# Computational intelligence and soft computing: some thoughts on already explored and not yet explored paths

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We comment upon the very essence, roots, potentials, and applicability of computational intelligence and soft computing. We followed a different path than those traditionally employed, and which are so well and in a deep and comprehensive way documented in other papers in this special issue. First, we consider relations between computational intelligence and artificial intelligence, starting from a reference to different kinds of views if how intelligence is meant in science, and whether it has a general nature or many different types. Then, we consider the issue of symbolic and numerical calculations, and the two attitudes for problem solving: a general one and problem specific. Then, we discuss soft computing – which is in our view a narrower area than computational intelligence – and consider two aspects implied by the inclusion of the two words: "computing" and "soft". First, we discuss how soft computing relates to the traditionally meant computing [in the sense of (a theory of) computation]. Second, we pursue a novel path that has not been practically considered in the literature, that is – first - relations of soft computing to soft sciences, and – second – relations of soft computing to Checkland's soft systems methodology. We hope that this paper will trigger a discussion and stimulate a new line of research with both soft computing and computational intelligence communities, on the one hand, and a broadly perceived soft science communities, on the other hand, that can bring about new ideas and novel problem formulations and solutions.

## 1. Introduction

The very essence of human nature is the existence of an unstoppable quest for discovering rules that govern what is going on in our world, both material and immaterial, from a close distance from us, exemplified by our neighborhood, distant countries and continents, to distant other planets, galaxies,etc. that are too far away to be comprehensible. This endless human curiosity has always led to the establishment of new areas or branches of science and technology because in the process of a deeper and deeper involvement in the analysis and discovery process it has always become obvious that situations and cases considered have been too specific to be dealt with using the same general paradigms and tools. In such a way, though the terms like "social sciences", "natural sciences", etc. still exist as denotations of general, wide categories characterized by some common characteristic features like the objects of interest exemplified by the human individual and social behavior, issues related to the chemical structures or relations, living organisms, etc.,

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more and more specific branches of science have been founded, like sociology, psychology, cognitive science, chemistry, physics, biology, medicine, etc. The same general specialization type path occurs in technology in which branches (sciences) like electrical engineering, civil engineering, mechanical engineering, on the one hand, and control, power engineering, mechatronics, etc., on the other hand, have emerged.

A special place in this process resulting from the human nature, acquisition of more and more knowledge, a need for specialization, etc. concerns also all kinds of issues related to mental, notably intelligent functions of the living organisms, in particular the human being. Since the very beginning of the mankind, people have been aware of that special faculty of an intelligent behavior they possess, either developed in the process of evolution or created, depending on a personal opinion. This faculty has made it possible to survive, adjust to adverse conditions, create great artifacts, and solve complex problems.

All the above have clearly triggered dreams that intelligent behavior of a human being will be mimicked and machines will be developed which will be able to perform tasks that have so far been reserved for the human beings. People have tried to achieve this since the early time, and have built (real or fake, with a bigger or smaller success) automatic "machines" for solving problems like human like movements, music playing, speaking, etc. However, more advanced human specific functions and activities like those related to natural language understanding and processing, learning, cognition, story summarization, playing non-trivial games, and the like have been found very difficult, if not impossible to grasp by using existing tools, mostly developed for mechanistic, inanimate systems.

It has become evident that, first, no success to even properly analyze such sophisticated processes, not to speak about their automation, is possible without, first of all, a study of the very nature of intelligence. Then, as a next step, one should mention the one concerned with what should and what can be done to automate those intelligent tasks, and which tools and techniques are to be employed. This, from the point of view and purpose of our presentation, has resulted in the establishment of *artificial intelligence* as traditionally meant, i.e. involving mostly symbolic computation and attempting to solve what may be called *general problems*.

To be more specific, we will summarize the very essence of how intelligence is meant, and then will proceed to the summarization of what is meant by artificial intelligence in the traditional, strict sense. Then, we will point out some unfulfilled promises of that pure and orthodox approach to building artificial systems that can exhibit human like intelligent behavior, notably related to the lack of attention paid to numerical calculations, instead of (or in addition to) symbolic calculations. From this perspective we will discuss how, why and when *computational intelligence* has been conceived, or has emerged, and how it has reshaped the scene of human endavor to develop systems, tools and techniques that could somehow mimic or perform tasks requiring intelligence. In particular, we will discuss areas in which numerical calculations have qualitatively changed the applicability and implementability of tools employed so far.

We will then proceed to the area of *soft computing*, but will not consider it to be equivalent to *computational intelligence*, the latter being – in our opinion, and in the perspective assumed in this paper – a broader area. Moreover, we will present soft computing as an area of modern computer science that involves: fuzzy logic (and rough sets), neural networks, evolutionary computation, and biologically inspired computation (like ant colony optimization, swarm intelligence, immunologically inspired systems, and the like). We do not think that the inclusion of probabilistic reasoning and, notably, machine learning is proper here, and this is different from what many people think; we will provide arguments in this respect.

