Science and dance collective motions

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Abstract - Modelling collective movements of animals, which is a field of current research in physics, was used to support educational innovation involving scientists (students and researchers) and professional dancers at the end of their initial training process. The basic elements to understand this model and the original association between science and art are described by showing the contributions - and their limits – to the informal teaching of science and dance.

Introduction

Current teaching encourages little interaction between disciplines such as physics and dance, and trying to articulate the practices of these disciplines must appear surprising. However, the overlap between science and the arts have always existed. Indeed, doesn't the word *art* come from the Greek *techne*? Moreover, History shows us many examples of interaction between art and science: the painter Leonardo da Vinci was also a physiologist and architect; photography involves a lot of chemistry and optics, and cinema was born from a study of movement, to cite only a few famous examples. These art-science interactions are ongoing. Indeed, chemists currently contribute to the restoration of pieces of art at the Louvre museum,

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and physicists (including at the ENS Lyon) are still trying to understand the phenomena of resonance in order to improve the construction of some musical instruments. The link between science and dance discussed in this paper is less common and, to our knowledge, has not been reported in teaching situations.

For two years, the Ecole normale supérieure de Lyon and *Pro-sess*, the dance class of the – Hallet-Eghayan company which trains professional dancers, have collaborated on an educational project involving science students of the ENS and dancers. The general framework of this project was to present a topic of current research to a small group of science students, then ask them to use the same topic to prepare the training of the dancers. A didactic transposition (using the meaning given by Chevallard, [1]) was therefore required to train the dancers. This process occupied the first semester of the academic year. During the second semester, the dancers, under the artistic direction of Michel Hallet-Eghayan and their dance teachers, had to develop a dance inspired and enriched by the newly acquired scientific knowledge. The artistic work often took place in the presence of a scientist (student, researcher or teacher) in order to stabilize the newly introduced knowledge.

The field used in the current project deals with collective movements, such as the modelling of moving herds, flock of birds, schools of fishes, swarms of grasshoppers, colonies of micro-organisms, etc. This natural phenomenon has long been known (locusts swarms were already mentioned in the *Old Testament* [2]), and has long interested biologists who have sought to observe and describe it [3]. More recently, this phenomenon has attracted the attention of physicists concerned by the universal characteristics of individuals in motion, rather than the specificities of each animal species [4-6]. Since the seminal work of Vicsek fifteen years ago [7], this topic has been an active field of statistical physics as evidenced by a recent review [8]. Many theoretical studies still feed this type of research [9, 10], but with the development of techniques to collect data, such as the positions of starling flights versus time, empirical studies have also been published [11]. Humanities and social studies are also concerned by concerted movements such as motions in trading rooms or the formation of wave in football stadiums. These examples illustrate that modelling collective movements can be useful in different domains. The rest of this article will clarify some scientific information relating to collective movements. Only part of the model was used with the dancers, and it is specified. Finally the article explains how it inspired both a dance and reflection on this dance.

Collective motions

Basically, modelling collective motions consists in determining under which conditions the interactions of individuals might lead to the formation of a group in motion. The flights of starlings (*Sturnus vulgaris*), for example, possess a high level of coherence. These birds are indeed capable of concerted manoeuvres, either spontaneously or in response to a predator attack which a model aims to describe. Moreover, the collective movements that emerge spontaneously, without any individual playing a role of leader, are obviously the most interesting. Such considerations lead the physicist who worked in this field to look for models in which all individuals are similar and follow "local" rules, that is to say that they have no information on the overall herd. Using more elaborated viewpoints, these collective motions have structuring properties (in the sense of the appearance of an order), qualitatively comparable to phases of condensed matter (ferromagnet, liquid crystal, etc.). A challenging topic for physicists!

Without going too far in the presentation of such models, the rest of this article describes the ideas used in the course that the science students of the project set up for the dancers. The model consists in little information about the properties of individuals: (1) the modulus of their velocity is identical, (2) individuals move while changing their trajectories to adopt the average speed of their nearest neighbours, and (3) they also modify their trajectories to avoid possible collisions with neighbours.

These characteristics of individuals already introduce a series of adjustable parameters as in the case of the second rule: the radius of the circle that defines the nearest neighbours and the maximum angle of deviation permitted to approach the average velocity of the neighbours. From an educational point of view, the science students had to consider current conceptions about velocity, direction, or radius of interaction. Indeed, the dancers had not taken science at the university and most of them had not even taken it at highschool. Using concepts such as velocity, trajectory, etc. with dancers with little scientific background deserved some attention.

