode analytique, mais peut être utile à l'analyse du mouvement.

V. Synthétisation (Invisible & Qualité)

Les analyses sont appropriées pour les éléments explicites qui ont plus de changements ou apparences, et qui devraient être capturés; la synthétisation pourrait prendre en compte des éléments implicites. C'est la distinction fondamentale entre l'analyse du mouvement et la synthétisation du mouvement. Les deux méthodes ne sont pas exclusives mais peuvent s'enrichir l'une l'autre. En effet, les modélisations de synthèse que nous proposons sont basées pertinemment sur la connaissance de l'analyse du mouvement. Dès lors, nous proposons d'utiliser les fonctions du masse-ressort pour relier l'état intérieur du corps et l'effort-shape de Laban, une théorie de l'analyse du mouvement.

V.I. Fonctions vibratoires du ressort & Invisibles

Nous proposons de modéliser l'état intérieur du corps du danseur par les fonctions vibratoires du ressort, avec un ressort fin/épais et un matériel souple/rigide. Nous proposons aussi de modéliser le rythme de la respiration du danseur grâce à un oscillateur vibrant à une fréquence constante.

- ressort fin d'un matériel souple (k, m)
- ressort épais d'un matériel souple ($2k, 2m$)
- ressort fin d'un matériel rigide ($2k, 0.5*m$)
- ressort épais d'un matériel rigide ($4k, m$)
- fréquence lent d'un oscillateur vibrant ($w_{oscillator}$)
- fréquence rapide d'un oscillateur vibrant ($2 * w_{oscillator}$)

L'oscillateur vibrant représente le moteur mental dans l'esprit du danseur. Le ressort vibré a deux facteurs : l'impédance et la fréquence naturelle, qui représentent l'intérieur du corps. Un ressort en matériel souple/rigide représente la capacité de résistance des muscles. Un ressort comprimé/étiré représente l'état potentiel instantané des muscles. Un amortissement représente l'état de fatigue des muscles. Le tableau II montre les paramètres physiques du masse-ressort modélisé dans l'état intérieur du corps.

Table II. Les paramètres physiques du masse-ressort modélisent l'état intérieur du corps.

Ressort vibré & Oscillateur vibrant		L'état intérieur du corps	
La fréquence naturelle racine (k/m)	matériel souple (k, m)	matériel du muscle	éparse féminin
	matériel rigide ($2k, 0.5m$)		dense masculin
Impédance racine ($k*m$)	ressort fin (k, m)	résistance du muscle	légère
	ressort épais ($2k, 2m$)		lourde
La fréquence de l'oscillateur	rapide $w_{oscillator}$	rythme du moteur mental	soudain rythme
	lente $w_{oscillator}$		soutenu rythme
L'amplitude de l'oscillateur	petite A	capacité du moteur mental	doux
	grande A		fort

V.II. Le contrôle de la qualité

Cette partie indique comment améliorer le contrôle de la qualité à l'aide d'un ressort et d'un oscillateur qui le fait vibrer. Le tableau III montre le contrôle de la qualité en rapport à l'analyse de l'effort-shape de Laban. Les avantages du contrôle que nous avons sur la qualité, comparés à l'effort-shape sont : (1) une bonne relation avec les invisibles (état intérieur du corps et moteur mental) ; (2) des paramètres intuitifs ; (3) le contrôle direct de l'énergie (sur la cause, non sur les résultats)

Table III. Le contrôle de la qualité en rapport à l'effort-shape de Laban

le contrôle de la qualité		effort-shape d'après Laban	
Amplitude	grande A	Poids	fort
	petite A		doux
Phase	petite ϕ	Espace	direct
	grande ϕ		indirect
Fréquence	rapide $w_{oscillator}$	Temps	soudain
	lente $w_{oscillator}$		soutenu
Couplage	non-couplage	Flux	libre
	couplage		entravé