Then, we will discuss another path related to soft computing which has not been practically considered in the literature. Namely, if one uses a word, like "soft" in our case, that has been used for a long time in some contexts, one should refer somehow to those contexts and how and why the term "soft" is employed. In this paper we will discuss two issues in this respect. First, since there exists a commonly used term " soft sciences", meant often as "inexact sciences", an opposite concept to "hard sciences", meant as "exact sciences", then a natural question is whether there is a relation of (some aspects of) soft computing with soft sciences.

Second, in an area that is maybe closer to the area of interest of soft computing and its applications, namely broadly perceived operations research, systems analysis, even management, there is a powerful and well established general approach to complex problem solving that includes "soft" in its name, namely Checkland's *soft systems methodology*. We will explore some conceptual relations between it and soft computing.

In principle, we will not repeat arguments included in other papers included in this issue, notably that by Magdalena [22], which are remarkably deep and provide much insight into the very essence of computational intelligence and soft computing. Clearly, and what is very valuable, those views of the particular authors differ somehow so that the reader can gain a full and comprehensive view of what various opinions are, which can later imply his or her own opinion.

We will also not repeat the arguments included in other papers on general issues related to soft computing, exemplified by first of all the seminal papers by Zadeh, which are too many to be cited in full but which are given in the list of literature, papers by Bonissone [2], Duch [9], etc., and also books and volumes on computational intelligence and soft computing exemplified by Engelbrecht [11], Rutkowski [31], Pedrycz [29], Duch and Mańdziuk [10], etc.

Since this special issue is a very special event in the scientific literature that attempts to provide the reader with a state of the art of modern view of what computational intelligence and soft computing is, we will to some extent repeat views of other contributors, which are consistent with ours, but also provide arguments for some unorthodox views.

We hope that our views, that differ from those most often assumed by the authors discussing the contents and essence of computational intelligence, soft computing, and related topics, will trigger discussion, and clarify many existing, already discovered links, and suggests some not yet discovered ones between many approaches that have emerged in diverse areas. In such a way, we hope to somehow help diminish the dangerous, yet still common fragmentation of science that is still implying so many repetitions, the so called rediscovering of the wheel, etc.

We will not provide a long and comprehensive list of references, and just concentrate on some basic ones that would serve the purpose of supporting our claims and justifications. Many other references may be easily found in other papers of this special issue that present a more common view as well as in the books cited above.

## 2. Natural intelligence and attempts to mimic it

The first question that should be considered and answered in the context of our discussion is to consider what the particular words occurring in both "computational intelligence" really mean so that the essence of their combination could be properly understood. We will start with "intelligence", and then provide some thought on " computing". naturally, we will limit the scope of our analysis to those aspects of the respective fields only which are relevant for our purposes, and many relevant papers and books will therefore be omitted here by obvious reasons.

Roughly speaking, *intelligence* is a term usually employed to describe a property, cognitive or mental capability of a living species (first the living species have been considered in this respect, then people started to talk about inanimate systems, to be briefly called "machines", or "intelligent machines") related to its/his/her capacity to reason, think in abstract terms, comprehend and understand, learn from experience, acquire knowledge, plan, solve problems, etc. This general view implies clearly various approaches to and definitions of intelligence, depending on the background, attitude of the observer, and the specifics of tasks meant.

Among researchers who have been focused on the behavior of the living organisms and their functioning in an environment, intelligence was related to an ability to adjust to the environment, to survive, and to act purposefully.

It is quite natural that the human beings have been aware of the existence and utmost relevance of intelligence since the very beginning of conscious life, and it has been obvious that various theories of intelligence have been gradually proposed. The first, obvious question, that is very relevant for our considerations, has become: is there one *general intelligence* or is there are *multiple intelligences*? In other words: do intelligent species posses a general, one capacity that drives the performance of all those intelligence related abilities exemplified by an ability to reason, comprehend, learn, plan, solve problems, or, do they possess multiple, different kinds of intelligence, each one being behind some specific ability?

As it can be expected, scientists have presented here different views. Among good sources of information on all kinds of aspects of intelligence, one can cite here the following: Carroll [4], Gardner [14], Guilford [15], Legg and Hutter [19]. Sternberg [38], Sternberg and Salter [36], Wake, Gardner and Kornhaber [40], etc. We will now briefly summarize main concepts and opinions of various researchers and scholars, and schools, and more information can be found in the above references.

The view of one, *general intelligence* has been probably first mentioned by Galton in the second half of the 1800s who viewed intelligence as an ability characteristic to living organisms that could be studied by measuring reactions to certain cognitive tasks. However, Spearman is generally considered to be the first who has discovering general intelligence in the early 1900s. Based on some studies he came to a conclusion that that there was a common function(s) within human intellectual activities that clearly included intelligence, and he called this common a *general intelligence*, and he also proposed some tools for measuring it.