A more elaborate model of collective movements, used with science students, but not with the dancers, involves other parameters, eg taking into account the uncertainty with which each individual considers the trajectory of its neighbours. In this case, the velocity angle adopted by an individual is still an average, but to which is added white noise expressed as $\eta\times\xi$, where ξ is a random angle between $-\pi$ and $+\pi$ and η is a fixed parameter between 0 and 1. The latter determines the amplitude of the noise. The study of the order established after a certain amount of time (which is hence the characteristic of the "phase") between the particles according to their density and intensity η of the noise can raise phase transitions.

Figure 1 summarizes the calculations that must be performed for each individual. The individual whose velocity is represented by the blue vector adopts the average velocity of the neighbours that stand in his interaction circle (the radius of which is one of the parameters of the model). This average is represented by the red arrow. This speed is furthermore affected by a random value ($\eta\times\xi$) lying, for example, within the range represented in dotted lines. For this scheme, η is 0.05.

The purpose of modelling the motion of herds of animals was not immediately perceived by the science students. Instead, these students were looking for a possible link between the model and the actual behaviour of the corresponding animals. Such a model has no such an ambition. It only shows that a spontaneous mass movement is possible, based on simple rules of interaction between individuals. The physicist way of thinking, after thorough study of phase transitions (such as the appearance of magnetization in ferromagnetic material), suggests then that this must entail some degree of "universality", that is to say it should be relatively independent on details of interactions between individuals, as long as they remain qualitatively similar to that of the model initially considered. A quote by Hugh Chaté (a physicist working on this theme at CEA Saclay) sums the problem up: “In this sense, what emerges is the universal, and that's of interest to the statistical physicist”. The physicist abandons the idea of describing in detail each specific case to focus on the features common to different systems with a similar phenomenology. Such an approach is not always easy for students to grasp. Another difficulty in understanding this idea may also be due to the fact that the movement of animals may sometimes have a real motivation, as the North-South migrations of birds in the early winter days. That motivation is not imbedded in the model. This model considers that, as a first approximation, the inner organisation of the flock is due to local positions of each individual and not to the migration movement.

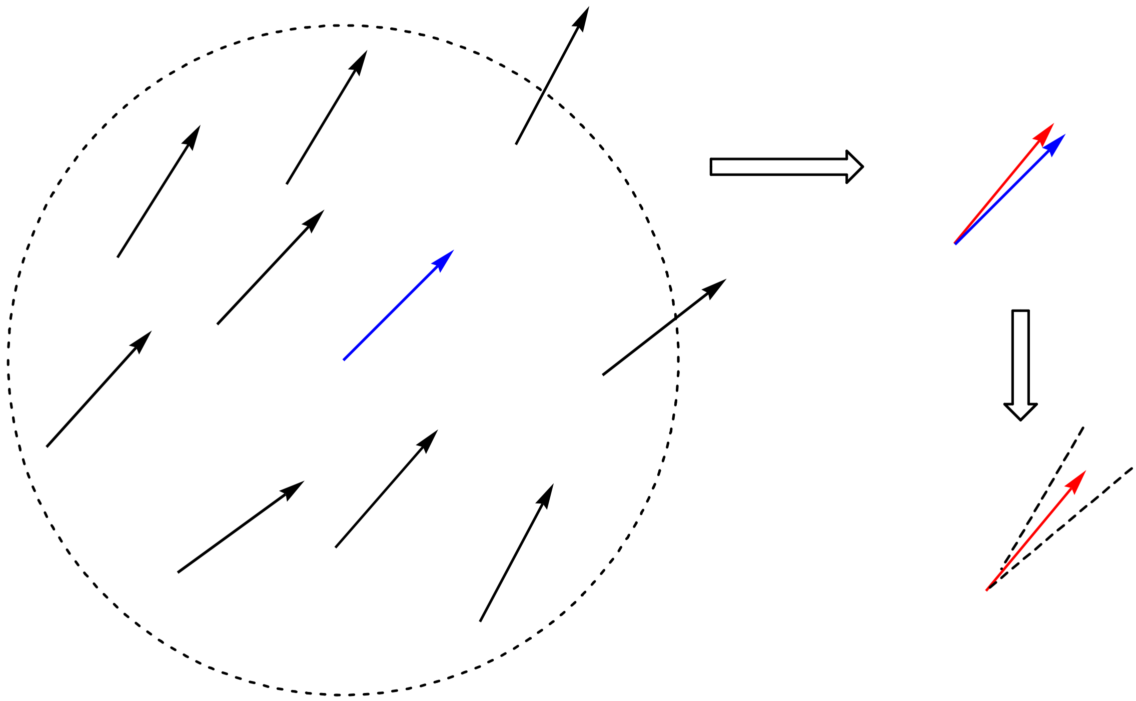

Figure 1 - Representation of the two stages of calculation needed to determine the speed of an individual (in blue) from those of its neighbours.

