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Computational Approaches to Artificial Intelligence: Theory, Methods and Applications

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1 Introduction

Scientists have been trying to implement human intelligence in computers in various ways. Artificial Intelligence (AI) may be defined as the branch of computer science that is concerned with the automation of intelligent behaviour. There are two main paradigms adopted in AI: (i) the symbolic, and (ii) the subsymbolic.

The symbolic paradigm is based on the theory of physical symbolic systems. The symbols have semantic meanings and they represent concepts or objects. Propositional logic, predicate logic and the production systems facilitate dealing with symbolic systems. AI implementations of these systems include rule-based systems, the logic programming and production languages and they have been applied to various fields, such as natural language processing, expert systems, machine learning, cognitive modelling and so on. Unfortunately, symbolic systems encounter difficulties in certain tasks, when inexact, missing or uncertain information is used, when only raw data are available for knowledge acquisition, or parallel solutions need to be elaborated. Nevertheless, these tasks are not considered difficult for the human brain.

The subsymbolic paradigm is based on the idea that intelligent behaviour is performed at a subsymbolic level (this is higher than the neuronal level in the human brain but is different from the symbolic one) by performing appropriate computations.

Neural computing is inspired by information processing and computation in the brain. Nodes, or artificial neurons, in models of neuronal network are usually considered as simplified models of biological neurons, i.e. real nerve cells, and the connection weights between nodes resemble to synapses between neurons. In fact, artificial neurons are much simpler than biological neurons. However, it is far from clear how much of this simplification is justified because of our poor understanding of neuronal functions when embedded in networks. Networks of these simple processing units are called Artificial Neural Networks (ANNs) offer a powerful and distributed computing architecture equipped with significant learning abilities. They help represent highly nonlinear and multivariable relationships. ANNs have the ability to adapt and learn new data, to self organize, to operate on-line (in real-time) and they can be implemented parallel and in VLSI (Very Large Scale Integrated Systems). They have already been successfully used in many real life applications.

In many applications areas, such as medical imaging, control, and decision making, learning from data encounters several difficulties. In certain case, the data sets are characterised by incompleteness (missing parameter values), incorrectness (systematic or random noise in the data), sparseness (few and/or non-representable records available), and inexactness (inappropriate selection of parameters for the given task). ANNs are able to handle these data sets and are mostly used for their pattern matching abilities and their human like characteristics (generalisation, robustness to noise).

Probabilistic neural networks (PNNs) constitute a special class of ANNs, which is known in the statistical literature as kernel discriminant analysis. PNNs are used in scientific fields such as bioinformatics, medicine, and engineering with promising results. However, their heavy dependence on their parameters limits their applicability. For this purpose, evolutionary and swarm intelligence algorithms that are described below can be applied to provide proper parameter configuration, thereby enhancing their performance and applicability.

Additional benefits in handling uncertainty can be gained by adopting fuzzy logic-based approaches. Fuzzy Logic theory forms a key methodology for representing and processing linguistic or, in general, qualitative information. It supports a diversity of mechanisms for knowledge representation focusing on a relevant selection of information granularity. Fuzzy Logic exploits imprecision in an attempt to make intelligent systems' complexity manageable. Along a similar line rough sets were developed they have already been found to be essential in coping with ambiguity. Fuzzy Logic has been applied with great success in control applications and robotics.

Another paradigm that belongs to this class of computational approaches to AI is Evolutionary Computation. This paradigm embraces genetic algorithms (GA), evolutionary computation and evolutionary strategies, Swarm Intelligence, Differential Evolution Algorithms which are biologically and nature inspired methodologies aimed at global optimization. These methodologies are particular effective when the function that has to be minimized is non-differentiable and discontinuous.

Evolutionary computing has been inspired by the learning and adaptation characteristics that are exhibited by the biological systems. Evolutionary Algorithms (EAs) can be incorporated in learning modules as part of information processing systems. Their major characteristics are their heuristic nature and their ability to learn. They are mainly considered as heuristic methods for search and optimisation that may not lead to the perfect solution but to a near perfect one. In nature, the criteria for perfection keep changing and what seems to be close to the perfection according to one "goodness" criterion may be far from it according to another. Thus, EAs operate as search heuristics for the "best" instance in the space of all possible instances. They begin only with a "fitness" criterion for selecting and storing partial solutions that are "good" and dismissing those that are "not good". EAs are also used for learning from data, especially in complex multi-optional optimisation problems. In this case, they do not need in-depth problem knowledge but a "fitness" or "goodness" criterion for the selection of the most promising individuals (they may be partial solutions to the problem). In this context, they exhibit adaptive behaviour through leaning, and accumulate facts and knowledge without having any previous knowledge. Genetic algorithms are one paradigm in the area of evolutionary computation. One application of this area is creating distributed AI systems with emergent collective computational abilities or even a certain level of intelligence, called Artificial Life.

Swarm Intelligence (SI) is strongly related to evolutionary computation. However, instead of imitating nature's evolutionary procedures (such as EAs), SI algorithms are based on the simulation of social behaviour. Many paradigms from nature justify that the exchange of information among members of a population provides them with an evolutionary advantage. There are a few swarm intelligence algorithms developed for solving combinatorial and numerical optimization problems. Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) are the most known methods and they have gained increasing attention due to their ability to solve efficiently and effectively a plethora of problems in various scientific and technological fields, including real-life applications, giving also rise to the field of Swarm Engineering.