Quite naturally, extensions to that simple general intelligence models have been proposed, For instance, Thurstone proposed a model of intelligence that included seven unrelated factors (verbal comprehension, word fluency, number counting facility, spatial visualization, associative memory, perceptual speed and reasoning). Cattell proposed two types of cognitive abilities in a revision of Spearmans general intelligence: fluid intelligence as the ability to discriminate and perceive relations (e.g., analogical and syllogistic reasoning), and crystallized intelligence as the ability to discriminate relations that had been established originally through fluid intelligence, but no longer required the identification of the relation. Carroll proposed a hierarchical model of intellectual functioning with three different levels of generality: the lowest, which is represented by narrow, highly specialized abilities exemplified by induction or spelling ability), the medium, which is represented by moderately specialized abilities in different domains that include moderate specializations in various domains, including fluid intelligence, crystallized intelligence, general memory and learning, broad visual perception, broad auditory perception, broad retrieval ability, broad cognitive speediness, and processing speed, and the upper one which generally boiled down to Spearmans general intelligence.

However, the concept of one general intelligence, even with its extensions as mentioned above, was not acceptable, and not consistent with many experiments. The concept of a *multiple intelligence* has been therefore conceived in recent decades (though some ideas in this respect are much earlier), and among many different theories and views here one can cite the following.

Gardner proposed to break down intelligence into at least eight different abilities: logical, linguistic, spatial, musical, kinesthetic, interpersonal, and intrapersonal. Sternberg proposed the so called *Triarchic Theory of Intelligence* that involves three fundamental aspects of intelligence: *analytic intelligence* which comprises the mental processes through which intelligence is expressed, *creative intelligence* which is needed when an individual faces a challenge that is nearly, but not entirely, novel or when an individual is concerned with the performance of a task, and *practical intelligence* which is related to “survival” in the environment. Basically, the triarachic theory argues that general intelligence is part of analytic intelligence, but to fully comprehend intelligence, all three aspects should be accounted for. Sternberg has recently defined intelligence as an individuals assessment of success by his/her own standards, with the success achieved by using combinations of analytical, creative, and practical intelligence, called *processing skills*.

It should be noticed that those few approaches to the capturing of the the essence of intelligence, and its various aspects, have appeared in psychology, cognitive and social sciences. A natural question to ask would be: what about views of intelligence that have appeared in computer science, artificial intelligence and the like?

There are a multitude of definitions and one can quote some of them. Many of them are referenced in the general books and review articles on artificial intelligence cited in the list of literature so that they will not be explicitly referenced. Notably, intelligence is viewed as the ability to achieve goals in the world (environment). This implies clearly many immediate questions. What are the goals, and how to define them, how to know if they are attained. usually, this is up to the judgment of an observer. Russell and Norvig [30] define intelligence in a similar way, calling it *rationality*, and they consider a system to be intelligent (rational) if it does the right thing, which is usually the best one (or, at least, good enough) that can help attain goals, We can quote many more definitions but they are similar. One should obviously remember that in each definition, when one speaks about a task, one means a complex task that need some intelligence, or ingenuity, for solution.

In this context one should also mention that artificial intelligence (AI) as a field that is heavily human centered, and refers to many human specific capabilities, should be a multidisciplinary field. For instance, Sloman[32] has put it as: "...It should be clear from all this that insofar as AI includes the study of perception, learning, reasoning, remembering, motivation, emotions, self-awareness, communication, etc. it overlaps with many other disciplines, especially psychology, philosophy and linguistics. But it also overlaps with computer science and software engineering ...".

Again, if we look at the essence of all those definition from our point of view, they represent rather the one intelligence type of an approach, even if the authors sometimes mention that for the solution of various tasks different types of intelligence are needed.

This very brief account of some aspects of intelligence is by no way comprehensive but it will serve our purpose of analyzing in a somewhat different some aspects of artificial and computational intelligence. For more information on those general theories of intelligence, both related to humans and animals, and also to some extent to machines, we refer the reader to, for instance: one can cite the literature as given in the beginning of this section.

Looking at the various views on intelligence outlined we can clearly see that the human attempts to build a machine, notably a computer system, that could perform various tasks in a way similar to the way the human being would do, or to mimick an intelligent behavior of even an animal, not to speak about a human being, can follow two basic lines of reasoning. First, we may wish to develop a system that would exhibit a "general intelligence" which would make it possible to use it for solving a multitude of tasks requiring intelligence, meant as mentioned before. This is clearly an ambitious task. It is maybe also in line with the traditional, "old school" of scientific inquiry that is oriented towards developing general tools going beyond the frontiers and limitations of particular problem classes or fields of science.

A second approach would be to assume that while developing and implementing systems exhibiting some sort of an intelligent behavior we should go a more modest, but more pragmatic way, that is, to try to assume that there are many different tasks an *effective and efficient solution* of which may require different types of intelligence (capabilities, tools and techniques), or multiple intelligence(s), and we should therefore use whatever may be effective and efficient to *solve* the problem. In this case the effectiveness and efficiency, and an ability to *solve the problem*, not "pure and beautiful" generality, is our primary concern. This may be viewed to be in line with virtually all modern approaches to scientific inquiry, notably in the modern, most relevant fields in high technology which are decisive for the social, economic and technological progress in the modern world. However, this is by no means limited to those technological areas as virtually all modern approaches in biology, human and social sciences, natural sciences also emphasize that constructive attitude and importance of having an ability to solve real world problems that are crucial for sustainability and development of our world.