The course built by the science students also used animations that were developed using NetLogo® software. These animations used the concept of periodic boundary conditions, which is to say that an individual who exits the screen returns with the same speed from the opposite side. They also illustrate the fact that the deviation of an individual is determined both by the velocity directions of its neighbours and to avoid a collision. Animations with hundreds of individuals show that the conditions imposed by the model allow the creation of a collective motion (Figure 2). In this case, the collective movement is visually translated by the grouping of individuals and the arrows, which specify their directions. The resulting animation is built from successive slides, each corresponding to small shifts of all individuals. Figure 2a is the initial state of the 300 individuals with randomized positions and directions. The following figures 2b-2d are derived from the calculation of 68 steps for figure 2b, then 92 steps and 177 steps for figures 2c and 2d respectively. The gradual formation of groups of individuals having the same speed is visible in these slides.

To allow them to take some critical distance in preparing their course for the dancers, the science students were introduced to several science education concepts, such as the notion of conceptions. Indeed, daily life strongly influences the ideas that each of us constructs about scientific concepts such as speed, direction or interaction (a constructivist point of view). Concepts related to mechanics are, of course, no exception to this tendency. In top of that, the science students were also able to rethink the notion of model as being different from a simulator. It took several sessions to get ready to structure the information they had to offer to the dancers. This is probably because they were creating a course they had never themselves attended as students.

