MERGING QUALITATIVE AND QUANTITATIVE REASONING IN SCIENCE

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In this brief communication, we emphasize two recent paradigms in information and knowledge representation and processing: the fuzzy logic and fuzzy set approach, and the chaos theory approach. Both these ways, developed in the second half of the last century, collapse into the *soft-computing* paradigm, which blurs the boundaries between the qualitative and quantitative representations, and may help explain brain processes. Although their perspective on the brain is different and refer to two different processes – basic level of processing and reasoning, respectively – the two approaches can be successfully merged to explain processes ranging from sensations to quantitative reasoning.

1. INTRODUCTION

The reasoning paradigms have changed several times during history, performing transitions from the qualitative-oriented paradigms to quantitative paradigms and backward. Although it is said that modern age relies on quantitative reasoning, this is only partly true. In daily life, qualitative reasoning prevails, while modern science tends to emphasize only the quantitative representations.

The two types of information, as defined by professor Drăgănescu, are the *structural* information and the *phenomenological* information. The former corresponds to computations "*which can always be reduced, in principle, to bits*", while the latter

> "has a manifestation in feelings, meanings, in qualia. Both types of information, it seems, may also act together, constituting a mixed type of information."
>
> (Drăgănescu, 2000 [1])

In addition,

> "The phenomenon of experience is a kind of information, namely phenomenological information…"
>
> (Ibidem)

In this paper, we deal with relationships that may exist between the two types of information, and show that there is a trend in AI to fill in the gap between the two information aspects and to merge the two types of information. We shall show here that between structural and phenomenological information we can establish several connections, which make the dichotomy between these types of information become less abrupt; moreover, it becomes more complex. A continuous transition between these levels (rather than types) of information is evidenced. However, this transition makes the polarization between the two levels of information more evident in several respects, mainly due to "jumps" in the dynamic behavior at the nervous cell and tissue levels.

Qualitative reasoning is one of the "exotic" tracks recently pursued in computer science and beyond it, in various disciplines and fields [2], [3], [4]. Although the philosophy and natural science community is aware of these recent developments, maybe the learned community is not aware of the potential consequences for all sciences and for the future developments. Actually, the potential implications range from abandoning the traditional limits between "numerical" and "qualitative" sciences, to blurring the crisp limits between "theory" and "philosophy" [5].

There are several branches tending to merge qualitative and quantitative reasoning. Among them, the "fuzzy" set theory and fuzzy arithmetic, along with fuzzy logic; the "qualitative reasoning" approach in computer science, chaos theory and symbolic dynamics, and the general "soft computing" paradigm that prolongs the fuzzy set approach.

In this communication, we briefly review the paradigms underlying these developments, and we present a viewpoint that attempts to merge and generalize them. We stress on the parallel between finite *versus* infinite representations, on the one hand, and qualitative *versus* quantitative descriptions, on the other hand. We try to exemplify this parallel and to show how finite representations may yield discrete representations, which in turn merge into infinity, similarly to the way the qualitative representations may yield quantitative representations. Moreover, we illustrate the return way, of "crisping" the infinite representations by means of finite representations, and the corresponding structural *versus* phenomenological relationship. The theories of fuzzy systems and neural networks are used in several examples. We also analyze several implications of future progresses in the same direction.

In the frame of this discussion, phenomenological representations and structural representations are the two sides of the same process, which has the ambivalence of qualitative-quantitative processes. From the natural sciences point of view, this is important because it may help understanding the brain processes. From the standpoint of the information sciences, such a conclusion may be important because it opens the door to new paradigms in computation. Finally, from the standpoint of philosophical and cognitive sciences, this conclusion can help merge conflicting paradigms.

2. QUALITATIVE *versus* QUANTITATIVE: THE FUZZY LOGIC APPROACH

Qualitative to quantitative transition is often seen in the frame of the approximation theory. As Zadeh has stressed, computing with quantities is **not** the only way of performing reasoning, or even computations. The paradigm of *soft-computing*, including fuzziness and analog reasoning – like in neural networks – is as powerful as the "crisp", purely quantitative computation. Approximations performed by soft-computing are guaranteed to produce valid results as the qualitative reasoning.

Historically, the first stage of the transition from quantitative to qualitative analysis was produced in the 1950s, when it became apparent that computers actually perform approximations, not mathematically rigorous computations. Interval analysis was developed mainly by Moore in order to cope with problems of errors in computations. Then, it became a method to cope with uncertainty. In fact, many of those dealing in the beginning years with uncertainty and fuzziness dealt with interval analysis (for instance, Arnold Kaufmann).

In a very simple example of transforming a purely geometric problem into an analytical one, and then into a qualitative one, we shall discuss the representation in Fig. 1. Here, a geometric object, a curve, can be seen as an equation involving numerical constants and variables; moreover, it can be seen as a set of rules describing the geometric object. In fact, an excellent approximation of the curve is provided by a set of rules and a set of appropriately defined membership functions.