An emerging area in which computational approaches have been found extremely essential recently is Data Mining and Knowledge Discovery. With the growing interest in sifting through a flood of data collected nowadays, there is a genuine need for Knowledge Discovery. The current way in which the Internet facilities are exploited along with an almost exponentially growing number of links calls for an evident use of data mining. An analysis of time series, going through huge databases, identification of trends therein, building patterns out of alarm records are just a number of other representative examples. A fundamental issue in data mining is clustering. Clustering can be defined as the process of partitioning a set of patterns into disjoint and homogeneous meaningful groups, called clusters. Clustering is fundamental in knowledge acquisition, and has been applied in numerous fields.

From the previous discussion it becomes apparent that all of the technologies discussed above should be used concurrently rather than separately in order to alleviate their complexity requirements. Consider, for instance, the design of neural networks. Here, fuzzy sets deal with interfacing and preprocessing information in neural networks, especially if it comes in a nonnumeric format. Evolutionary techniques are instrumental in determining not only the connections of the network but, more importantly, an entire topology of the network as well as its size. The important observation is that computational approaches retain their generality while being flexible enough to address the needs and specificity of particular applications.

2 The papers

The Session on "Computational Approaches to Artificial Intelligence" is part of the *International Conference of Computational Methods in Sciences and Engineering 2004 (ICCMSE 2004)* that was held between 19-23 November 2004 at Vouliagmeni-Kavouri, Attica, in Greece. The Session aimed at bringing together a variety of research works concerned with computational methods for knowledge engineering, data modelling and complex problem solving, and to show how computational approaches can be applied to challenging real-world problems, such as applications in economic geography, adaptive networks, cryptography and cryptanalysis.

In particular, the Session comprised eleven referred papers, which looked at the theories, methods and applications of computational intelligence. Next, a brief description of these contributions is presented.

2.1 Theory and Methods

Anastasiadis et al., [1], build on a mathematical framework to propose new globally convergent first-order batch training algorithm for neural networks. Their approach ensures that the direction of search is always a descent one and provides accelerated learning, outperforming other recently proposed methods.

Couceiro et al., [2], focus on knowledge representation methods presenting compositions of clones of Boolean functions. These can be interpreted as representation theorems, providing representations of Boolean functions analogous to the disjunctive normal form, the conjunctive normal form, and the Zhegalkin polynomial representations.

Georgiou et al, [3], focus on self–adaptive probabilistic neural networks and investigate the sensitivity of the networks performance to the spread parameter's value. They propose algorithms for the selection of an optimized value that employ state-of-the-art computational intelligence optimization algorithms, like Particle Swarm Optimization, Differential Evolution and Evolution Strategies.

Parsopoulos and Vrahatis, [8], introduce Unified Particle Swarm Optimization, a new scheme that harnesses the local and global variants of the standard Particle Swarm Optimization algorithm, combining their exploration and exploitation abilities. Convergence in probability can be proved for the new approach in unimodal cases and preliminary results justify its superiority against the standard Particle Swarm Optimization.

Pavlidis et al., [10], explore nonlinear systems theory as applied to modeling the emergence of economic agglomerations. They apply topological degree theory to investigate the existence of a fixed–point to a system of equations that describes their model. The fixed–point corresponds to the short–run equilibrium of the model. They further study its uniqueness, and efficient computational methods to determine it.

Tasoulis and Vrahatis, [11], propose a modification of the k-windows clustering algorithm that they have proposed recently. The k-windows algorithm attempts to enclose all the patterns that belong to a single cluster within a d–dimensional window. In this contribution they propose to modify this algorithm by using semi algebraic data structures instead of windows.

2.2 Applications

Ghinea and Magoulas, [4], address the problem of integrating user preferences with network Quality of Service parameters for the streaming of media content, and suggest protocol stack configurations that satisfy user and technical requirements to the best available degree. Their approach is able to handle inconsistencies between user and networking considerations, formulating the problem of construction of tailor-made protocols as a prioritisation problem that can be solved using fuzzy programming.

Laskari et al., [5], study cryptographic systems whose security relies on the hypothesis that the underlying mathematical problems are computationally intractable, in the sense that they cannot be solved in polynomial time. The authors study the performance of artificial neural networks on the approximation of data derived from the use of elliptic curves in cryptographic applications. In another contribution, [6], the same authors propose an optimisation approach to a problem introduced by the cryptanalysis of Feistel cryptosystems. They study the performance of Evolutionary Computation methods in addressing this problem for a representative Feistel cryptosystem, the DES. This approach is applicable to all Feistel cryptosystems that are amenable to the differential cryptanalysis method.

Manetos and Photis, [7], argue that contemporaneous and interdependent spatial phenomena cannot be analyzed and represented efficiently with conventional deterministic techniques. They propose the development of a new integrated spatial toolbox that provides an integration of Data Mining methods like neural networks and fuzzy clustering under a consistent methodological framework to model urban growth dynamics. They apply their approach focusing on the greater region of Athens, Greece. Their interpretation of results reveals the efficiency of the proposed framework in capturing spatial trends and revealing future tendencies.

Parsopoulos et al., [9], consider data fitting schemes that are based on different norms to determine the parameters of curve–models that model landslides in dams. The Particle Swarm Optimization method is employed to minimize the corresponding error norms. The method is applied on real–world data with promising results.

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