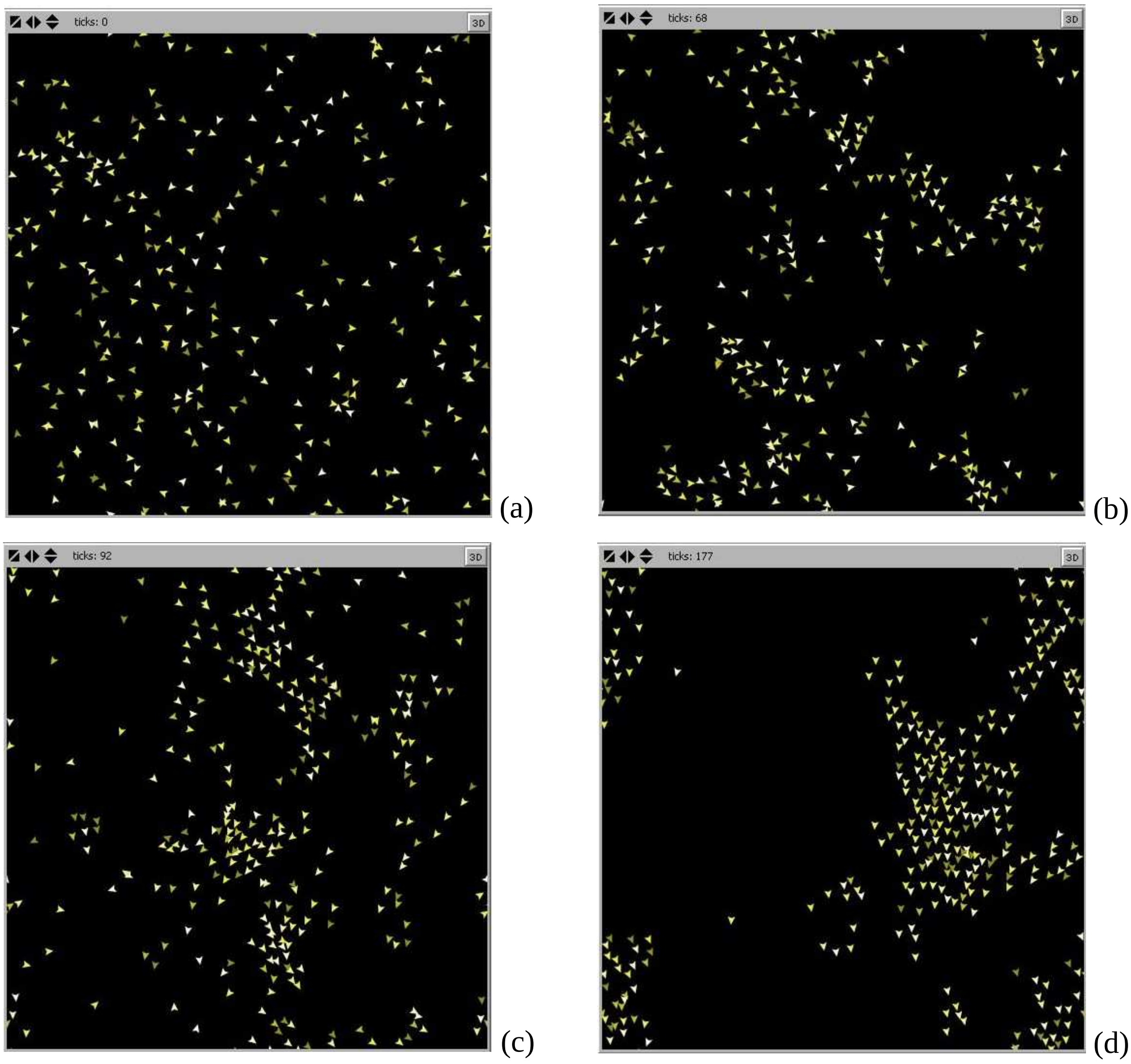

Figure 2 - Representation of the creation of a herd modelled with NetLogo ® based on 300 individuals subjected to the common module rules governing speed, partial alignment at short distances, and avoidance at close range. Simulations conducted by Marine Michelotti, a student at ENS Lyon.

Dance

Following the scientific training period, the dancing began without preconceived ideas, but with the memories of a similar project that had taken place the previous year. The previous project was supported by a completely different scientific theme (the birth of matter and the solar system). The dancers were almost the same in both projects whereas the scientific students were all different.

No longstanding tradition exists for collective motions in dance. The ideas had to build gradually. The result of the work of 6 dancers and their trainers, whose purpose was primarily artistic, led to an interesting and original concept. Their work brought forth the idea that dancers should be guided by the rules of the model, particularly the orienting rule, trying to incorporate such an idea into the language of dance. This model-guided dance led to the formation of a group of dancers slowly evolving in quasi-random motion. It let the audience imagine the collective motion, not only by the homogeneity of the movement, but also by the attitude of the dancers who adopted a common direction for their gaze. It happened that this method of moving let one (Figure 3) or two (Figure 4) dancers find themselves outside of the group for a period of time that was brief, but sufficient to start a solo or a *pas de deux* (a duo). Such a situation created a different artistic rhythm in the dance, and the solo or the *pas de deux* could momentarily become the focal point, momentarily bracketing the collective motion for a while (Figure 5).

This concept is neither choreographical – since there is no choreographer deciding exactly what is to happen – nor free improvisation, as the dance of each individual is conditioned by their neighbours except during the solos. This type of dancing is a novelty that emerged from the joint reflection of science and dance. The term *living composition* was chosen by the dancers to name such a creative process. This process often led the dancers to transgress the rules of the model; we think it is part of a living composition to have the feeling of being guided by two antagonist rules: the rules of the scientific model and the art rule. As a living composition is not choreographed, a solo is not decided in advance by the dancer or by the group, but emerges on the spur of the moment from the inner logic of the dance. Picture on figure 3, taken during a gala, shows 4 dancers performing a collective motion and a fifth that escaped the group and started a solo.

Figure 3 – Collective motion of 4 dancers wherein one escaped to create a solo (Charlotte in the foreground). © Henriette Ponchon de St André//L'Atelier d'Images.

Figure 4 – Three dancers in the foreground within a collective motion while in the background, a *pas de deux* escapes from the group © Henriette Ponchon de St André//L'Atelier d'Images.

Figure 5 – *Pas de deux* from a collective movement: Emeline (in blue) and Charlotte (in salmon), with a dancer hiding herself in the wings. © Henriette Ponchon of St. Andrew / / Workshop Images

What the dancers learned from science teaching

The seven dancers were interviewed at the end of the project to determine what they had learned from the science teaching, but also within the artistic aspect of the project. One of them remembered everything, in minute detail, both in terms of general ideas about what was a model or the principle of a simulation, and details of programming in NetLogo®. Another, of Chinese origin, had never done any science during her initial education and had been handicapped by language difficulties during the project. She was unable to talk about science, reacting through dance to questions asked by the interviewer in scientific terms. The other 5 dancers could use the main ideas of the science training, but only few of the details.