In this perspective one can clearly see both the essence, differences and specific features of artificial intelligence and computational intelligence, and we will briefly comment upon this now.

Artificial intelligence (AI) appeared as a more or less well defined field in the 1950s when – in a golden period for many fields of science and technology, to a large extent caused by Cold War and a fierce competition between the American and Soviet researchers and scholars to show their technological edge and advantage – some famous people, like Minsky, Simon, McCarthy, Turing, Rochester, Newell, etc. at top American universities exemplified by MIT, Yale, Stanford, etc. tried to fulfill an old dream to build machines that would exhibit some sort of *intelligence* in their behavior, and would automate tasks like cognition, learning, problem solving, etc. that have been so far reserved for the human beings, and maybe to some limited extent for some animals. The term *artificial intelligence* is attributed to John McCarthy who proposed it at a conference in 1956 at Dartmouth College (according to many reports even earlier, at a talk at MIT, where the field was "officially launched" (cf. McCarthy, Minsky, Rochester and Shannon [26]). The basic assertion and claim of the conference was that: "... aspect of learning or any other feature of intelligence can be so precisely described that a machine can be made to simulate it ... ".

Unfortunately, the founding fathers of artificial intelligence were too optimistic and this did not materialize, and hence step by step both funding and media exposure became lower and lower, with some occasional changes of trends like the eruption of expert systems in the 1980s.

Later, many other people proposed various definitions of artificial intelligence, and in our computer science related context some of better known ones are those of (we will not give references, for brevity, but they can be found in the papers and book on AI and its history listed in the paper):

- Bellman (1978): " ... the automation of activities that we associate with human thinking, activities such as decision making, problem solving, learning ... ",
- Stottler (1999): "... Artificial intelligence is the mimicking of human thought and cognitive processes to solve complex problems",
- Whinston (1992): "Artificial Intelligence is ... the study of the computations that make it possible to perceive, reason, and act. From the perspective of this definition, Artificial Intelligence differs from most of psychology because of the greater emphasis on computation ... ",
- to name a few becase there are many more.

In this short note there is not enough space for a detailed discussion on why that failure has occurred, would it have been avoidable, etc. We will only focus on some aspects that seem to be relevant in this respect, and also for our purpose.

Since the very beginning of artificial intelligence as a recognized field of science and technology, the basic philosophy was related to the assumption that human intelligence, to be mimicked, can be formalized using mathematical, maybe even more specifically – logical, tools. Another point of departure was clearly related to a what we have called as a traditional, old school type scientific attitude, that is an attempt to develop general tools which would make it possible to solve problems related to cognition, learning, planning, problem solving, decision making, etc. in different areas, without an explicit accounting of their very specifics or domain knowledge. This has resulted in a huge and extremely costly research effort on all kinds of theorem proving systems, general problem solvers, etc. It is quite obvious that such a generality of problems to be deal with in an uniform way has called for more general, symbolic computation based approaches based, at least in the beginning, on traditional two-valued logic. Many powerful theoretical results have been obtained, and also some implemented systems have been offered, but the success had been far from what had been promised.

Another important error of the developments in artificial intelligence, notably in the first, early period, was that not enough attention was paid to the dealing with imperfect information, in particular uncertain, imprecise, vague, etc., imperfect reasoning schemes, etc. In this context one can also mention that not enough attention was paid to logics going beyond the traditional Boolean one, like multivalued, temporal, modal, non-monotonic, etc. logics. These aspects had first become topics of intense research much later.

From our perspective we can clearly see that the paradigm adopted by the founding fathers of artificial intelligence, and later followed by their disciples, can be viewed in the context of various kinds of theories of, and perspectives on intelligence as a reflection of a single type intelligence attitude. Virtually all kinds of early efforts in artificial intelligence were closely focused on a how to develop general paradigms, and then their related tools and techniques.

As already mentioned, the optimistic promises of the founding father of artificial intelligence, and then their top disciples and followers, did not materialize. Maybe, looking from what we know now, it was quite obvious that the very reason for all those failures was too strong an emphasis on generality, mainly on the development of means that could be applicable and solve all kinds of problems, and be not domain specific. Moreover, one can also now claim that concentration on symbolic computation, ignoring the importance of numerical computation, was also a relevant cause of failure and unfulfilled promises.

These apparently obvious facts have not been clear to the artificial intelligence community for so many years. The best proof for this is when one looks at articles published in *Artificial Intelligence*, by far the most prestigious journal in the field. It took much time until articles on many relevant issues and problems that are both inherent to, and crucial for artificial intelligence, like on pattern recognition, vision, etc., which require numerical calculations have found their way to artificial intelligence and similar journals. Finally, however, more and more people have become convinced that numerical calculations are to be an essential part of the models. An example may here be David Marr from MIT, working on vision, who even rejected all symbolic approaches (exemplified by McCarthy's logical approaches and Minsky's frames), and stated that what artificial intelligence really needs is to understand the physical machinery of any real problem or field from the bottom up before any symbolic processing can occur [23].