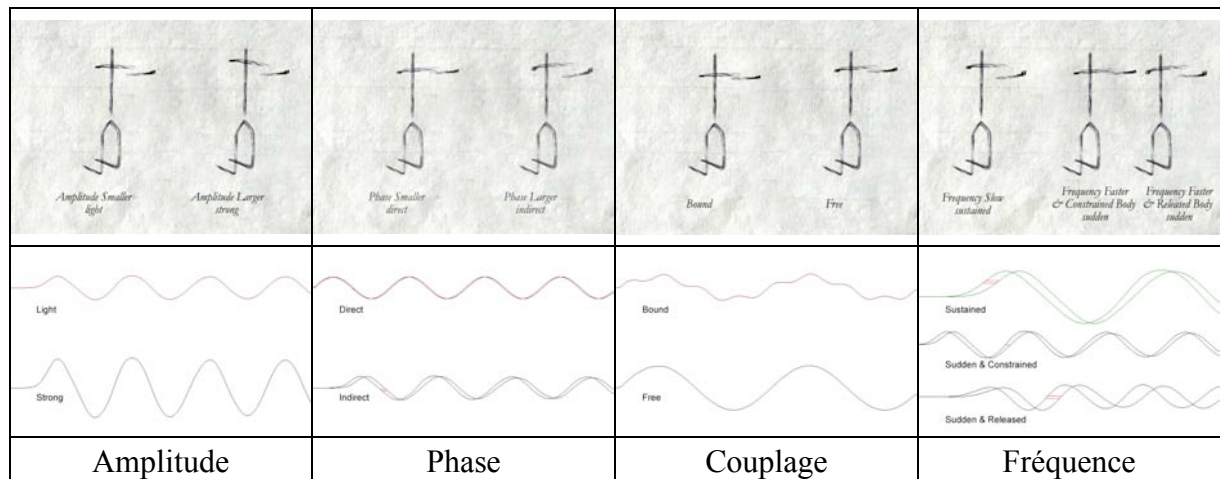


Figure II: Les résultats du contrôle de la qualité.

VI. Analyse

Dans cette partie, nous analysons et expliquons les raisons qui font que lorsque l'homme accélère ses mouvements, il lui est difficile de garder la même trajectoire de mouvement. Nous supposons que c'est l'effet de la relation entre l'oscillateur vibrant (contrôle mental) et la vibration du ressort. Ces deux facteurs pourraient être traités simultanément. Cela signifie que lorsque le danseur accélère son mouvement, il devrait moduler ses muscles en même temps pour garder la même trajectoire de mouvement.

Notre modèle de synthèse explique ce phénomène comme indiqué ci-dessous :

1. $w_{oscillator}$ fait vibrer le ressort (k, m) dans figure 3-(a).
2. $2 * w_{oscillator}$ fait vibrer l'autre ressort (2k, 0.5m) dans figure 3-(b).
3. $2 * w_{oscillator}$ fait vibrer le ressort (k, m) dans figure 3-(c).

Les résultats de la figure III expliquent qu'une vitesse double de la même trajectoire de mouvement, avant et après accélération de lecture, maintiendrait la même différence entre les deux points d'observation contigus, c'est-à-dire deux masses contiguës ou deux points d'articulation. Cependant, dans nos modèles, une fréquence double change la phase (délai), qui ne peut alors maintenir la même trajectoire de mouvement résultante. Ce phénomène des coordonnées de fréquence paraît moins approprié pour le contrôle du mouvement que dans la lecture de donnée des mouvements. Néanmoins, cela révèle la différence entre le contrôle du mouvement non humain (virtuel) et le contrôle du mouvement humain. Cette différence peut aider à la compréhension du mouvement. Par exemple, dans ce cas, il s'agit de l'effet de la simultanéité entre le contrôle moteur et l'état du corps.

Pour conclure, comment un danseur réussit-il un mouvement très dynamique? Une possibilité : il s'entraîne dans le but de gagner plus de force. Cela revient, en terme de modélisation, à assigner plus d'énergie à l'oscillateur vibrant. Une autre possibilité : le danseur module ses muscles autant que possible pour réussir de tels mouvement dynamiques. En modélisation, cela se traduit en remplaçant « un enchaînement de ressorts épais » par « un enchaînement de ressorts fins » sans changer l'oscillateur moteur. Au moyen de la construction et la manipulation de modèles, il est possible de percevoir la conscience du mouvement à l'aide du contrôle du modèle.

