What is Soft Computing? Revisiting Possible Answers

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1. Introduction

"What is Soft Computing?" is likely to be the first question you will be asked by an outsider once you reveal that you work in Soft Computing or that you apply Soft Computing techniques. Nevertheless, this can be a startling question, and a difficult one to answer, for a researcher or a practitioner in Soft Computing: if you are familiar with the field, you do not ask such a question yourself and thus you may not have a clear cut definition available. Of course, there is also the additional problem that, as a term of natural language, "Soft Computing" lacks a precise and generally accepted definition. Furthermore, the field that has been labeled "Soft Computing" is fairly new and thus still evolving rapidly, making it difficult, if not impossible, to provide a final answer. Nevertheless, the simple fact that the question is commonly asked, forces us to spend some thought on apt and comprehensible answers.

This paper explores several answers that have been suggested in the past, each of which uses a different approach and emphasizes different aspects. These include definitions and characterizations of Soft Computing

- by essential properties,
- as a family of techniques,
- as a complement of hard computing,
- as a tool for coping with imprecision and uncertainty.

However, none of them can be called the "correct" or "best" answer: depending on the context, the background of the person asking the question

and other factors, each of them may be the most appropriate to give.

2. Soft computing defined by essential properties

As this is not the first time the question is analyzed at this conference, it would be interesting to take into consideration the result of that previous analysis arriving to a certain definition of soft computing:[1]

> Every computing process that purposely includes imprecision into the calculation on one or more levels and allows this imprecision either to change (decrease) the granularity of the problem, or to "soften" the goal of optimization at some stage, is defined as to belonging to the field of soft computing.

It is clear that this is a quite general definition including all those techniques and approaches that, according to the practice, are considered as the components of soft computing.

If we go further in this approach, it is possible to say that, in summary, soft computing encompasses two main conceptual components, namely approximate reasoning and function approximation and optimization. From that point, and considering that soft computing is an evolving concept, its evolution can be easily interpreted in terms of the integration of new topics/techniques that are in accordance with these properties and the corresponding conceptual components.

3. Soft computing as the mixture of several preexisting techniques

The term soft computing was coined to refer to a family of computing techniques particularly adapted to cope with a class of problems for which other techniques were not quite well suited. Zadeh[2] established that:

> Basically, soft computing is not a homogeneous body of concepts and techniques. Rather, it is a partnership of distinct methods that in one way or another conform to its guiding principle.
>
> ...
>
> The principal constituents of soft computing are fuzzy logic, neurocomputing, and probabilistic reasoning, with the latter subsuming genetic algorithms, belief networks, chaotic systems, and parts of learning theory. In the partnership of fuzzy logic, neurocomputing, and probabilistic reasoning, fuzzy logic is mainly concerned

with imprecision and approximate reasoning; neurocomputing with learning and curve-fitting; and probabilistic reasoning with uncertainty and belief propagation.

As the presence of genetic algorithms has gained importance in the field, more recent enumerations have included evolutionary computation (EC, a family including genetic algorithms) as an independent constituent of soft computing.

Although the four constituents share some common characteristics, they are considered complementary as desirable features lacking in one approach are present in another. Consequently, after a first stage in which they were applied in isolation, the last decade of the past century witnessed an increasing interest on hybrid systems obtained by symbiotically combining the four components of soft computing.

In this sense one of the main characteristics of soft computing is that of hybridization. Hybrid approaches could be considered as one of the main contributions of Soft computing, with neuro-fuzzy systems being the first and probably the most successful hybrid approach till now.

Neuro-fuzzy systems incorporate elements from Fuzzy Logic (FL) and Neural Networks (NN). These idea of hybridization originates from two observations:

(1) Fuzzy Systems are neither capable of learning, adaptation or parallel computation, whereas these characteristics are clearly attributed to NNs.
(2) NNs lack flexibility, human interaction, interpretability or knowledge representation, which lies at the core of FL.

Similar arguments were used latter to generate other hybrid approaches like Genetic Fuzzy Systems, where the main aim was to join the robust search capabilities of EC, and the already mentioned properties of FL.