These few remarks related only to one crucial characteristic feature of artificial intelligence, namely an emphasis on symbolic computations, can be complemented by other remarks of many other examples of new directions, paradigms, tools and techniques, which have been neglected by the traditional artificial intelligence community. These examples can be found in many books on artificial intelligence and computational intelligence.

As the importance of, first of all, numerical computations (either alone or as complementing symbolic computations) has become more and more evident, new areas have been advocated as promising tools to solve problems. Moreover, ideas and results from many modern fields of science, notably cognitive science, psychology, economics, behavioral science, brain science, systems science, philosophy, etc. have found a fertile ground in a broadly perceived artificial intelligence community meant as those who intend to build intelligent machines capable of performing tasks reserved so far for the human beings. This process has lasted many years and its history is fascinating showing a huge power of multi-disciplinary research and how dangerous is the traditional segmentation or fragmentation of science.

The time has therefore come for many new scientific disciplines who have been in a position to capitalize on the good and bad experience of the traditional artificial intelligence, new developments in many other areas, and also a change of a general attitude in applied sciences towards problem solving, problem specific approaches, incorporation of domain knowledge, hybrid approaches, scalability, etc. We will speak in this perspective about *computational intelligence*.

From our point of view there are the following aspects are important for defining what computational intelligence is, by knowing first why it has emerged.

First, as we have already mentioned, the traditional approach to artificial intelligence is heavily focused on an one intelligence type attitude because to a large extent it has tried to develop some general problem representations, search techniques, problem solvers, methods of learning and knowledge acquisition, etc.

For sure this quest for generality is an important cause of failures because the proverbial "what is good for everything is good for nothing" seems to be valid in general. We would therefore rather go for a problem specific tools and techniques, and then maybe try to hybridize particular tools and techniques.

These different tools and techniques may be viewed as a reflection of the multiple intelligence type approach because most, if not all nontrivial problems to be solved have multiple aspects whose solution may require different capabilities and skills, that is, a sort of multiple intelligence.

We would readily give up generality in exchange for an effective and efficient solution of the problem. This would imply that we would pay less attention to more general, symbolic type approaches and computations, and would go to a large extent for numerical computations.

We would emphasize a crucial role of handling imperfect information of all types, notably uncertain, imprecise, vague, incomplete, missing, etc.

Finally, all these aspects can be somehow subsumed that they are closely related to the very purpose of virtually all efforts to build intelligent systems, that is, those which can solve non-trivial problems in a human consistent, intelligent way. And then, there is a natural step to use first nature inspirations, and then finally human inspirations to derive effective and efficient tools.

This agenda is what we think determines the very essence of computational intelligence and show that it is a natural consequence of a long time development of artificial intelligence and related fields.

In our view, computational intelligence may be best viewed as a new field of science and technology that includes:

- neural networks,
- evolutionary computations of all kinds,
- fuzzy logic (with rough sets),
- ant and swarm type algorithms,
- “deeper” nature inspired paradigms like the immunological paradigm,
- chaotic systems and computations,
- harmony search algorithms,
- probabilistic reasoning.

Referring briefly to the agenda given above, we can very roughly summarize how the particular fields in computational intelligence respond to the issues raised above as follows. First, neural networks can be viewed as a tool for the representation of relations between relevant features and variables which should be available to the animate and inanimate system to be able to somehow construct part of a formal model of relations that are relevant for the modeling and solution of the problem considered. Evolutionary computation, swarm intelligence, immunological paradigms, etc. are examples of our attempts to fully employ, maybe to mimick to some extent some very specific features and courses of actions that nature uses to solve problems and to best satisfy general goals related to survival and evolution. Chaotic systems are tools that can help model and mimick many phenomena occurring in nature whose essence boils down to the so called *emergence*, that is the occurrence of something unexpected that may qualitatively change the status of the system, ways of behavior or common courses of action; an example may here been creative activity, inventions, etc. Harmony search algorithms, with clearly Eastern roots and philosophy, are gaining importance and popularity in some decision and optimization tasks. Finally, which is most relevant for our purposes, fuzzy logic, rough set, etc. are tools that make it possible to formalize and operationalize the use of imprecise concepts and relations in the problems and systems considered, and to implement some more sophisticated and human consistent types of logics that underly the behavior of human beings, either individuals, groups or even institutions. A similar role is played by all kinds of probabilistic reasoning that can provide tools and techniques to represent and handle uncertain data, information or relations.

To summarize, we would see computational intelligence as a new “meta-area” of computer science (or information technology) that employs some newly developed tools and techniques which the traditional artificial intelligence – heavily symbolic computation driven, binary logic based, and without a proper account for uncertainty and imprecision – has somehow not appreciated enough, maybe even neglected.

We have therefore presented our view on how computational intelligence should be understood. Now,we will proceed to present our view on the very essence of *soft computing* which is a strongly related concept.