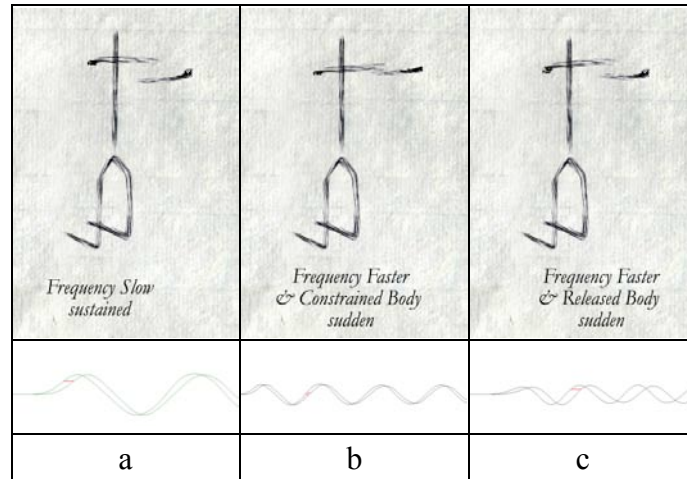


Figure III: *Un exemple de la relation entre l'oscillateur vibrant et la vibration du ressort.*

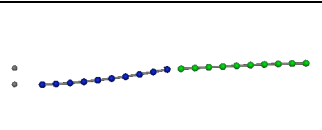
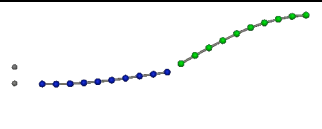
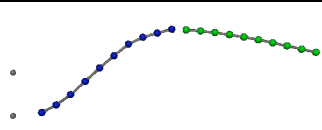
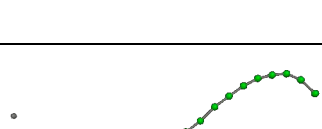
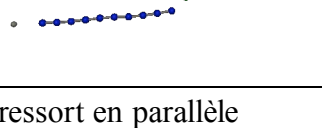
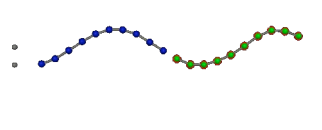
VII. Complexité

Parce que le comportement humain et l'état intérieur du corps sont très compliqués, nous complexifions nos modélisations de synthèse de trois façons:

- La combinaison spatiale du ressort en série et en parallèle.
- Les transitions temporelles du ressort telles que les changements d'état intérieur du corps.
- La composition séquentielle de l'oscillateur vibrant.

Les combinaisons spatiales impliquent que les états intérieurs du corps sont différents à un même instant, par exemple la moitié du corps est rigide et l'autre moitié est souple. Le tableau IV montre des ressorts complexes, à savoir un enchaînement complexe de ressorts combinés en série ou en parallèle.

Table IV. La combinaison spatiale du ressort en série et en parallèle.

La combinaison du ressort en série	
Amplitude Grande à Petite fin à épais $Z_1(k, m) < Z_2(2k, 2m)$	
Amplitude Petite à Grande épais à fin $Z_1(k, m) > Z_2(0.5k, 0.5m)$	
Vélocité de propagation lente à rapide éparse à dense $w_1(k, 2m) < w_2(2k, m)$	
Vélocité de propagation rapide à lente Dense à éparse $w_1(2k, m) > w_2(k, 2m)$	
La combinaison du ressort en parallèle	
Composing, in parallel, the same material but thin/thick strings results in the same amplitude	
Transition of propagating velocity; composing strings by different materials.	

La transition temporelle implique des changements de l'état intérieur du corps, par exemple les muscles contractés qui se relâchent. Le tableau V montre la transition temporelle d'un ressort, à différents états.

Table V. Les changements d'état intérieur du corps.

