Hybrid Computational Intelligence

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INTRODUCTION

This article introduces computational intelligence and describes its aims and its main components. Then it focuses on the definition of hybrid intelligent systems and briefly describes the most popular among them. The increased popularity of hybrid intelligent systems during the last decade, is due to the extensive success of these systems in a wide range of real-world complex problems, but also has to do with the increased capabilities of computational technology. One of the reasons for this success has to do with the synergy derived by the computational intelligent components, such as machine learning, fuzzy logic, neural networks, genetic algorithms, or other intelligent algorithms and techniques. Each of the partial methodologies provides hybrid systems with complementary reasoning and searching methods that allow the use of domain knowledge and empirical data to solve complex problems.

BACKGROUND

Computational Intelligence

More than fifty years of tentative research have rolled since the term Artificial Intelligence was coined within the members of the computer society, in an attempt to characterize the existence of intelligence nuggets in machine performance and behavior, as well as in algorithmic design and performance. Computational Intelligence represents the evolution of a part of Artificial Intelligence during the 90's, mostly related to well-established and popular computational techniques, such as neural computation, evolutionary computation, machine learning and fuzzy logic.

According to (Duch, 2007), a brief survey of the scope of CI journals and books including the term computational intelligence in their title shows that at present, it is an umbrella for three core technologies (neural, fuzzy and evolutionary), their applications, and selected fashionable methods.

The IEEE Computational Intelligence Society defines its subjects of interest as neural networks, fuzzy systems and evolutionary computation, including swarm intelligence.

In addition, Professor James Bezdek in (Bezdek 1994) defined a computationally intelligent system as follows:

A system is computationally intelligent when it deals with only numerical (low level) data, has pattern recognition components, does not use knowledge in the AI sense; and additionally when it (begins to) exhibit (1) computational adaptivity, (2) computational fault tolerance, (3) speed approaching human-like turnaround and (4) error rates that approximate human performance.[1]

In the MIT Encyclopaedia of the Cognitive Sciences, the neutral term of computational intelligence is used to gather two complementary views of AI, one as an engineering discipline concerned with the creation of intelligent machines, the other as an empirical science concerned with the computational modelling of human intelligence. According to (Abbod et al., 2002), "either natural systems like brains, immune systems, ecologies, societies or, artificial systems like parallel and distributed computing systems, artificial intelligence systems, artificial neural networks, evolutionary programs, are characterised by apparently complex behaviours that emerge as a result of often non-linear spatio-temporal interactions among a large number of component systems at different levels of organization."

Consequently, researchers in a number of distinct areas including computer science, artificial intelligence, neural networks, cognitive science, computational economics, mathematics, optimization, complexity theory, control systems, biology, neuroscience, psychology, engineering, etc., have begun to address, through a

DOI: 10.4018/978-1-4666-5888-2.ch016

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combination of basic as well as applied techniques, theoretical as well as experimental research, analysis and synthesis of such systems. Intelligent systems could be considered those systems that have the properties of self-maintenance, adaptivity, information preservation, and increase in complexity, but use other means to achieve such objectives.

Computational intelligence tools and techniques have now become methods of choice for a number of complex domains of application, due to their specific characteristics. In a sense, computational intelligence could be considered a complementary toolbox to standard Operational Research (OR) methods and techniques for optimization, problem solving and decision-making (i.e., mathematical programming, simulation, probabilistic reasoning, etc.). Some areas of computational intelligence have become particularly known over time, due to their effectiveness in facing specific real-world problems. A very thorough analysis of what is meant by computational intelligence and what the trends of modern AI are can be found in Nilsson (1998) and Chen (2000).

From now on let's consider as main components of computational intelligence, the four main streams of research that dominate the area of AI during the last two decades, namely, (1) fuzzy sets and soft computing, (2) neural networks, (3) genetic algorithms and evolutionary computation (including also nature inspired intelligence) and (4) machine learning[2] and data mining.

A collection of research work on computational intelligence and learning techniques in the sense presented above can also be found in Zimmermann et al. (2001). A reference to the basic concepts of the most popular intelligent components of hybrid intelligent architectures follows.

Fuzzy Logic

Fuzzy logic (Zadeh, 1965; Zadeh, 1973; Zadeh, 1999; Zadeh, 2001; Alavi & Leidner, 2001; Newell & Simon, 1972; Weiss, 1999), in fact can be seen as a language with syntax and local semantics where we can imprint any qualitative knowledge about the problem to be solved, usually with the assistance of a field expert. The strong point of fuzzy logic is the robustness of its interpolative reasoning mechanism. The impact of Fuzzy Logic has been extremely high during the past years with the appearance of several patents[3] awarded all over the world, e.g.

- Number of fuzzy-logic-related patents issued and applied in Japan: 7,149
- Number of fuzzy-logic-related patents issued in the United States: 21,878
- Number of fuzzy-logic-related patents applied in the United States: 22,272
- Number of fuzzy-logic-related patents issued and applied in WIPO (International): 50,999
- Number of fuzzy-logic-related patents issued and applied in China: 25,454 (not including all the years, and not including Taiwan or Hong Kong)
- Number of fuzzy-logic-related patents issued and applied in EPO (EU): 3,268 (not including individual countries in Europe)
- Number of fuzzy-logic-related patents issued and applied in Australia: 2,350
- Number of fuzzy-logic-related patents issued and applied in Canada: 556

Machine Learning and Data Mining

Machine Learning (Michalski et al., 1983; Michalski et al., 1986; Kodratoff & Michalski, 1990; Mitchell, 1997), was conceived four decades ago for the development of computational methods that could implement various forms of learning, in particular mechanisms capable of inducing knowledge from examples or data (Kubat et al., 1997, p.3). Knowledge induction seems particularly desirable -especially from field experts who want to understand the outcome of computational approaches - in problems that lack algorithmic solutions, are ill-defined, or only informally stated. Research in machine learning has been mainly devoted to developing effective methods for building learning (rule-based) systems that will acquire high-level concepts and/or problem solving strategies through examples in a way analogical to human learning.

Evolutionary Computation and Nature Inspired Intelligence

Genetic algorithms (Holland, 1975) provide a way to perform randomized global search in a solution space. Usually a population of candidate solutions, encoded internally as chromosomes, is evaluated by a fitness function in terms of its accuracy. The best chromo-

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