## 3. Soft computing: is it really computing?

Now, we will briefly present our view on how soft computing should be understood. First, one should bear in mind that the concept has been introduced by Professor Lotfi Zadeh. He used to start mentioning it probably as early as the late 1980s, and often 1991 is said to be the year when soft computing appeared. Then, Zadeh had set a more rigorous framework (cf. for instance Zadeh [43].

Since the main constituents of soft computingand its essence have been presented in an expert, comprehensive and insightful way by other contributions inthis special issue, we will present some other aspects which – in our opinion – are often overlooked, or to which not enough attention is paid.

We will therefore assume as a point of departure the view that is common in literature, and also emphasized by most of the contributors to this special issue, that *soft computing* is a consortium of the following areas: fuzzy logic (with rough sets), neural networks, and evolutionary computations. Some people add in this context probabilistic reasoning and machine learning though, in our view this is not proper. First. machine learning concerns a different type of problems and procedures that are of a more fundamental and general nature and purpose, and probabilistic reasoning – though may be viewed as handling similar problems that fuzzy logic and rough sets do, i.e. providing means for dealing with imperfect information and relations, in this case of a probabilistic uncertainty type – may be a proper choice. However, though the neural network, evolutionary computation and fuzzy logic (rough sets) communities have found some common grounds to at least organize joint conferences (notably the WCCIs - World Congresses on Computational Intelligence), these scientific gatherings are rarely widely attended by representatives of the broadly perceived probabilistic reasoning community. So, at least for the time being, in my opinion the inclusion of probabilistic reasoning into soft computing is certainly reasonable, but maybe more desirable than existing. The future may however change this situation as more and more people are aware of an utmost importance of both unifying and hybrid approaches in the context of many areas, in soft computing too.

First, though it is a common practice that names of everything – including areas of science and technology – are often given in a strange, not to say improper way, it is always look at some relations to areas that are included in the “new name”. In our case these are: “computing” and “soft”. It may be therefore interesting to look how the new name, in our case “soft computing”, is related to the very meaning of its traditional components, namely “computing” and “soft”.

Let us consider the first constituent of the term “soft computing”, namely “computing”. Basically, is should be understood in the sense of a (theory of) *computation* which may be described as an area of modern computer science and mathematics which is – roughly speaking – concerned with how to formulate and solve various problems in science and technology using formal models and algorithms which have roots and foundations in mathematics and logics.

From this perspective, soft computing is a legitimate term. First, though it involves tools and techniques of non-traditional computational paradigms like fuzzy logic (rough sets), evolutionary computation, neural networks, and the like, these tools constitute legitimate models of systems and processes! To be more specific, in the case of fuzzy logic based rule based modeling, a model – that is a relation between some input and output variables – is known, and must be known, in order to be able to use such fuzzy rule based models at all! Clearly, what some authors cited in other contributions in this issues say that in soft computing the availability of models is not required is some obvious misunderstanding and misconception. It is easy to see that without a model we would not be able to perform any inference, i.e. to perform any analysis between the input and output variables. However, the models are of a different type than the ones traditionally used, exemplified by ordinary or partial differential and/or difference equations, traditional logical inference schemes, etc. The same concerns evolutionary computation. The models and algorithms do exist but they are just of a different nature that the traditional ones like those propose in the area of optimization because they employ a different scheme of searching the solution space in question, and a different way of moving in the direction of better solutions, and finally reaching best (optimal) ones. The same concerns neural networks. They constitute an architecture and a collection of appropriate weights, and in this essence they are a model though of a different type than the traditional models employed in, for instance, operations research, systems modeling, automatic control, etc. These models, at the level of their ability to be used by tools of soft computing, are explicit, indeed.

There is a different aspect, which is probably meant by the authors who emphasize that models employed or needed by soft computing need not be explicit (so, presumably, they may be implicit), is that the soft computing tools do include as an inherent ingredient an ability to learn those models in the course of their use. It is true, notably in the case of neural networks, but also in a sense in evolutionary computations and fuzzy rule based systems, notably in their hybrid settings. However, this is not a new idea because – for instance – more than half a century ago a concept of dual control was born which is similar in spirit. In many other areas similar concepts have also been advocated!

Therefore, to operationally use soft computing tools and techniques explicit models are needed but their development may proceed somehow during the computational and solution process.

Another question is related to the scope of problems soft computing is concerned with or is best suited for. We do fully agree with the opinion of most proponents of soft computing that it may be the proper (maybe the best?) set of tools and techniques to formulate and solve problems for which:

- an essential aspect is to adequately and fully capture uncertainty and imprecision (and all kinds of information imperfection) in the sense that a commonly use simplification of the broadly perceived "certainty equivalent" type is too big a simplification; this should be meant in the sense that, if we use mathematical programming as an example, the use of a simpler and easier to solve linear programming instead of maybe a more adequate but much more difficult to solve nonlinear programming may not be a good solution; this concerns fuzzy logic in particular,

- traditionally used models of a process or system under consideration – like ordinary (partial) differential equations – do exists and may be built, though maybe the difficulty and cost of their building is too difficult or prohibitively costly; in such a case we allow for "less accurate and less adequate" models but less costly or time consuming;

- though formal mathematical techniques and algorithms for solving problems of the class considered exist and may be in principle used, they usually require exact and explicit mathematical models of processes and systems under consideration, and their operation is based on well founded and strict mathematical and algorithmic procedures; however, this procedures deliver the best results only in the case when all formal requirements are fulfilled, and in the are of interest of soft computing there is too much imprecisely stated and specified values, relations, models, goals, constraints, etc. so that maybe the use of traditional methods does not make much sense, and presumably much more robust and adaptive nature inspired solution techniques can do.