Les transitions temporelles du ressort	
Du ressort fin (gauche) au ressort épais (milieu) jusqu'aux changements matériels (droite)	

De plus, la composition de l'oscillateur vibrant fournit une large variété de mouvements humains complexes. Un oscillateur vibrant peut frapper un masse-ressort (sans provoquer de vibration) ou le faire « osciller ». Cela renvoie à quatre types d'oscillation : (1) oscillation sans perte d'énergie, c'est-à-dire sans amortissement ; (2) sous-amortissement ; (3) amortissement critique ; (4) sur-amortissement. Par exemple, l'octroi d'un léger sous-amortissement provoque un effet excité, en comparaison à l'oscillation périodique qui se répète. Après, nous étendons la composition de l'oscillateur à deux directions : x et y pour le mouvement plan, qui, avec z, forment le mouvement spatial. Selon les courbes de Lissajou [Cundy and Rollett 1989], la variété des trajectoires dépend de la racine carrée de ω_x/ω_y et de la différence de phase. Par conséquent, nous pouvons assigner des trajectoires d'oscillation en deux dimensions, au tableau VI, telle qu'une ligne, un cercle, une ellipse, une parabole, une courbe, une courbe en huit couché, etc.

Table VI. La composition de l'oscillateur vibrant.

Linear/Planar oscillator	
oscillateur avec amortissement	oscillateur sans amortissement

VIII. Contribution

La contribution principale des graphiques par ordinateur est que nous utilisons une simulation basée sur la physique fondamentale, la modélisation du masse-ressort, pour arriver à réaliser le comportement complexe de l'humain. Nous innovons une manière spécifique de construire des modèles dynamiques et d'initier les paramètres physiques appropriés ; par conséquent notre méthode résout l'incontrôlabilité de la modélisation de la dynamique. De plus, nous montrons les relations entre le phénomène physique du masse-ressort et le comportement dynamique du danseur. C'est-à-dire que, au lieu de se perdre dans des équations et des algorithmes de mouvement compliqués, notre méthode se concentre sur la signification, la simplicité et l'efficacité.

Grâce aux contributions ci-dessus, notre nouvelle écriture de la danse tient compte du « mouvement », de la « qualité » et des « invisibles ». Les figures dynamiques peuvent conserver l'état intérieur du corps et interpréter immédiatement le mouvement. Nos modèles dynamiques pourraient être traités comme des modèles prédictifs, utiles à la compréhension du mouvement. Par ailleurs, grâce à la nouvelle écriture de la danse, une chorégraphie virtuelle innovatrice est en train d'être créée. Elle décrit : « la danse est la conséquence de la transmission d'énergie dans l'itinéraire imaginaire ». En même temps, elle est conservée par la notation dynamique et elle sera représentée en « réel ».

Résumé

Cette thèse s'attache à définir une nouvelle manière de modéliser des mouvements dansés basée sur le modèle physique modulaire masses–interaction et la simulation numérique. Ce type de modèle est envisagé pour servir deux objectifs : d'une part, comme outil de production de mouvements dansés par ordinateur et d'autre part comme moyen d'écriture. Ce type de modélisation permet de construire des modèles qui non seulement produiront des mouvements, mais également s'attacheront à rendre leurs qualités ainsi que l'obtention de qualités dites « invisibles », en ce sens qu'elles sont internes au danseur et qu'il n'est en général pas possible d'extraire d'une captation du mouvement. Cette écriture de la danse, que l'on peut qualifier de « notation dynamique » est nouvelle car elle permet en même temps de « noter » donc de conserver le mouvement, et de le produire. Cette notation dynamique implique une simulation dynamique du corps tel que perçu par le danseur d'une part et d'autre part la conservation des états dynamiques de cette simulation.

