# COMPUTATIONAL INTELLIGENCE

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**Summary**

We give a brief introduction to computational intelligence. We review different opinions on the very meaning of the term and discuss how computational intelligence is related to artificial intelligence. To indicate developments in the field we give figures on the number of relevant patents and publications. Furthermore, we discuss how various topics treated by the other articles in this topic can be seen from different perspectives.

## 1. Introduction

The study of (human) intelligence has a rich history over three millenniums. In the twentieth century the invention of computers provided a facility for building and studying systems that exhibit features or behaviour traditionally attributed to intelligence, but are not natural in the sense that they are human engineered. The emerging science, or engineering discipline, is usually called the field of artificial intelligence (AI). Although the name itself is general enough to cover any approach to human engineered intelligent systems, its meaning - at least its most common interpretation - is restricted by the conventions of the AI research community. Roughly speaking, traditional AI is strongly oriented to symbolic representations and manipulations (reasoning) in a top-down manner. That is, the structure of a given problem (environment, domain context) is analysed beforehand and the construction of an intelligent system is based upon this structure. Think, for instance of expert systems representing the problem domain in formal logical terms and applying formal reasoning procedures to derive conclusions, determine actions, within the given structure.

Recently it has been argued that there is a group of alternative approaches to realize intelligent features or behaviour. These approaches, although different from each other, share the property of being non-symbolic and operating in a bottom-up fashion, where structure emerges from an unordered begin, rather than being imposed from above. These fields, evolutionary computation (EC), fuzzy systems (FS), and neural networks (NN) were grouped under the name computational intelligence (CI). The most influential pioneering publication from Marks and Bezdek date back to the early nineties. The major scientific event often seen as marking the birth of the new field has been the IEEE World Congress on Computational Intelligence in 1994, Orlando, Florida. It featured three simultaneous conferences, the IEEE International Conference on Evolutionary Computation, Fuzzy Systems, and Neural Networks.

## 2. What is computational intelligence?

Although used fairly widespread, there is no commonly accepted definition of the term computational intelligence. Attempts to define, or at least to circumscribe, CI usually fall in one or more of the following categories:

- Conceptual treatment of key notions and their roles in CI.
- ``Relative definition'' comparing CI to AI.
- Listing of the (established) areas that belong to it.

In the sequel we summarise various interpretations of the term CI along the lines of development (quasi-chronologically). The first published definition is due to J.C. Bezdek who states that:

``... (strictly) computational systems depend on numerical data supplied by manufactured sensors and do not rely upon ``knowledge''.''

Later, in 1994, Bezdek offers that CI is ``low-level computation in the style of the mind'', whereas AI is ``mid-level computation in the style of the mind''. The envisioned difference is that mid-level systems include knowledge (tidbits), while low-level systems do not. According to this perception, computational architectures utilise sensor data and the term artificial should be reserved for architectures that have a clearly identifiable non-numerical component or knowledge. His proposal is to call a system computationally intelligent when:

``It deals only with numerical (low-level) data, has a pattern recognition component, and does not use knowledge in the AI sense; and additionally, when it (begins to) exhibit (i) computational adaptivity; (ii) computational fault tolerance; (iii) speed approaching human-like turnaround, and (iv) error rates that approximate human performance.''

A particular aspect of Bezdeks view (discussed in more details in the next section) is the importance of pattern recognition, especially the role of neural networks. Marks' definition - falling into the third category - is listing neural nets as one of the building blocks of CI, the others being genetic algorithms, fuzzy systems, evolutionary programming, and artificial life. Let us remark, that contemporary terminology would place genetic algorithms and evolutionary programming both under the umbrella of evolutionary computing. In their seminal book on CI, Eberhart *et al.* elaborate further on the very notion of CI and relate their vision to that of Bezdek. Their view is summarised as:

``... Computational intelligence is defined as a methodology involving computing (whether with a computer, wetware, etc.) that exhibits an ability to learn and/or deal with new situations such that the system is perceived to possess one or more attributes of reason, such as generalisation, discovery, association, and abstraction. The output of a computationally intelligent system often includes predictions and/or decisions. Put another way, computational intelligence comprises practical adaptation concepts, paradigms, algorithms, and implementations that enable or facilitate appropriate actions (intelligent behaviour) in complex and changing environments."