From this point of view, soft computing that started as the *partnership of fuzzy logic, neurocomputing, and probabilistic reasoning* has evolved to integrate many symbiotic approaches in between those techniques.

4. Soft computing as opposite to hard computing

The term *soft computing* distinguishes those previously enumerated techniques from *hard computing* (conventional approaches) considered as less flexible and more computationally demanding. The key aspect for moving from hard to soft computing is the observation that the computational ef-

fort required by conventional approaches which makes in many cases the problem almost infeasible, is a cost paid to gain a precision that in many applications is not really needed or, at least, can be relaxed without a significant effect on the solution. In other words, we can assume that this imprecision is a small price to pay for obtaining more economical, less complex and more feasible solutions.

To clarify that it would be easier to talk in terms of optimization, and the situation is that, for many different applications a sub-optimal solution is enough, and having that in mind when designing the optimization process will provide the difference in between obtaining a solution that satisfies our needs or getting lost when searching for the optimal solution. We can even say that:[3]

> Actually, the distinguishing feature of soft computing is straightforward. Hard computing uses an explicit model of the process under consideration while Soft computing does not do this. Instead, as an indispensable preliminary step, it infers an implicit model from the problem specification and the available data.

Working out the analogy in between both previous paragraphs we can see that building the explicit model is a first step in the process of finding the optimal solution, while, in absence of such an explicit model, the use of an implicit model usually drives us to a (sub-optimal) solution satisfying our needs. Considering again the view of soft computing as blending approximate reasoning and function approximation/optimization, this view concentrates on the second part, the one usually assigned to neural networks and evolutionary computation. But if we consider optimization with a broader view, new components should be integrated in soft computing.

In the same way that evolutionary computation gained some presence in the field, meriting for a soloist role in the ensemble (and not a secondary role as occurred in some initial definitions), other new bio-inspired search and optimization techniques have appeared on stage more recently to play similar roles as EC. And even heuristic techniques that emerged inspired by the principle that satisfaction is better than optimization could be considered as part of soft computing.[4]

5. Soft computing as a tool to cope with uncertainty and imprecision

Soft computing techniques are meant to operate in an environment that is subject to uncertainty and imprecision. According to Zadeh,[2] the guiding

principle of soft computing is:

> exploit the tolerance for imprecision, uncertainty, partial truth, and approximation to achieve tractability, robustness, low solution cost and better rapport with reality.

Imprecision results from our limited capability to resolve detail and encompasses the notions of partial, vague, noisy and incomplete information about the real world. In summary, soft computing is designed to cope with all those "uncomfortable characteristics" that real world use to add to the problems under consideration. In other words, it becomes not only difficult or even impossible, but also inappropriate to apply hard computing techniques when dealing with situations in which the required information is not available, the behavior of the considered system is not completely known or the measures of the underlying variables are noisy.

But we can go one step further and analyze those situations where *imprecision* is not a drawback of the information we are managing but an intrinsic characteristic of that information. In that sense it is quite important to distinguish in between measurements and perceptions, and to discriminate those situations where we work on the basis of imprecise measurements from those others where we *compute with perceptions.* Compute with perception is clearly an approach to approximate reasoning (again one of the constituents of soft computing). In that sense, soft computing as a tool to cope with uncertainty and imprecision should clearly include computing with words and perceptions as one of its basic components.

Computing with words is inspired by the remarkable human capability to perform a wide variety of physical and mental tasks without any measurements and any computations. As a methodology, computing with words provides a foundation for a computational theory of perceptions.

A basic difference between perceptions and measurements is that, in general, measurements are crisp whereas perceptions are fuzzy. One of the fundamental aims of science has been and continues to be that of progressing from perceptions to measurements. One of the potential achievements of soft computing will be to return to perceptions in order to take profit of its qualities as a carrier for intrinsically imprecise information.

6. Soft computing at the European Centre for Soft Computing

The European Centre for Soft Computing is a research center with the structure of a private foundation which started its activities in 2006 and

is involved in R+D, technology transfer, dissemination, training and in general any activity that will produce the advancement of Soft Computing.

The Centre focuses on Soft Computing following a well known principle of Genetic Algorithms that could be described as *maintain an appropriate balance in between Exploitation and Exploration*, i.e., try to improve those useful techniques and fundamentals SC already has (exploit) while at the same time search for completely new options (explore) that will eventually outperform those already known.

