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Force

Annie Luciani [ACROE&INPG]

Physical modelling and interactive physically-based computer models and simulation rise the new important question of the increase of the presence and believability of virtual worlds. The notion of force is then at the core of the modelling process and interaction, since it intervenes in the computation processes and algorithms [→ Algorithm] and in the interaction process by means of force feedback devices [→ Haptics, haptic devices]. It is consequently useful to remind fundamental properties of the concept of force and to have in mind the non-trivial transformations caused by their computer implementation.

In 1687, an idea was born which changed people's approach towards the world and nature: *Principia Mathematica* was published by Isaac Newton and influenced humanity. The core idea was the importance of interaction: action to / action from, formally expressed by the action-reaction principle. Previously, another representation system of the world had been proposed by Maupertuis, based on the minimum-action principle. Maupertuis' concept of action had a different meaning than in Newton's action-reaction principle. Maupertuis' work, though, has had less influence than Newton's. However, one can note that later on, Lagrange and Hamilton revisited Newton's representation, which led back to a Maupertui's-like minimum action principle.

These two representation systems are totally equivalent as for the representation of the dynamics of systems – at least as long as these systems do not evolved at speeds close to the speed of light (relativity theory) and are not at the atomic scale (quantum theory). Nevertheless they differ completely with regards to the concept of representation on which they are based.

The Newtonian's approach is based on, and only on, the idea of interaction. It expresses, step by step in time and space, the correlations of the evolutions of observable phenomena. This means that it considers:

- at least two phenomena, and not only one
- and the phenomenological correlation – i.e. the phenomenological co-evolution of both, and not the evolution of each one.

The basic and non-trivial notions used are (i) the distinction between extensive variables and intensive variables and (ii) the action-reaction principle (sometimes called mutual influences).

These two axioms (the duality of the variables and the symmetry of the influences) are the two inseparable fundamentals of this model of nature. We may say that it represents an algebra of interaction between the two observed evolving phenomena. This means that the abstract – or representational - process starts from two evolving phenomena exhibiting an observable correlation (and after, may continue *ad libitum* with any number of correlated phenomena). This concept is a differential concept, differential in time and differential in space.

The Maupertuis' approach is based on the analysis of the space of movements, where a movement is a point on a 4D space (spatial variables and time). It considers all possible movements, and it determines the rules that regulate the realized ones, via integrated variables such as energy, or quantity of motion. The process consits in minimising such integrated variables. The integrated variables are well summarized under the heading of the general term "Maupertuis' Action". This vision is indeed more a geometry of the 4D motion space, aiming at describing the topological and geometrical organization of this space, as it is elicited in the term analytic mechanics.

Although the two visions are completely equivalent to explain and formulate the dynamic behaviour of nature, in the Maupertuis' vision, the action/reaction principle is implicit and masked in an integral vision of time and space.

In the Newtonian representation of mechanical phenomena, extensive variables can be positions, displacements, and their derivative (velocity and acceleration). The most representative intensive variable is precisely what is called a force. Due to the action-reaction principle, intensive and extensive variables cannot be separated. Intensive variables (e.g. force) do not represent "things" but mutual influences, i.e. observed correlations, or the so-called interactions. The interaction is symmetrical and formulated by a non–oriented equating rule:

Influence (or force) 1→2 = - Influence 2→1

Moreover, the physical rules that represent the dynamic behaviour of two interacting physical objects are equating relations, that correlate intensive variables and extensive variables describing the two observable phenomena. In other words, there is no causality between extensive variables and intensive variables. The force (intensive variable) does not produce the displacement (extensive variable), nor the reciproque.

Conclusion 1: Newton's formalism as an algebra for dynamics systems

Newton's action-reaction based formalism, by implementing the interaction concept as action to / action from, i.e. actions exchanged, can be, in fact, considered as an algebra for dynamics systems. More than being strictly reduced to representing natural phenomena (Physics for *Physis*), the involved mathematics can be indeed used with benefit to represent a wide variety of dynamic phenomena, that can physical or not.

Conclusion 2: Force feedback as a non-trivial concept

As long as we aim at studying directly the coupling between the human machine and the physical world, it is, strictly speaking, not valid to talk about force feedback, the two physical interacting bodies being non separable. Moreover, dynamics, and besides it, the principle of action-reaction, which the concept of force is a formal descriptor, is an abstract representation of the system composed of the two bodies. Dynamics is an abstraction, a "beautiful intellectual intuition, able to mentally re-generate for us the phenomenon".

Conclusion 3: Force computation and physics

In order to be able to talk validly of force feedback, a non-trivial transformation must be done, from an indivisible interacting entity system, to an input-output representational system. This is a necessary transformation to allow defining force feedback and force feedback devices.

The transformation of a non-oriented interaction between two physical bodies, into an oriented bidirectional input-output electrically-based situation, and further into a digitally-based situation, has important non-trivial consequences. It leads to introduce causality between computed variables (from extensive to intensive, and vice-versa), which contradicts the non-causality principles that ground physics. In addition, when supported through exchanges between sensors and actuators [→ Effector] by means of a computational process, this causality is aggravated by the introduction of a temporal causality [→ Stability].

Finally, in the context of interactive computational physics, such as needed when introducing force feedback devices, one must note that the Newton's differential formulation is well adapted. First, it enables potentially a step-by-step computation of the dual intensive/extensive variables. Second, by being based on the action/reaction principle, it allows an objective modelling and analysis of inter-influence between bodies or phenomena. However, a special attention has to be put on the translation of the notion of force, and in the process of their digital implementations. Most works and methods in the sciences of simulation and in real-time interactive simulations, tackle these very critical questions. When observing macroscopically the behaviours of a virtual reality system, layman has to be aware of the discrepancies between the simulated world and the real world, which are derived from this important transformation and that are not always obviously apparent.

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