Therefore, soft computing may be viewed as a proper paradigm for all kind of problems in which, first, both the values of variables, parameters, relations, etc. are too imperfectly (mostly with "too much" uncertainty and imprecisely) known to be able to enter the traditional models and algorithms. Second, in which though explicit models are needed, they do not need to be precise and may be somehow refined or adjusted in the course of problem solution. Third, the use of traditional models in such an overwhelmingly imperfect, ill-specified and formally deficient situations and problem settings considered may preclude the use of traditional solution techniques based on optimization of formal logical inference. So, a commonly encountered claim that soft computing is a proper set of tools and techniques for solving problems when there are no effective algorithms, should rather be changed to "…when they are no efficient enough algorithms …". This somehow improper use of words is that in many languages "effective" and 'efficient" are mixed, though they mean something different.

### 4. Soft computing: is it really soft?

Therefore, we have expressed above our view of how soft computing should be meant in the context of computing, as a way for solving problem. Now, we will briefly comment upon the second ingredient of the name "soft computing", namely a tiny, yet relevant term of "soft".

The first question one should ask is whether there is something in science that is termed "soft", no matter of in which area, then one should think about its very meaning and connotations, and finally of relations to our area or field of interest.

For a long time there has been in science an informal (but widely used) rough division into "hard sciences" and "soft sciences" though many philosophers of science do not support this distinction since they consider it artificial and not taking into account the very nature of scientific inquiry, though maybe using different tools (cf. Feyerabend [13] or Kuhn [18]).

Basically, hard sciences, exemplified by mathematics, physics, chemistry, astronomy, most technological sciences, etc. are described as the ones that are based on, and employing more rigorous and accurate premises, lines of reasoning, tools and techniques, and hence providing more rigorous, accurate and in many cases more definite conclusions. On the other hand, soft sciences, exemplified by social sciences, humanities, anthropology, management, etc. are described as the ones whose point of departure and foundations are less rigorous and accurate, and provide less definite answers. There are of course examples of sciences which may be viewed as something in between like economics.

Traditionally, hard sciences have often been considered more relevant, a target which all sciences should eventually follow, and one could even find statements by some well known mathematicians and/or physicists that for them science begins when mathematics starts playing a crucial role. Though it is difficult to overestimate the role of mathematics, and more generally formal approaches in science, such statements are certainly exaggerated and do not take into account the (present) reality that, on the one hand, non-trivial and operational mathematical models are not available for all kinds of problems our world and society face, and – on the other hand – many soft sciences have made a huge progress and developed much understanding and models (though of a different kind that the formal ones) that are in a position to describe and explain many phenomena in or world, and often provide constructive answers and hints. Therefore, we would be very cautious to overestimate one and underestimate another type of science, they just use different paradigms and tools. Though many people consider hard sciences more difficult, soft sciences are clearly more difficult in the sense that hard sciences deal with much well defined and much less complex problems, and the main difficulty is of a rather technical type related to the use of sophisticated formal tools. On the other hand, soft sciences concern issues and problems related to incomparably more complex systems, notably with a human being as a key element, whose description is usually unknown. And these problems are of much more relevance to the society and the world.

Let us briefly comment upon soft computing, whether it is a "soft" or "hard" science. Unfortunately, it is not so clear. First, soft computing is certainly hard in the sense that in any case we use hard, well defined, rigorous and accurate mathematical modeling and solution tools. Just to give an example, fuzzy logic - which was so often and explicit mentioned by Professor Zadeh - is not fuzzy *per se*, and is a set of precise tools and techniques to formally handle imprecisely specified data and relations. The same can be said, from this point of view, about neural networks and evolutionary calculations. They are all areas based on precise mathematical and algorithmic constructs. What is relevant is that they are based on some perceptions or interpretations of the problem specifics, or intentions of the user as to what a solution should be or what would be sufficient for solving the problem. And these perceptions are soft, indeed, as they are related to issues that are subjects of interest and inquiry in inherently soft sciences related to the human mind.

It is easy to see that, from the above perspective, soft computing is at the crossroads. On the one hand, even if it is termed "soft ...", it is based formally on rigorous and accurate modeling paradigms, tools, techniques, algorithms, etc. Therefore, for many people in the areas of really soft sciences it would be clearly an example of a hard science. However, if we look from the perspective of perceptions of the very user perceptions, intentions of the users, acceptance of relaxed procedures and solutions, etc. this may be viewed as an example of a soft science. One should however bear in mind that soft computing can be viewed from that perspective neither as an orthodox hard science nor as an orthodox soft science. Maybe, a proper description would be to term it like a "soft+ science" (i.e. "soft plus science) and "hard- science" (i.e. hard minus science)? However, if so, then it may pose some problem to the philosophers of science who have already had some problems with some cases of sciences like all technological sciences which are more and more important yet do not follow the traditional paradigm of scientific inquiry.