▪ **The general level of science**: what is a model? What is it used for? What is the status of hypotheses or laws in science? etc. were reasonably well understood ideas through the example of collective motions. The idea that the role of a model is to generalize, simplify, and that it is a prerequisite for a simulation approach were frequently found in the words of the dancers. These 5 dancers admitted that it was either a discovery or an opportunity to make concrete some vague ideas of what they were taught in upper secondary school science courses. All of them could use these notions with correct meanings during the interviews.

▪ **The conceptual level**: Fields of interaction, repulsion, direction, etc. were well accepted concepts that dancers found useful for dancing. Such a vocabulary seemed to be necessary to work out living composition (and perhaps more widely, any dance activity). All dancers arrived more or less at the same level of understanding and use of these concepts. For example, a dancer explained, during the interview, how her conception of direction evolved during this project, "*the direction to me was right left, whereas it's just a line*". However, the dancers often expressed these notions in terms of dance, not in terms of science. The most characteristic was perhaps to say that energy is *a common breathing pattern*. It is certainly useful way of defining energy during a dance course, but it is perfectly irrelevant in physics. Yet all dancers appreciated being able to use the vocabulary carefully introduced during science courses. As a case in point, the scientific concept of direction made it possible to describe the situation of the collective motion when all dancers face in the same direction (see figure 2). The scientific meaning of the term was used instead of the left – right idea of direction. However, there remain inconsistencies between the desire of a precise vocabulary and actual use of these terms during dance activity. For example, about the field of repulsion defined as the area where people deviate from their path to avoid a collision, a dancer expressed herself during the interview in terms of strength:

The dancer – *sometimes, it makes me feel really pushed away [from the collective motion group], there is a force that ...*

The interviewer - *oh how do? you feel it?*

The dancer - *well it’s inside you, you feel a presence that, whoosh, that instinctively pushes you to go toward some place, well, but only if there is no one already there, you see.*

The concept of force had never been used during the scientific training, and the words 'feel pushed away’, 'inside', 'one feels a presence' or 'instinct' are characteristic of dance discourse.

▪ **Details are essential for scientists**: detailed definition of concepts (eg speed), what can be done with combinations of vectors, the interpretation of a graph using geometric properties of distance, etc. had been discussed during scientific training, but seldom became functional for the dancers. For example, if the concept of instantaneous speed is generally understood, the average speed is problematic, as illustrated by a dancer during the interview: "*the average speed is the sum of all velocity vectors, in a group the average speed is the distance over time, it is the sum of all other vectors, I feel I get messed up* ...” This confusion may come from the scientific use of the term "average speed" to refer, according to the context, to two different concepts: the speed averaged over time (usual meaning), or the speed averaged over a group of individuals (meaning specific to the modelling of collective movements).

While it was out of question to solve, within a few hours, problems of misunderstanding that last for years in school teaching, the analysis of the interviews shows what was learned during the project. General scientific ideas seem to be well understood, whereas the accuracy in defining and using scientific details were not. This situation is almost the opposite of current practices in school science classes where the goals, taking as reference the French Baccalaureate exams, are to understand scientific concepts well, to calculate precisely, etc. but not to develop any reflection on what science is.

Conclusion on the relationship between science and dance

The assessment on science learning during the project is interesting to analyze. The general scientific ideas captivated the dancers. The dancers understood them at an acceptable level of accuracy; they could talk about them using the appropriate vocabulary, and they used the notions in their own dancing. They even appreciated being able to dance within a framework provided by notions derived from science and felt that it enhanced their art. This is encouraging, as the project when we defined it, was to make possible the discovery of Science based on a topic of current research for the training of dancers. This project was very open at the beginning, but we were able to focus down to two objectives. The first objective, discovering science through some general ideas, was reached. A second bolder objective was to contribute to the evolution of dance. This, also, seems to have been achieved, both individually as each dancer mentioned her personal dance enhancement, but also on a collective level, since the idea of living composition was not present before the project began. Certainly, the artistic management was crucial, but the support of scientific ideas was very profitable.

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