With this approach the Centre maintains lines of research positioned on the *Fundamentals of Soft Computing* and focusing on its most common techniques, while exploring some of those new topics as *Bio-inspired search techniques* or *Computing with perceptions*, mentioned in previous sections as new components of soft computing. Some of the problems under consideration at the Centre are described below.

Evolutionary algorithms working on real world problems having very large search spaces have very heavy computational demands. Two strategies to alleviate this problem are the optimization of the representation of individuals and basic operations, and moving to **distributed evolutionary computing**. These aspects have been studied in joint work with Mme. Fatima Z. Hadjam, of the University of Djillali Liabes, Sidi Bel Abbes, Algeria, in the context of evolutionary design of digital circuits.[5]

Problems of the real world are mostly dynamic: they evolve through time. Modeling these problems with **ensembles of neural networks** require the ability to cope with **incremental learning**. Some requirements are: The ensemble should be able to learn additional information from new data; it should not require access to the original data using to train the existing network; it should preserve previously acquired knowledge (that is, it should not suffer from "catastrophic forgetting"), but should gradually forget in the case of non-monotonic evolution, and should be able to accommodate new features that may be introduced with the new data[6] (joint work with the research group of Prof. Héctor Allende, of the Technical University Federico Santa María, Chile).

From the point of view of **Fuzzy Systems design**, the centre is involved in the integration of expert knowledge and knowledge extracted from data, looking for compact and robust systems with a good **accuracy-interpretability trade-off**. The objective is not only to maximize the comprehensibility but also to look for a high accuracy. A deeper analysis is needed in order to give an interpretability measure associated to Fuzzy rule based systems allowing for its comparison from the interpretability point

of view.[7]

The main aim of the research unit Applications of Fuzzy Logic and Evolutionary Algorithms is to propose new methodologies to tackle complex real-world problems by means of either evolutionary algorithms or fuzzy logic and fuzzy systems in isolation or by their hybridization. A couple of examples of such problems are described in following paragraphs.

A first example is the use of a **FL-EC hybrid** approach to develop an intelligent system to assist the forensic anthropologist in the identification of a missing person by a usual technique called photographic supra-projection.[8] It is based on superimposing a scanned 3D model of the skull found against a face photo of the person to establish whether this is the same person through the partial matching. EC capabilities to tackle a highly multimodal search space, together with FL abilities to deal with uncertainty, degrees of confidence and partial matching, provide to Soft Computing a clear opportunity to solve this problem.

On the other hand, the impracticability to get optimal solutions for many real-world problems in reasonable time using classical hard computing approaches has caused the successful development of heuristic techniques. Currently, we are applying **multi-objective ACO algorithms** to solve a defiant real-world problem, the time and space assembly line problem (TSALBP), which involves to achieve optimal assignments of a subset of tasks to each station of the assembly line of a plant with respect to two or three conflicting objectives to be minimized: its cycle time, its number of stations and their area.[9]

On the way toward **Computation with Words** and Perceptions, the mathematical analysis of which fuzzy algebras verify some concrete laws or properties is becoming more and more important. In particular, to help the design or modeling of fuzzy systems and, specially, complex phrases in natural language in a given relational environment.[10]

The Research Unit **Cognitive Computing** has the multidisciplinary approach of Cognitive Science. The main motivation is the idea that Computing with Words is necessarily Computing with Meanings. The notion of meaning comes from the fact that the users of words are mental and intentional beings.[11] The meaning of words is related with the experience that users try to transmit but also with the specific characteristics of the partners' personalities and the context where the communication takes place.[12] First steps in this direction aim to produce linguistic summarizations of data obtained by sensors.[13,14]

The Intelligent Data Analysis research unit investigates and develops

methods for intelligent data analysis and probabilistic reasoning, with a focus on probabilistic methods (graphical models), fuzzy methods (especially fuzzy clustering[15] and statistics with fuzzy data[16]), frequent pattern mining methods (especially frequent subgraph mining), and non-parametric inferential methods (especially non-parametric under order restrictions).

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