One thing that should be mentioned in this context is that, as we have already mentioned, hard sciences have been often considered superior to soft sciences, much more scientific, specific and constructive. this all has resulted in the fact that “soft” in the context of science has been generally considered in a pejorative sense. The same situation has clearly been with soft computing! For so many years the scientific establishment in many, if not most, countries has been quite apprehensive, to say the least, to fully recognize, not to speak to appreciate the power and virtues of soft computing. Luckily enough, due to many strong foundational advances and – above all – industrial applications, exemplified by so many implementations of fuzzy, evolutionary, neural, etc. tools and techniques for solving a multitude of practical problems, the situation has been greatly improving.

While considering relations of soft computing to other areas, paradigms or methodologies that have been proposed in science and have proved to be successful, and which contain “soft” in their name, one should definitely mention the so-called *soft systems methodology* (or SSM, for short) developed by Checkland and his collaborators (cf. Checkland [6]or Wilson [41]), which has been widely employed in many organizations around the world. Basically, soft system methodology is an approach to organizational (business) process modeling which can be applied for both usual problem solving and introducing of changes. It is meant for solving difficult problems exemplified by: how to reduce poverty, how to improve the educations system, etc. Obviously, these situations are characterized by a multitude of criteria, value systems, parties involved, etc. and even the (more or less formal, or maybe even more specific) problem formulation is difficult not to speak about its solutions. Needless to say that this is clearly a soft problem, from many points of view!

The process of arriving at a problem formulation and then reaching a solution goes via some steps exemplified by discussions, reaching agreements, developing conceptual models, finding feasible actions and eventually good solutions, and finally proposing some good (it makes no sense to speak about optimal!) solutions that may then be implemented. The soft systems methodology has been very well documented and analyzed from many angles, and numerous real world applications have been reported.

Notice that if we look at soft systems methodology and if we wished to try to introduce some more formal tools and techniques to its repertoire, a natural choice would be to try to tailor our soft computing tools and techniques. Yet, for a strange reason nobody has done this! For instance, in most cases data, information and knowledge available is uncertain and imprecise, and – for instance – fuzzy sets may be of use. Second, conceptual models that are looked for in soft systems methodology concern very sophisticated situations and for sure fuzzy rule based modeling or neural networks could help very much to build those models so that they could be meaningful and operational. Third, evolutionary techniques should help attain realistic solutions under such uncertain and imprecise data and problem formulations that should give at least better, if not good solutions. And last but not least, soft computing should help formalized intentions of the user in the sense of what a good solution should be, what is really sought, and what real constraints, goals, etc. exist. Unfortunately, there has not been any more comprehensive and serious attempt to use soft computing tools and techniques in soft systems methodology, and vice versa. This is another example of a fragmentation of science that has done so much harm to the progress in so many scientific areas.

In this section we will try to just indicate some relations of soft computing, a relatively small area within (as traditionally considered) computer science and/or information technology, with soft sciences, a huge set of various areas and fields in science. This analysis is by no means exhaustive, even comprehensive, and its purpose is to indicate the relevance of bridging the gap between branches of science, and going beyond strict confines of scientific disciplines. This may be viewed as a suggestion for a new research direction that can bring about results that can be of use of both soft computing and soft sciences in general.

The same concerns our remarks on soft systems methodology. We wished to show that there is a widely used paradigm or methodology, with clear roots in broadly perceived soft sciences, and soft computing can clearly be of help it by providing more formal tools and techniques to obtain more specific analyses and maybe results. And vice versa, soft computing would gain very much by finding a well known methodology, with a very good application record, that would claim that soft computing has provided answers and solutions to its crucial problems.

## 5. Concluding remarks

We have tried to comment upon the very essence, roots, potentials, and applicability of computational intelligence and soft computing. We have followed a different paths than those traditionally employed,and which are so well and in a deep and comprehensive way documented in other papers in this special issue. First, we have considered relations between computational intelligence and artificial intelligence, starting from a reference to different kinds of views if how intelligence is meant in science, and whether it has a general nature or many different types. Then, we have proceeded to the analysis of soft computing – which is in our view a narrower area than computational intelligence – and considered two aspects implied by the inclusion of the two words: “computing” and “soft”. First, we discussed how soft computing relates to the traditionally meant computing (in the sense of a theory of computation). Second, we pursued a novel path that has not been practically considered in the literature, that is – first - relations of soft computing to soft sciences, and – second – relations of soft computing to Checklamd’s soft systems methodology. We hope that our finding, remarks and suggestion will trigger a discussion and stimulate a new line of research with both soft computing and computational intelligence communities, on the one hand, and a broadly perceived soft science communities, on the other hand, that can bring about new ideas and novel problem formulations and solutions.

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