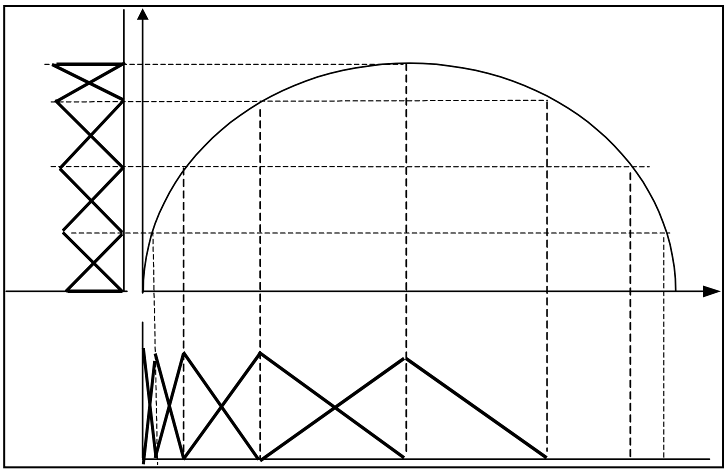

Fig. 1. – Providing a fuzzy logic based representation to a crisp geometrical or analytical object.

The rules read:

If x is very low, y is very low.
If x is low, y is low.

If x is rather low, y is rather low.
If x is low-to-medium, y is low-to-medium.
If x is medium, y is medium.
……

The drawing shows, on the horizontal axis, only the membership functions corresponding to the range "very low" to "medium". Because of the symmetry, the membership functions from "medium" to "very large" will be similar. It is easy to show by simple but lengthy computations that the fuzzy representation – involving qualitative aspects in the rules and quantitative elements in the definition of the membership functions and of the defuzzification operation – is an excellent approximation of the analytic curve. We shall not deal with details of the approximation theory involving fuzzy membership functions, like the choice of the number of triangular membership functions, or their shape. Such details can be found elsewhere. We stress that this example shows that qualitative reasoning is able to deal with problems traditionally dealt with by the qualitative sciences. Moreover, it shows that qualitative reasoning, or a mixture of qualitative and quantitative reasoning can even replace the traditional quantitative reasoning.

3. CHAOS, COMPLEXITY, AND MIND

The example above illustrates only one possibility to use qualitative reasoning, instead of quantitative reasoning. However, an even more pertinent case is that of converting chaotic movements, with analog states and with attractors having a shape that can be described rather vaguely, qualitatively, into discrete, well-determined quantities (numbers). This new trend has been recently proposed by many researchers in the neural networks and artificial life fields. The method has been named "computing with chaos (attractors)." It is believed that such transformations take place in our brains, which are analog "chaotic machines", not numerical machines. The non-repetitive exact shapes of the attractors – at least at finite time scales – stands here for the imprecision, for the qualitative rather than quantitative representation of the information. On the other hand, the similitude of the shape of the attractors, even for finite time scales, stands for the *equality*, and for the ability to perform quantitative representations.

The key point is that a parametric nonlinear dynamic system can perform "jumps" from one attractor to another. While typically the attractors evolve slowly in shape, when the parameter(s) change(s), the jumps are almost discontinuous. We can say that the evolution is discretized. Assigning to each class of states (types of attractors) a different label, the conversion to discrete quantities is performed. The phenomenon of attractor jumping is well known in the field of neural networks and chaos theory. Parametric chaotic systems are defined by the number of such jumps, which reflects the *memory capacity* of the system. Systems that are more complex exhibit dynamical transitions from one type of attractor to another – a process that is known as *itinerant chaos*. Under these considerations, the boundary between phenomenological and structural knowledge disappears. Moreover, *feelings, meanings*, and *qualia* become aspects of the same dynamics.

The transition from quantity to quality is easy to model as a drift in the continuous-regime range toward a discontinuity. This is particularly true in complex chaotic systems, where discontinuous jumps in dynamics occur.

Chaos theory can explain many peculiarities of the behavior, peculiarities that look quite uncorrelated, such as clustering of ideas and concepts during thinking, clustering of individuals, traffic clustering, and rhythmic clapping. Such apparently complex phenomena appear to have a unique and quite simple "explanation" (model).

In the case of chaotic computation, the transition, namely from qualitative to quantitative representation, is actually performed. This is somewhat similar to the *defuzzification* operation, performed in the case of fuzzy logic, to go from fuzzy representations to "crisp" (numerical) representations. As it goes for the statistical and fuzzy data and knowledge, there is no unique way to perform the transformation to classical numerical data and knowledge. Several researchers, including the present authors, have proposed various such ways.

4. CONCLUSIONS

We have emphasized that there exist two ways that contribute to removing the hard boundary between qualitative and quantitative representations, thus opening the way to the understanding of the brain processes. The two paradigms rely on the fuzzy logic and chaos theory, respectively. Although these data and knowledge representation methods neither eliminate all the differences between qualitative and quantitative representation, nor answer all the questions related to the dichotomy qualitative *versus* quantitative, they can help partly filling in the gap between them.

In this paper, we have exemplified connections between the structural and phenomenological information. These connections are at the very basic level of the cellular and neural tissue activity, and rely on the nonlinear dynamic (chaotic) behavior of these elements. Higher levels of representation still rely on this connection, as proved by the models of the reasoning based on fuzzy logic.

There are currently several research directions aiming to generalize and renew the computation principles and the computing machines. Among these directions, quantum computing, computing with attractors and cellular automaton computing promise to revolutionize both the computation principles and the hardware. The first two methods go far beyond the typical trends in innovating computing hardware, as based on classic neural networks, fuzzy logic and GA. However, this revolution in computing, acting at the hardware level and computational principles should be paralleled by a re-thinking of the very philosophical aspects of computation.

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