Nous avons développé ce que nous avons appelé, une grammaire de mouvements dansés qui consiste à disposer d'un ensemble de modèles combinables de mouvements élémentaires. Une première série de modèles s'est attachée à modéliser des verbes élémentaires d'action dansée. Nous avons créé ensuite une série de modèles concernant les adjectifs de la danse, qui peuvent être des références qualitatives. Enfin, nous nous sommes attachés à modéliser les déclencheurs internes, que nous avons appelé « moteur mental », et les états intérieurs du corps, que nous avons appelés « les invisibles ». En d'autres mots, durant le processus de construction de la modélisation, plusieurs invisibles sont pris en compte afin de générer le mouvement le plus proche possible d'une qualité « dansée » et d'améliorer la maîtrise de cette qualité. La grammaire de l'écriture de la danse, qui va de la simplicité à la complexité, est représentée comme la combinaison spatiale/la transition temporelle du corps réactif et de la composition du (des) oscillateur(s) vibrant(s).

En termes de représentation du mouvement, ces modèles sont utiles pour la chorégraphie assistée par ordinateur et pour l'animation de personnages. En termes de conservation du mouvement, ils sont utiles pour suivre à la trace les « invisibles » : moteur mental, état intérieur du corps et pré-mouvement. En termes de compréhension du mouvement, ils sont utiles aussi bien à travers la construction de la modélisation que de la manipulation. Nous présentons ainsi deux exemples significatifs: « le fluide-saccadé paradoxal » et « la relation entre l'oscillateur qui fait vibrer et le corps qui réagit ».

Nous obtenons ainsi une bibliothèque de verbes de la danse composée de cinq types de mouvement – ondulation, équilibre, tour, déplacement, saut - et de quatre contrôles

de la qualité - amplitude, phase, fréquence et continuité.

Nous affinons deux concepts en accord avec les principes de la danse contemporaine : l'un est « une vie dynamique de la cause » ayant pour but le pré-mouvement/la cause ; l'autre est « la transmission d'énergie dans un itinéraire imaginaire » à partir du moteur mental et des états intérieurs du corps.

Deux créations numériques concernant les verbes de la danse et les qualités de mouvement sont présentées. Une chorégraphie virtuelle et une représentation dansée, dans laquelle le code chorégraphique virtuel se concentre sur la propagation du souffle vital, le « Qi » (c'est-à-dire la transmission d'énergie), est engagée. La « simplicité » et la « non permanence » sont les considérations philosophiques qui influencent notre recherche scientifique et esthétique.

Abstract

The thesis is concerned with the grammar of physically based modelling (a digital means) for computer choreography (dance interpretation) and for dance writing (dance conservation). The concern in the novel dance writing is with mass-interaction based modelling, a kind of physically based animation, taking account of “motion”, “quality” and “invisibles”. The novel dance writing provides for an innovative concept: “dynamic notation” (or “dynamic figure”) implying movement conservation and movement reproduction at once. The dynamic notation means one sort of dynamics simulation on the one hand, and the conservation of dynamical body’s inner state on the other hand.

At the first level, we create a series of dance verb-dependent models that can generate dance movements (motion). At the second level, we create a series of dance adjective-dependent models that can be qualitative references (quality). At the third level, we indicate the mental motor and body's inner states, which are hidden within these models (invisible). In other words, during the process of modelling construction, the invisibles are taken into account to generate movement and improve qualitative control.

In terms of movement representation, these models are useful for computer-assisted choreography and for character animation. In terms of movement conservation, these models are useful to track “invisibles”: mental motor, body's inner state and pre-movement. In terms of movement understanding, these models are useful as well through modelling construction and manipulation. We thus presented two significant examples: “paradoxical fluid-bound” and “the relation between driving oscillator and driven body”.

In results, we obtain a dance verb library with 5 movement patterns and 4 qualitative controls: amplitude, phase, frequency and continuity. We refine two concepts in accordance with the thoughts of contemporary dance: one is “a dynamic life of cause” aiming at pre-movement/cause; the other is “energy transmission on imaginary itinerary” aiming at mental motor and body’s inner state. The dance writing’s grammar, from simplicity to complexity, is represented as the spatial combination/temporal transition of driven body and the composition of driving oscillator(s). Moreover, two digital creations concerning dance verb and motion qualities are presented. A virtual choreography & dance performance, in which virtual choreographic code is concentrated on the propagation of vital breath “Qi” (i.e. energy transmission), is in progress. “Simplicity” and “impermanence” are the influential philosophical thoughts underlie our scientific research and aesthetics.