One of the main differences between this view and that of Bezdek is the emphasis on adaptation, rather than pattern recognition. This is stated explicitly as:

``In summary, adaptation is arguably the most appropriate term for what computationally intelligent systems do. In fact, it is not too much of a stretch to say that *computational intelligence and adaptation are synonymous*." (Italics from Eberhart *et al.*)

This line is carried further by Fogel.

``These technologies of neural, fuzzy and evolutionary systems were brought together under the rubric of Computational Intelligence, a relatively new field offered to generally describe methods of computation that can be used to adapt solutions to new problems and do not rely on explicit human knowledge."

While the first part of this quote describes CI by listing the fields belonging to it, the second part stresses adaptation as a key notion in computational intelligence. Actually, Fogels view is an amplification of that of Eberhart *et al.* in the sense that he sees *intelligence and adaptation as synonyms* (italics from the authors of this paper) formulating it this way:

``Any system ... that generates adaptive behaviour to meet goals in a range of environments can be said to be intelligent. In contrast, any system that cannot generate adaptive behaviour and can only perform in a single limited environment demonstrates no intelligence." (Note that Eberhart *et al.* identify **computational** intelligence and adaptation.)

It exceeds the scope of this paper to go into investigations of the notion of intelligence. A detailed discussion of this and many related issues from a CI point of view can be found in a later paper by Bezdek. We close this section with an `outlier', a particular interpretation of computational (and artificial) intelligence after Poole *et al.*, where the authors state:

``Computational intelligence is the study of the design of intelligent agents. ... An intelligent agent is a system that acts intelligently: What it does is appropriate for its circumstances and its goal, it is flexible to changing environments and changing goals, it learns from experience, and it makes appropriate choices given perceptual limitations and finite computation."

Further reading discloses that the term computational intelligence is offered as an alternative for artificial intelligence. We will further discuss this aspect in the next section.

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## Biographical Sketches

**Bart G.W. Craenen**

His research interests lie in the field of Artificial Intelligence (AI), more specifically in the field which is called Natural Computing (NC) and Computational Intelligence (CI). He specialises in solving Constraint Satisfaction Problems (CSPs) with Evolutionary Algorithms (EAs).

Evolutionary algorithms, sometimes called Genetic Algorithms (GAs), work on the principles of Darwin, the well known biologist. EAs use a population of partial solutions (of a problem) as individuals and performs evolutionary operators on them. These operators are guided by the principle of survival of the fittest and include crossbreeding (called crossover or recombination) and mutation.

Constraint satisfaction problems, and the more general constrained problems, are fundamental problems in artificial intelligence with great practical and theoretic relevance. Constrained problems have relevant practical applications in planning, default reasoning, and scheduling, etc. Informally, constraint satisfaction problems consist of finding an assignment of values to variables in such a way that the given set of constraints (expressed over these variables) are satisfied. Although this sounds simple enough, theoretically, all interesting constraint satisfaction problems are computationally intractable (or NP-hard), which explains their theoretical relevance.

Next to constraint satisfaction problems, he has become interested in time tabling and scheduling and, as a spin-off, evolutionary art. For the group here in Amsterdam he maintains the evolutionary art page and have made an evolutionary mondriaan evolver. As a member of the EvoNet training committee he maintains the training committee's homepage (as well as other things).

Since October 2001 he is a PhD student at the Computation Intelligence Group, division Intelligence, Faculty of Sciences of the Vrije Universiteit Amsterdam, Amsterdam, the Netherlands. From October 1999 until October 2001 he worked as a Scientific Programmer at the Vrije Universiteit Amsterdam, Amsterdam, the Netherlands

**Prof. Dr. A.E. Eiben** studied Mathematics in Hungary. He obtained a PhD degree from Eindhoven University of Technology. He worked as a Post-doc at the Free University in Amsterdam, as an assistant Professor at the universities of Leiden and Utrecht. Five years ago he became full professor in computer science at the Free University in Amsterdam. He now serves as the department chair of the faculty of exact sciences.

Evolutionary computing is the binding factor in much of his academic research that can be catalogued under natural computing, or soft computing, with applications in optimization, data mining, artificial life, and artificial societies. Specific research subjects are multi-parent recombination, constraint handling and self-calibrating algorithms, the effect of communication in ALife, and modelling evolving societies. In cooperation with the City Museum of The Hague I managed the Escher Evolver project, an evolutionary art application. I was/am involved in various European projects: EvoNet (IST-1999-14087), DREAM (IST-1999-12679), NEW TIES (FP6-502386).